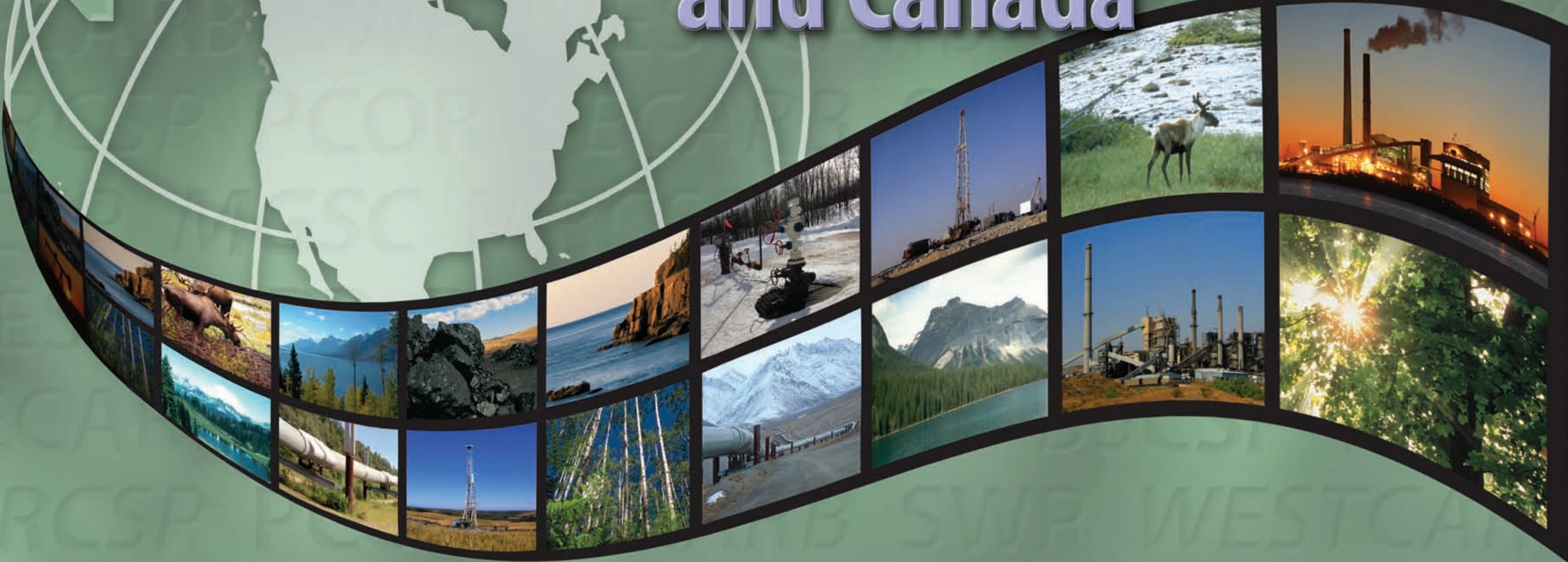
Third Edition

2010 Carbon Sequestration Atlas of the United States and Canada



U.S. DEPARTMENT OF ENERGY

NETL the ENERGY lab

Foreword

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) is proud to release the third edition of the *Carbon Sequestration Atlas of the United States and Canada (Atlas III)*. Production of *Atlas III* is the result of collaboration among carbon storage experts from local, State, and Federal agencies, as well as industry and academia. *Atlas III* provides a coordinated update of carbon capture and storage (CCS) potential across most of the United States and portions of Canada. The primary purpose of *Atlas III* is to update the carbon dioxide (CO_2) storage potential for the United States and Canada, and to provide updated information on the Regional Carbon Sequestration Partnerships' (RCSPs) field activities. In addition, *Atlas III* outlines DOE's Carbon Sequestration Program, DOE's international CCS collaborations, worldwide CCS projects, and CCS regulatory issues; presents updated information on the location of CO_2 stationary source emissions and the locations and storage potential of various geologic storage sites; and further provides information about the commercialization opportunities for CCS technologies from each RCSP.

