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Energy Procedia 00 (2013) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

GHGT-11

U.S. DOE's Efforts to Promote Knowledge Sharing Opportunities from R&D Efforts: Development of the U.S. Carbon Utilization and Storage Atlas and Best Practices Manuals

John Litynski[a], Andrea McNemar[a], Traci Rodosta[a], Dawn Deel[a], Derek Vikara[b], and Rameshwar D. Srivastava[b], Larry Myer[c], and Robert Kane[c]

[a.] *National Energy Technology Laboratory, United States Department of Energy, Pittsburgh, PA 15236, USA, and Morgantown, WV 26505, USA.*

[b.]. *KeyLogic Systems, National Energy Technology Laboratory, United States Department of Energy, Pittsburgh, PA 15236, USA.*

[c.] *Leonardo Technologies, National Energy Technology Laboratory, United States Department of Energy, Pittsburgh, PA 15236, USA*

Abstract

Knowledge sharing among various stakeholders is essential to promote the commercialization of carbon capture, utilization, and storage (CCUS) technologies. The United States Department of Energy (DOE) promotes information and knowledge sharing through various avenues, including the development and distribution of Best Practices Manuals (BPMs), the development of online tools and resources, involvement in working groups on CCUS, and other public outreach and education efforts. One of NETL's main initiatives to promote information and knowledge sharing is the development of a series of BPMs that outline uniform approaches to address a variety of CCUS-related issues and challenges. A major online resource developed by DOE is the National Carbon Sequestration Database and Geographic Information System (NATCARB), which is a geographic information system (GIS)-based tool developed to provide an interactive visual representation of CCUS potential. The series of past and future carbon storage Atlases featuring the Regional Carbon Sequestration Partnerships (RCSPs), such as the to be released *United States Carbon Utilization and Storage Atlas*, complements NATCARB, and contains additional information regarding commercialization opportunities for CCUS technologies from each of DOE's RCSPs. Building on past successes, NETL is expanding the NATCARB effort through the North American Carbon Atlas Partnership (NACAP) to better assess CCUS potential throughout all of North America. NETL has been actively disseminating knowledge and developing the future required workforce through training centers that are focused on training personnel for future implementation of CCUS technology.

Selection and/or peer-review under responsibility of GHGT

Keywords: DOE, NETL, Regional Carbon Sequestration Partnerships, Knowledge Sharing, Best Practices ARRA Regional Carbon Sequestration Training

1. Overview

The United States Department of Energy (DOE) is the lead federal agency for the research, development, demonstration, and deployment of carbon capture, utilization, and storage (CCUS) technologies. The Carbon Storage Program, implemented by the DOE's Office of Fossil Energy and managed by the National Energy Technology Laboratory (NETL), is helping to develop technologies to capture, separate, and store CO_2 to mitigate greenhouse gas emissions without adversely impacting energy use or hindering economic growth. Since 1997, DOE's Carbon Storage Program has significantly advanced the CCUS knowledge-base in selected technology areas through a diverse portfolio of applied research projects. DOE acknowledges that knowledge sharing among various entities is essential in order to commercialize CCUS technologies. Results and lessons learned from both field projects and core research and development efforts will provide the foundation for future, large-scale CCUS field tests globally and will address future challenges associated with public acceptance and the development of infrastructure and a regulatory framework. DOE promotes information and knowledge sharing through various avenues, including the development and distribution of CCUS Best Practices Manuals (BPMs), development of online tools and resources, involvement in CCUS-related working groups, and other public outreach and education efforts.

This paper summarizes DOE's efforts to encourage knowledge sharing and provides a summary of the of the BPMs, refinements made to the National Carbon Sequestration Database and Geographic Information System (NATCARB) on-line resource, highlights from the to be released *United States Carbon Utilization and Storage Atlas (Atlas IV)*, DOE's contributions to the North American Carbon Atlas Partnership (NACAP), and American Recovery and Reinvestment Act of 2009 (ARRA)- supported training centers.

2. Establishing Best Practices for Utilization and Storage

Sharing of lessons learned and best practices from the R&D projects sponsored by DOE's Carbon Storage Program is essential for the deployment of CCUS. DOE promotes information sharing from all of the projects it sponsors, including projects in the Core R&D element of the Carbon Storage Program and the Regional Carbon Sequestration Partnership (RCSP) activities, through the various technical working groups established by DOE. These groups include experts whose objective is to provide a forum for sharing information and developing uniform approaches for contending with common CCUS challenges. The working groups are: (1) Geological and Infrastructure; (2)Monitoring, Verification and Accounting (MVA); (3) Simulation and Risk Assessment; (4) Capture and Transportation; (5) GIS and Database; (6) Water; (7) Enhanced Oil Recovery and Storage; and (8) Public Outreach and Education.

The working groups also focus on the need to develop a uniform approach for addressing a variety of common issues, including an organized, national perspective on characterization, validation, and development issues for DOE's Carbon Storage Program. These working groups remain active and are integral to the successful development of the infrastructure needed for the planned field activities and future commercial deployment of CCUS technology.

One of NETL's main initiatives to promote information and knowledge sharing is the development of a series of BPMs that outline uniform approaches to address multiple CCUS-related issues and challenges. The lessons learned from the Carbon Storage Program's sponsored activities, particularly RCSP and other field tests, are integrated into a series of seven BPMs. The first editions of the BPMs **were** completed in 2009 and 2010 will be updated at least once prior final version in 2020. A brief summary of each is provided below; the current editions of the BPMs are available on the NETL Carbon Storage Program Website at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html.

2.1 Monitoring, Verification, and Accounting for CO_2 Stored in Deep Geologic Formations

The MVA plan for a storage project will have a broad scope, covering CO_2 storage conformance and containment, monitoring techniques for internal quality control, and verification and accounting for regulators, and monetizing benefits of geologic storage. This BPM provides guidelines for developing and executing an MVA plan and organizes the technologies into three categories: technologies that can support compliance with existing United States Environmental Protection Agency (EPA) regulations for UIC Class VI and GHG reporting; technologies for effective reservoir management; and technologies under development meant to expand the knowledge base of geologic processes but not ready for deployment (see Table 1 for categorization of subsurface technologies). The BPM provides an extensive discussion of existing and evolving monitoring tools, the information that each tool can provide, and its R&D status. The manual also contains a number of case studies from the RCSP field projects that document the steps taken by the Partnerships to deploy these technologies.

Table 1: Field Readiness and Applicability of Subsurface Monitoring Tools [1]

Monitoring Approach		Field Readiness of Technology	Techniques	Applicability of Technology		
				UIC Class VI Rule	GHG Reporting Rule	Reservoir Management
Subsurface Monitoring	Well Logging Tools	Commercial Stage	Density, neutron porosity logs, pulsed neutron tools, acoustic logging, dual-induction logging	✓		✓
	Wellbore Monitoring Tools	Commercial Stage	Downhole/wellhead pressure, temperature gauges, flow meters, sonic logging, oxygen-activation logs, radioactive tracer surveys, corrosion monitoring	✓	✓ See *	✓
		Development Stage	Fiber-optic distributed temperature sensor system, distributed thermal perturbation sensor	✓	✓	✓
			Cable-less ruggedized sensors for downhole P.T. corrosion	✓	✓	✓
	Seismic Methods	Commercial Stage	Time-lapse surface seismic (3-D, 2-D) Borehole seismic (vertical seismic profile)	✓	✓	✓
		Early Demonstration Stage	Cross-well seismic, passive (micro) seismic	✓	✓	✓
		Development Stage	Fiber-optic geophone technology for borehole seismic surveys, Cable-less data acquisition for multi-component, 3-D seismic data	✓	✓	✓
	Subsurface Fluid Sampling and Tracer Analysis	Commercial Stage	Wireline-based samplers	✓	✓	✓
		Early Demonstration Stage	U-tube sampling, modified reservoir fluid sampling system, gas membrane sensor system	✓	✓	✓
	Gravity	Early Demonstration Stage	Remotely-operated vehicle-deployable-deep-ocean gravimeters (ROVDOG), borehole gravity measurements	✓		✓
	Electrical Techniques	Early Demonstration Stage	Cross-well electrical resistivity tomography (ERT), surface-downhole ERT	✓	✓	✓
		Development Stage	Controlled-source electromagnetic (CSEM) surveys	✓	✓	✓