A key aspect of CCS deals with the amount of carbon storage potential available to effectively help reduce greenhouse gas emissions. As demonstrated in *Atlas III*, CCS holds great promise as part of a portfolio of technologies that enables the United States and the rest of the world to effectively address climate change while meeting the energy demands of an ever increasing global population. *Atlas III* includes the most current and best available estimates of potential CO_2 storage resource determined by a methodology applied consistently across all of the RCSPs. A 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. Carbon dioxide storage resource assessments do not include economic, chemical, or regulatory constraints; only physical constraints are applied to define the accessible part of the subsurface. Economic and regulatory constraints are included in geologic CO_2 **capacity** estimates. Under the most favorable economic and regulatory scenarios, 100 percent of the estimated CO_2 storage resource may be considered CO_2 capacity.

The data in *Atlas III* is current as of March 2010. It will be updated every 2 years as new data are acquired and methodologies for CO_2 storage estimates improve. Furthermore, it is expected that, through the ongoing work of the RCSPs, data quality and conceptual understanding of the CCS process will improve, resulting in more refined CO_2 storage resource estimates.

About Atlas III

The *Carbon Sequestration Atlas of the United States and Canada* contains three main sections: (1) Introduction; (2) National Perspectives; and (3) Regional Perspectives. The Introduction section contains an overview of CCS technologies, a summary of the DOE's Carbon Sequestration Program, a brief description of the RCSP Program, and information on the National Carbon Sequestration Database and Geographic Information System (NATCARB). The National Perspectives section provides maps showing the number, location, and magnitude of CO_2 stationary sources in the United States and portions of Canada, as well as the areal extent and estimated CO_2 storage resource available in geologic formations evaluated within the RCSP regions. The National Perspectives section also contains a summary of the methodologies and assumptions employed to calculate CO_2 emissions and the estimated CO_2 storage resource of various geologic formations. The Regional Perspectives section includes a detailed presentation of CO_2 stationary sources, CO_2 storage resource assessments, updates on field projects, and information on CCS public outreach for each RCSP.

Carbon dioxide storage resource estimates were derived from data collected by each RCSP. This data is representative of each RCSP region and necessary to estimate parameters, such as area (A), thickness (h), and porosity (ϕ). The data were compiled in NATCARB. National CO_2 emission maps and CO_2 storage resource maps covering the United States and parts of Canada were developed by NATCARB for *Atlas III* from the information provided by the RCSPs. Carbon dioxide emission maps show the location and magnitude of CO_2 stationary sources. The National CO_2 storage resource maps illustrate areas of potential CO_2 storage.

Carbon dioxide geologic storage information in Atlas III was developed to provide a high level overview of CO_2 geologic storage potential across the United States and parts of Canada. 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 CCS project developers a starting point for further investigation of the extent to which geologic CO_2 storage is feasible. This information is not intended as a substitute for site-specific characterization, assessment and testing. Please refer to page 14 of *Atlas III* for additional information on this level of assessment.

DOE thanks the many individuals who contributed to *Atlas III*.

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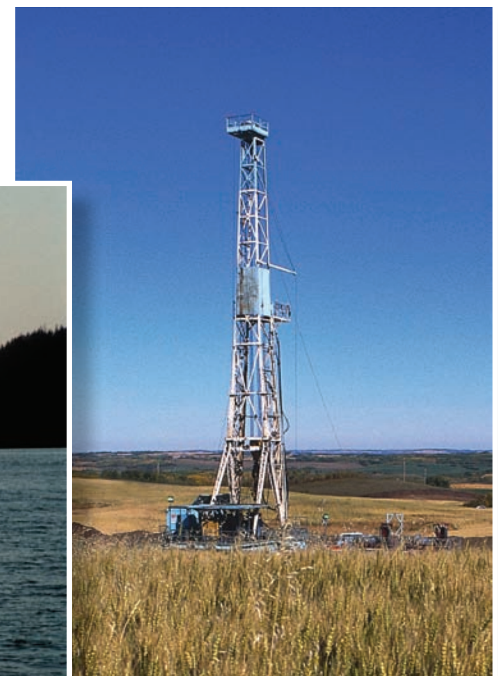
The Greenhouse Effect

Greenhouse gases (GHGs) present in the atmosphere contribute to the greenhouse effect, which is the trapping of radiant heat from the sun in the Earth's atmosphere. One GHG of particular interest is carbon dioxide (CO_2) because it is one of the most prevalent GHGs. Carbon dioxide is a colorless, odorless, nonflammable gas that provides a basis for the synthesis of organic compounds essential for life. Atmospheric CO_2 originates from both natural and manmade sources. Natural sources of CO_2 include volcanic outgassing, the combustion and decay of organic matter, and respiration. Manmade, or anthropogenic, sources of CO_2 are primarily derived from the burning of various fossil fuels for power generation and transportation. However, industrial activities contribute to CO_2 emissions as well.

The greenhouse effect is a natural and important process in the Earth's atmosphere. However, GHG levels have significantly increased above pre-industrial level. According to the Energy Information Administration (EIA), annual global energy-related CO_2 emissions have reached 31 billion metric tons (34 billion tons). This increase in atmospheric GHGs is considered by many scientists to be a contributing factor to global climate change.

The United States is one of 192 countries that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC). This treaty was approved in 1992 and calls for the stabilization of atmospheric GHGs at a level that could minimize impact on the world's climate. Conservation, renewable energy, and improvements in the efficiency of power plants, automobiles, and other energy consuming devices are all important steps which must be taken to mitigate GHG emissions. Carbon capture and storage (CCS) also promises to provide a significant reduction in GHG emissions. No single approach is sufficient to stabilize the concentration of GHGs in the atmosphere – especially when the growing global demand for energy and the associated potential increase in GHG emissions is considered. Technological approaches that are effective in reducing atmospheric GHG concentrations, while, at the same time, allowing economic growth and prosperity with its associated energy use, are needed.

CREDIT: NASA



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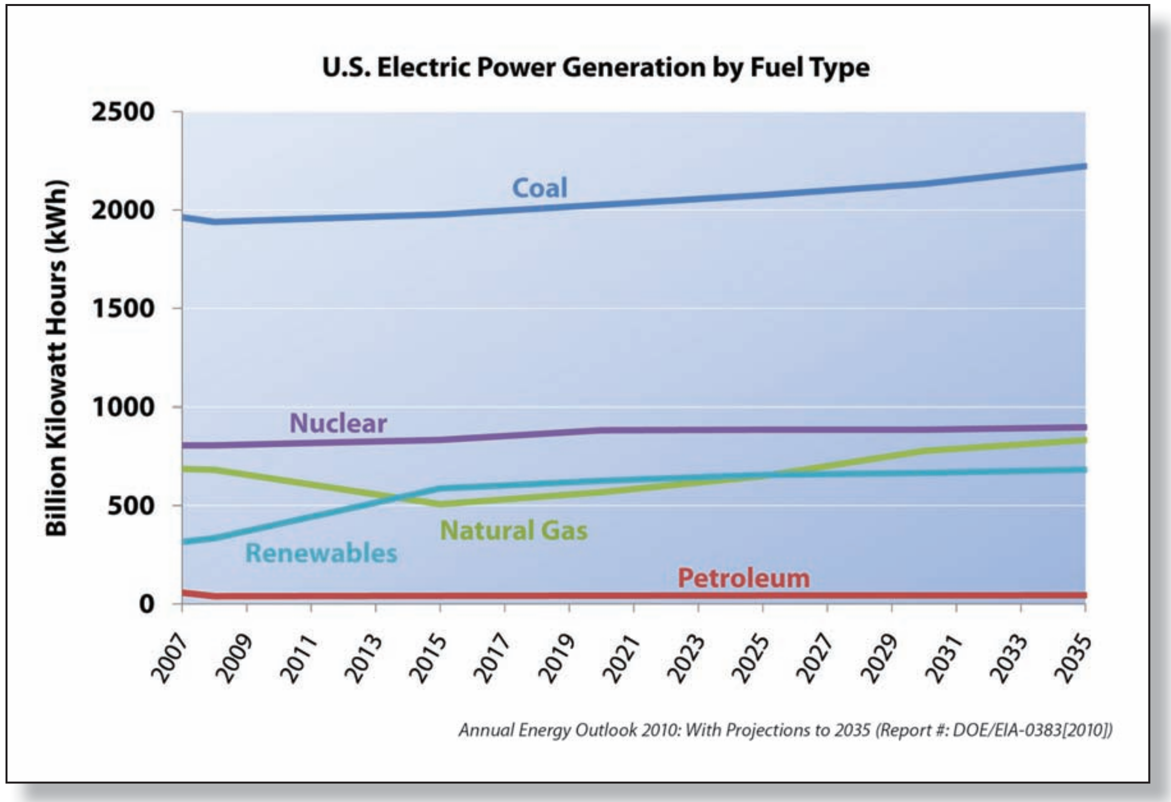
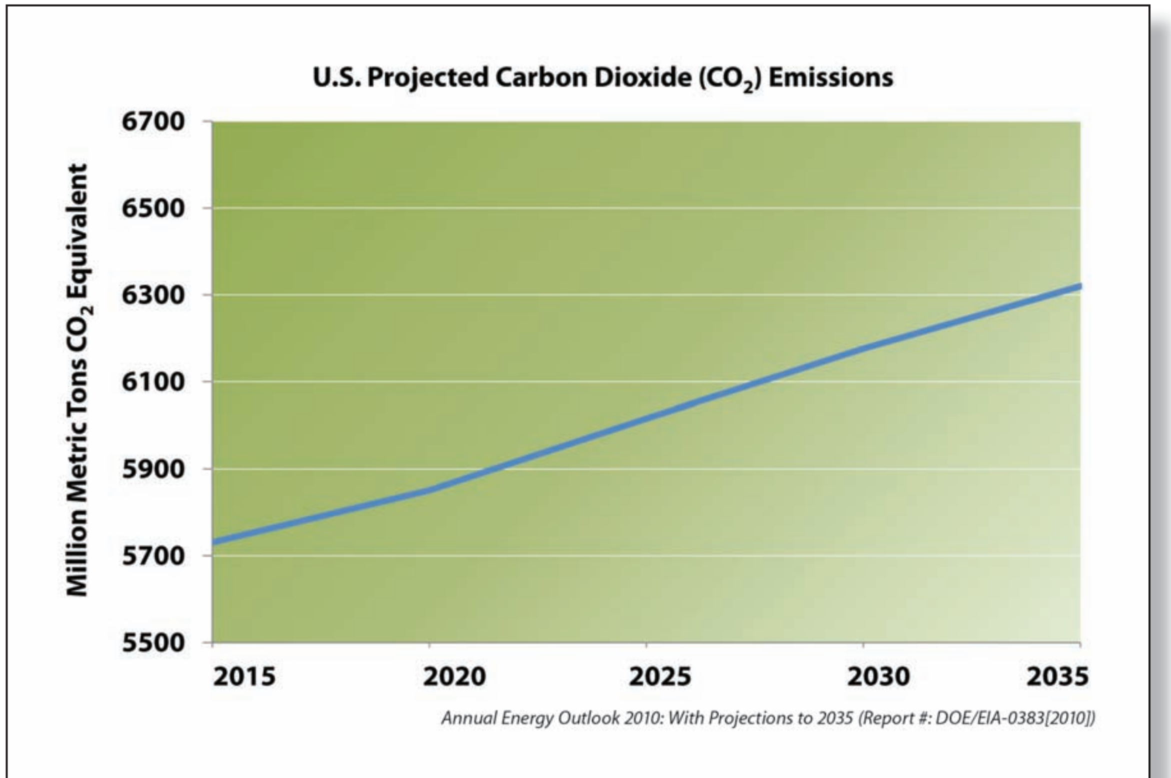




A Technology Approach to Reduce Greenhouse Gas Emissions

The U.S. Department of Energy's (DOE's) Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) manages a Carbon Sequestration Program focusing on the research and development (R&D) of CCS technologies with significant potential for reducing GHG emissions in order to mitigate global climate change. The Carbon Sequestration Program supports the UNFCCC goal to stabilize GHG emissions, as well as the President Obama's goal of bringing 5 to 10 commercial CCS demonstrations online by 2016 and reducing carbon emissions by 80 percent by 2050.

Power generation from coal is one significant source of CO_2 emissions; therefore efforts to reduce these emissions is a critical R&D goal. The graph titled "U.S. Electric Power Generation by Fuel Type," shown at top left, displays the Annual Energy Outlook's 2010 predictions of growth in energy generation by various fuel types. Coal is predicted to continue to dominate U.S. power generation for the next 25 years.