2.2 Public Outreach and Education for Carbon Storage Projects

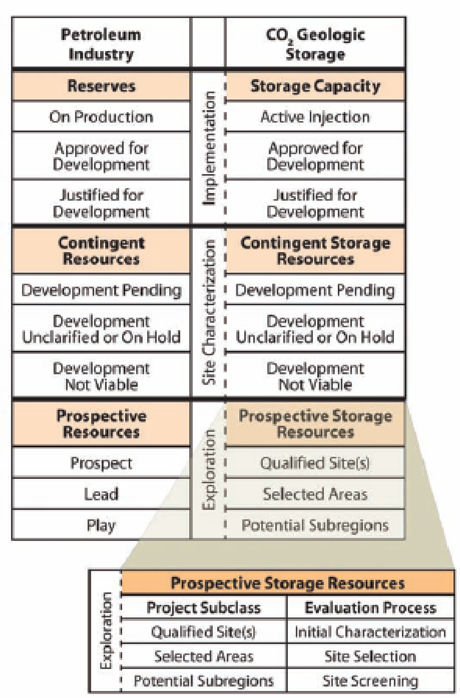
This BPM represents a distillation of best practices for public outreach and education to support the implementation of CO_2 storage projects. The manual focuses on a 10-step process for the implementation of a comprehensive education and outreach plan for field projects. This process, summarized in Table 2, was developed based on the experience gained implementing the RCSP small-scale (injection of less than 500,000 tons per year of CO_2) storage projects.

* Flow meters are also applicable to Subpart UU of the EPA GHG reporting rule.

Table 2: Best Practices for Public Outreach and Education for Carbon Storage Projects [2]

Best Practice	Recommended Action
Integrate Outreach with Project Management	Include outreach as part of the critical path of a CO_2 storage project, in sync with key project stages.
Establish a Strong Team	Establish a clearly defined structure that delineates roles and responsible; include individuals with technical, communication, education, and community relations backgrounds.
Identify Key Stakeholders	Identify all stakeholders in the project lifecycle at the local, regional, and national level.
Conduct Social Characterization	Social characterization involves gathering and evaluating information to obtain and accurate portrait of stakeholder groups, their perceptions, and their concerns about CO_2 storage.
Develop a Strategy and Communication Plan	Outreach strategy and communications plan ties together the information, planning, and preparation; plan is tailored to stakeholder needs and a particular CO_2 storage project.
Develop Key Messages	Identifying a set of key messages that can be consistently repeats in outreach activities and materials can help stakeholders develop a clearer understanding of the project and how concerns will be addressed.
Develop Materials Tailored to Audiences	Outreach material must be tailored to match the audience’s degree of interest, education, and time constraints.
Proactively Manage the Program	Outreach projects should be actively managed to ensure that consistent messages are being communicated and the requests for information are fulfilled throughout the project life cycle.
Monitor the Program and Public Perceptions	Monitoring the performance of the outreach program allows the project team to stay abreast of how the community perceives the project and gauge the effectiveness of outreach.
Refine the Program as Warranted	Be ready to adapt to changes in information about the site, unexpected events and other conditions that may have a strong influence on the public’s perception of CO_2 storage during project implementation.

2.3 Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations



The process of identifying and characterizing suitable geologic storage sites involves a methodical and careful analysis of the technical and non-technical aspects of potential sites. This BPM presents a framework for this process which is analogous to the methods used in the petroleum industry to advance a project through a series of resource classes and project status subclasses until the project begins producing hydrocarbons. A comparison of the geologic storage and petroleum industry frameworks is shown in Figure 1. The BPM focuses on guidelines and process maps for carrying out the site screening, site selection and initial characterization steps of the exploration phase of a project.

The primary audience for this manual is storage project developers and CO_2 producers and transporters. However, it will also be of use in informing local, regional, state and national governmental agencies, and the general public about the rigorous analyses and best practices in selecting optimal CO_2 geologic storage sites. The BPM also summarizes the experiences of the RCSPs in characterizing the geologic storage capacity in their regions and how the results of their field activities are used to validate this capacity.

Figure 1 Comparison of Petroleum Industry and CO_2 Storage Resource Classification [3]

2.4 Geologic Storage Formation Classifications

While geologic formations are infinitely variable in detail, they can have many similarities which result from the conditions under which they were formed (i.e., the depositional environment). The depositional environment influences how formation fluids are held in place, how they move, and how they interact with other formation fluids and solids (minerals). Using the depositional environment as a basis, this BPM divides geologic formations suitable for CO_2 storage into eleven reservoir classes, depending on depositional environment: deltaic; fluvial deltaic; strandplain; shelf clastic; turbidite; eolian; fluvial and alluvial; shelf carbonate; reef; coal and organic shale; and basalt. The BPM discusses the geologic characteristics relevant to CO_2 storage for each class. It also identifies two classes of seals (shale and evaporites) that need to be considered when developing field projects. The BPM further discusses the efforts that DOE is supporting to characterize and test small- and large-scale CO_2 injection into the different formation classes. Table 3 provides a summary of DOE-supported field projects that are assessing the different geologic storage classes.

Table 3: Matrix of Field Activities in Different Reservoir Classes [4]

Matrix of Field Activities in Different Reservoir Classes		High Potential Reservoirs					Medium Potential Reservoirs				Lower/Unknown Potential Reservoirs*	
Reservoir Class		**Deltaic**	**Shelf Clastic**	**Shelf Carbonate**	**Strandplain**	**Reef**	**Fluvial Deltaic**	**Eolian**	**Fluvial & Alluvial**	**Turbidite**	**Coal**	**Basalt (LIP)**
Large-Scale Field Tests[a]	**Saline**	-	-	1	1	-	1	-	1	-	-	-
	EOR	1	-	-	-	1	2	-	-	-	-	-
Small-Scale Field Tests[b]	**Saline**	2	1	1	1	-	-	-	1	-	-	1
	EOR	1	1	3	1	2	1	-	1	-	6	0

Notes:
The number in the cell is the number of investigations by NETL per geologic storage formation classification.
** Potential reservoirs were informed from petroleum industry and field data from the Carbon Storage Program.*
[a] Large-Scale Field Tests – Injection of more than 1,000,000 tons of CO_2.
[b] Small-Scale Field Tests – Injection of less than 500,000 tons of CO_2 for EOR and 100,000 tons for saline formations.
[c] Site Characterization – Characterize the subsurface at a location with the potential to inject at least 30,000,000 tons of CO_2.

2.5 Risk Analysis and Simulation for Geologic Storage of CO_2

Risk analysis (risk assessment) and numerical simulation are critical tools used iteratively in conjunction with site characterization, monitoring, and public outreach throughout all of the stages of a geologic CO_2 storage project (site screening, site selection, project design, project operation, closure, and long-term stewardship) to help meet the goals of safe, secure, and verifiable permanent storage. The manual covers three major technical topics: fundamental aspects of risk analysis, fundamental aspects of numerical simulation, and application of risk analysis and numerical simulations. The tools and methods discussed in the BPM (e.g., see Table 4) will guide CCUS implementation by providing stakeholders (operators, project developers, general public, and regulators) with tools to predict the near-term and long-term fate of stored CO_2, including the extent of CO_2 movement and pressure changes in the reservoir, projected amount of long-term CO_2 storage, and potential risks and consequences of CO_2 leakage in the project vicinity. The BPM also illustrates the concepts of risk analysis and numerical simulation by describing the experience gained by the RCSPs as they implemented multiple field projects.

Table 4: A Summary of Numerical Codes for Geologic CCUS Simulation [5]

Name of Code	Developer/ Supplier	Coupling	Processes Modeled
NFFlow-FRACGEN	NETL	H	Two-phase, multi-component flow in fractured media.
Eclipse	Schlumberger	T,H	Non-isothermal multiphase flow in porous media.
MASTER	NETL	T,H	Black oil simulator, compositional multiphase flow.
TOUGH2 (TOUGH+)	LBNL	T,H	Non-isothermal multiphase flow in unfractured and fractured media.
GMI – SFIB	Geomechanics International	M	Three-dimensional stress modeling for compressional (wellbore breakout) and tensional (tensile wall fractures) stress failure, fracture modeling.