The graph titled "U.S. Projected Carbon Dioxide (CO_2) Emissions," shown at bottom left, illustrates the projected increase in CO_2 emissions throughout the United States over the next 25 years. Following AEO's 2010 assumptions, if no actions are taken, the United States will emit more than 6,300 million metric tons (6,930 million tons) of CO_2 by 2035, increasing 2007 emission levels by more than 10 percent. The United States can work toward reducing GHG emissions with the development and implementation of appropriate CCS technologies.

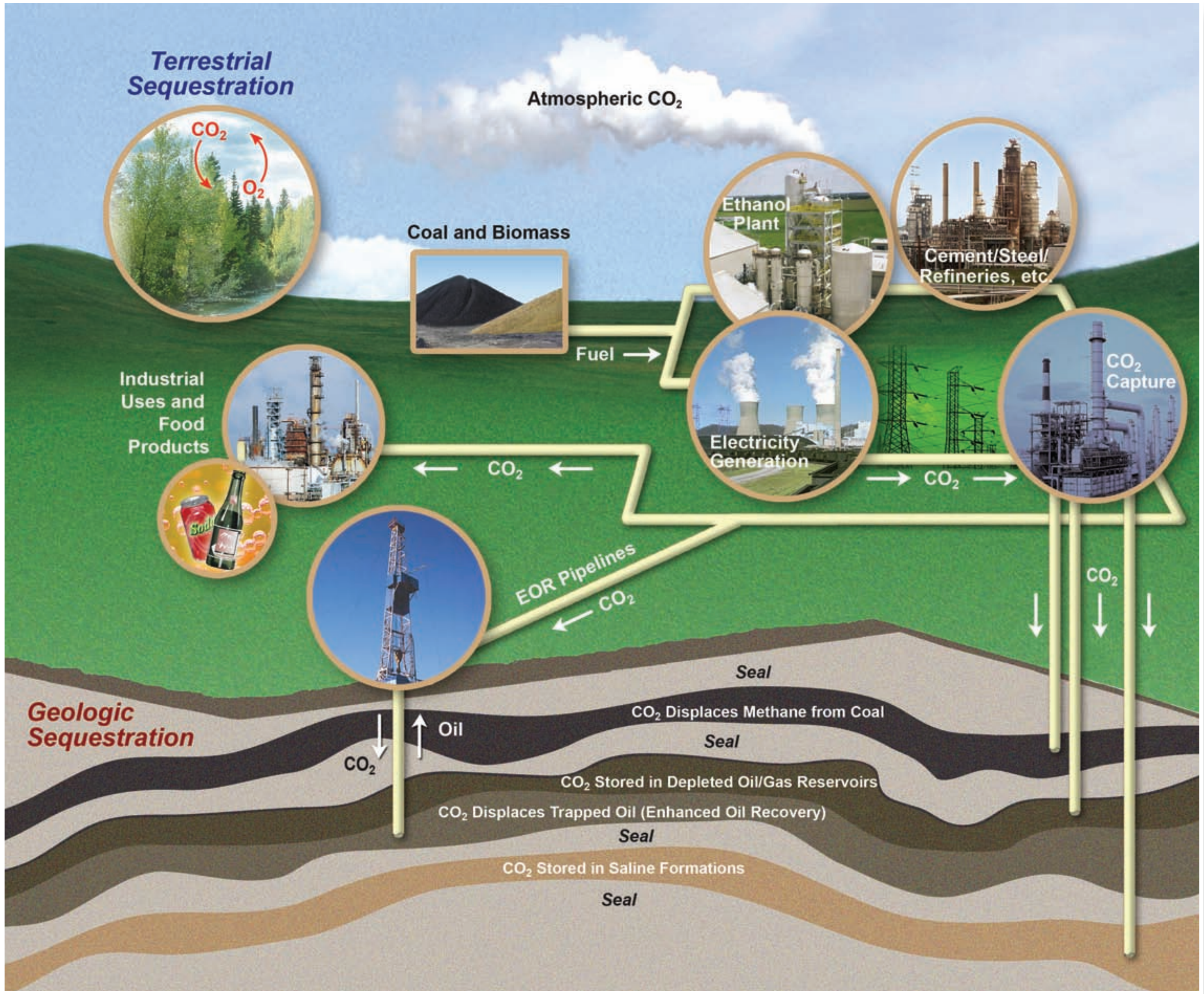
What is Carbon Sequestration?