ABACUS	SIMULIA	T,M	Geomechanical, single and two-phase flow.
COMET3	ARI	T,H,M, sorption	Black oil production, hydrocarbon recovery from desorption-controlled reservoirs.
TOUGH-FLAC	LBNL	T,H,M	Non-isothermal multiphase flow in unfractured and fractured media with geomechanical coupling.
The Geochemist's Workbench	University of Illinois	C	Chemical reactions, pathways, kinetics.
PSU-COALCOMP	Penn State University /NETL	T,H, sorption	Compositional simulator with dual porosity, sorption.
CrunchFlow	LLNL	T,H,C	3-D, multiphase transport with equilibrium and kinetic mineral-gas-water reactions.
GEM-GHG	Computer Modelling Group Ltd.	T,H,C	Non-isothermal multiphase flow in porous media.
NUFT-C	LLNL	T,H,C	Non-isothermal multiphase flow and chemical reactions in porous media.
PFLOTRAN	LANL	T,H,C	Non-isothermal multiphase, multicomponent, chemically reactive flows in porous media. Can be run coupled or uncoupled.
PHAST	USGS	T,H,C	Multicomponent, 3-D transport with equilibrium and kinetic mineral-gas-water reactions.
STOMP-family of codes	PNNL	T,H,C	Non-isothermal multiphase flow in porous media, coupled with reactive transport.
TOUGHREACT	LBNL	T,H,C	Non-isothermal multiphase flow in unfractured and fractured media with reactive geochemistry.
OpenGeoSys: [Couples GEM, BRNS, PHREEQC, ChemApp, Rockflow]	UFZ-BGR-CAU-GFZ-PSI-TUD-UE	T,H,M,C	Porous and fractured media THMC simulation.
FEHM	LANL	T,H,M,C	Non-isothermal, multiphase flow (including phase-change) in unfractured and fractured media with reactive geochemistry & geomechanical coupling.
CO_2-PENS	LANL	-	Systems-level modeling of long-term fate of CO_2 in sequestration sites.
COMSOL	COMSOL	-	General partial differential equation solver with finite element solver.

T: Thermal; H – Hydrologic; M – Geomechanical; C - Geochemical

2.6 Carbon Storage Systems and Well Management Activities

Wells are a critical component of any CCUS project; they will be drilled and completed for multiple purposes, including: exploring the suitability of geologic formations; injecting CO_2; monitoring the behavior and location of injected CO_2; and, in the case of CO_2 enhanced oil recovery (EOR), producing hydrocarbons from the injection zone. The purpose of this report is to share lessons learned regarding site-specific management activities for the well systems of carbon storage projects. This manual builds on the experiences of the Regional Carbon Sequestration Partnerships (RCSPs) (e.g., Figure 2) and acquired knowledge from the petroleum industry and other private industries that have been actively drilling wells for more than 100 years. Specifically, this manual focuses on the planning, permitting, design, drilling, implementation, and decommissioning of wells for geologic storage projects.

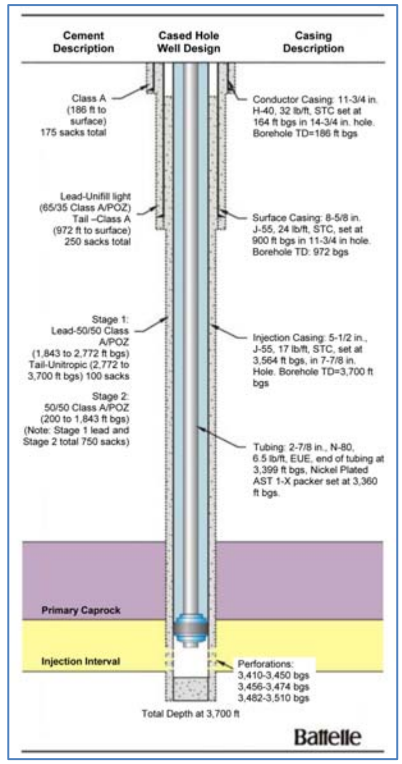


Figure 2 Example casing design for a CO_2 injection well [7]

2.7 Terrestrial Sequestration of Carbon Dioxide

This manual is based on the field experience of the RCSPs' field projects and covers land types and management methods that can maximize carbon storage in vegetation and soil [6]. It also covers the analytical techniques necessary to monitor, verify, and account for terrestrially stored carbon (required for this carbon to be traded) and how these technologies were applied in the various field projects.

3. Geologic Storage Data Sharing and Integration

NATCARB is an interactive, relational database and geographic information system (GIS) that integrates CCUS data from the RCSPs and other sources (Figure 3). Key geospatial data (including CO_2 stationary sources and potential geologic storage sites and utilization opportunities), interactive maps, and background information on the process of storing CO_2 are available free of charge to the public via the NATCARB viewer (http://www.natcarb.org) . The interactive viewer provides web-based access to disparate data (from CO_2 stationary sources, potential geologic CO_2 storage formations, and field projects) and employs analytical tool capabilities (i.e., storage resource estimation, cost estimation, and data graphing and plotting features) required for addressing CCUS deployment, thus providing all stakeholders with improved online tools with which to display and analyze CCUS data.

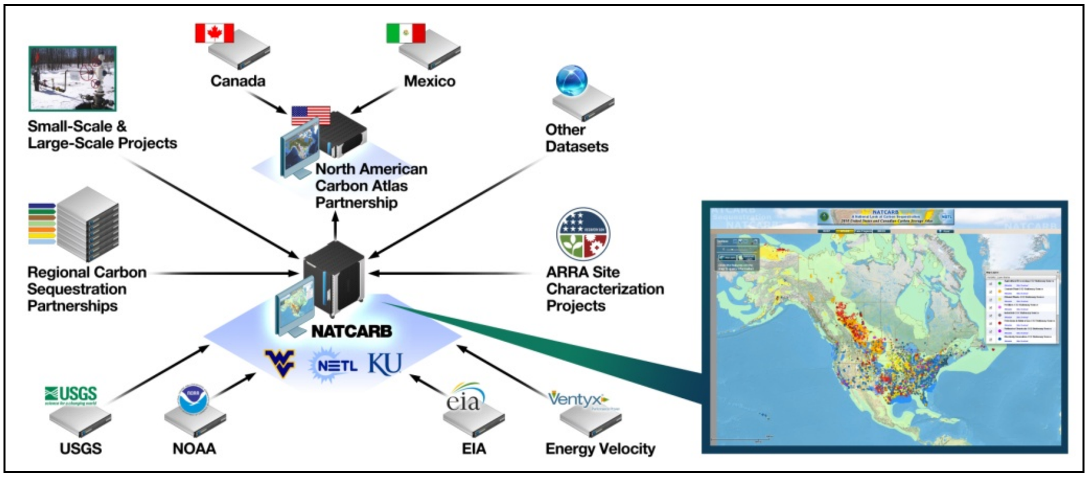


Figure 3 NATCARB Schematic

NATCARB is a functional demonstration of distributed data-management systems that cross the boundaries between institutions and geographic areas. Data are generated, maintained, and enhanced locally at the RCSP level, or at specialized data warehouses, and assembled, accessed, and analyzed in real-time through a single geoportal [8, 9]. NATCARB online access has been modified to address the broad needs of a spectrum of users. NATCARB includes not only GIS and database query tools for technical research, but simplified display for the general public using readily available web tools, such as Google Earth™ and Google Maps™. Not only is NATCARB connected to all the RCSPs, but data are also obtained from public servers, including the U.S. Geological Survey-EROS Data Center and from the Geography Network. Data for major CO_2 sources have been obtained fromEPA databases, and data on major coal basins and coalbed methane wells were obtained from the Energy Information Administration (EIA). NATCARB is one piece of a larger NETL effort to establish an Energy Data Exchange (EDX), a corporate database and geographic information system which will be a clearing house for data related to every aspect of production and use of fossil fuels, including CCUS.

Using RCSP data from NATCARB, DOE NETL is planning to release the fourth version of the *United States Carbon Utilization and Storage Atlas* (*Atlas IV*) in December 2012. *Atlas IV* provides an update of carbon capture, utilization, and storage (CCUS) potential across most of the United States and portions of Canada, as reported by the RCSPs. It presents updated information on the location of CO_2 stationary source emissions and the storage potential of geologic formations within the RCSP regions, as well as information about commercialization opportunities for CCUS technologies. *Atlas IV* will provide updated information on the RCSPs' field activities, and will include information on DOE's Carbon Storage Program, DOE's international CCUS collaborations, worldwide CCUS projects, CCUS regulatory issues, ARRA Site Characterization projects, NETL's Office of Research and Development activities, and NETL's Office of Strategic Energy Analysis and Planning efforts. . The production of *Atlas IV* is the result of collaboration among carbon storage experts from local, State, and Federal agencies, as well as industry and academia.

Atlas IV will include the most current and best available estimates of potential CO_2 storage resources in saline formations, unmineable coal areas, and oil and gas reservoirs. The CO_2 storage resource estimate is defined as the fraction of pore volume of porous and permeable sedimentary rocks available for CO_2 storage and accessible to injected CO_2 via drilled and completed wellbores. A consistent methodology for calculating storage resource has been developed by NETL and members of the seven

RCSPs [10] and applied consistently across all regions. The methodology, which is summarized in the *Atlas,* is based on volumetric methods for estimating subsurface volumes, in-situ fluid distributions, and fluid displacement processes. Oil and gas reservoirs are assessed at the field level, while saline formations and unmineable coal areas are assessed at the basin level. The storage resource estimates do not include economic or regulatory constraints. The *Atlas* is updated and published every two years as new data are acquired and methodologies for CO_2 storage estimates are refined. Furthermore, it is expected that, through the ongoing work of the RCSPs, data quality and conceptual understanding of the CCUS process will improve, resulting in more refined CO_2 storage resource estimates. Areal extents of geologic formations and CO_2 resource estimates presented are intended to be used as an initial assessment of potential geologic storage. This information provides CCUS project developers a starting point for further investigation of the extent to which geologic CO_2 storage is feasible.

NETL has expanded the NATCARB effort through the North American Carbon Atlas Partnership (NACAP) to better assess CO_2 storage potential throughout North America. Natural Resources Canada (NRCan), the Mexican Ministry of Energy (SENER), and the U.S. DOE have released the *North American Carbon Storage Atlas (NACSA*) (http://www.nacsap.org/), which was produced under the leadership of the North American Carbon Atlas Partnership (NACAP). NACSA provides a coordinated overview of capture and storage potential across Canada, Mexico, and the United States. The primary purpose of NACSA is to show the location of large stationary CO_2 emission sources and the locations and storage potential of various geological storage sites. NACSA includes the most current and best available estimates of potential CO_2 storage resource determined by each of the three countries' selected methodology. NACSA is a first attempt at providing a high-level overview of the potential for large-scale CO_2 storage throughout North America.

4. Training

While CCUS technologies offer great potential for mitigating greenhouse gas emissions, deploying these technologies will require a significantly expanded workforce trained in various disciplinary specialties. The NETL Carbon Storage Program is managing undergraduate and graduate student training through ARRA funded University-based Geologic Sequestration Training and Research Projects. These projects focus on fundamental research in the following areas: simulation and risk assessment; MVA; geological-related analytical tools; methods to interpret geophysical models; and well completion and integrity for long-term CO_2 storage.

ARRA provided funding to establish seven CCUS training centers (Figure 4) focused on the applied engineering and science of CCUS for site developers, geologists, engineers, and technicians. Training is completed via CCUS short courses; regional CCUS training conferences; targeted CCUS training seminars; and transfer of the lessons learned from CO_2 storage projects. In addition, the training centers provide a platform for technology transfer for CO_2 storage and instruction on planning and operating commercial CCUS projects

Figure 4: Locations of CCUS Training Centers

As of June 2012, a total of 5,523 professional development hours (PDHs) and 1,129 continuing education units (CEUs) have been obtained, and more than 2,941 students have participated in CCUS training provided by the seven training centers. The goal of these training centers is to become self sustaining (without Federal funding) and to continue the training efforts to ensure that a technically trained CCUS workforce will be available when CCUS is commercially deployed.

Summary

Carbon capture and storage and other clean coal technologies can play a critical role in mitigating greenhouse gases while supporting U.S. energy security. DOE's Carbon Storage Program is supporting a valuable knowledge-sharing initiative, which is distributing results and lessons learned from CCUS research and development efforts. These knowledge-sharing efforts serve as the foundation for future, large-scale CCUS deployment and address future challenges associated with public acceptance, infrastructure, and a regulatory framework. One of DOE's main initiatives to promote information and knowledge sharing is the development of a series of BPMs that outline uniform approaches to address issues and challenges in MVA; public outreach and education; site screening, site selection, and initial characterization; geologic storage formation classification; risk analysis and simulation; and well management. NATCARB is a major online resource developed and maintained by DOE to provide an interactive visual representation of CCUS potential. The *United States Carbon Utilization and Storage Atlas* also provides updates of CCUS potential across most of the United States and portions of Canada, as reported by RCSPs, and provides supplemental information on RCSP and Carbon Storage Program activities. The *North American Carbon Storage Atlas* is a first attempt at providing a high-level overview of the potential for large-scale CO_2 storage throughout all of North America. Finally, the Carbon Storage Program is providing training of a future CCUS workforce through support of University-based Geologic Sequestration Training and Research Projects and ARRA-funded seven regional CCUS training centers.

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