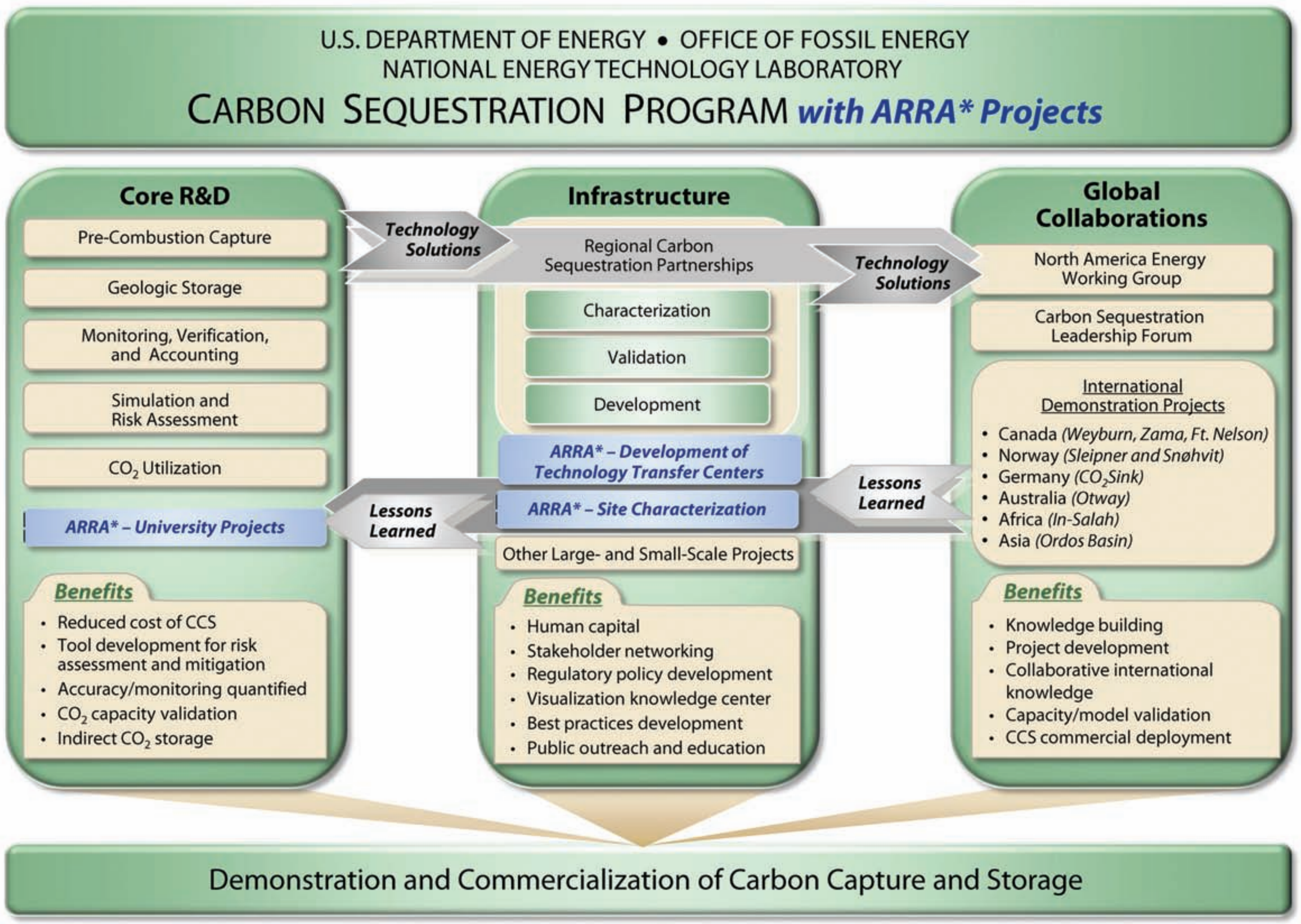
Carbon capture and storage (CCS) is the process of capturing and storing CO_2 that would otherwise accumulate in the atmosphere. DOE is investigating a variety of technology solutions for CCS including advanced capture techniques and CO_2 storage, or carbon sequestration, options. Geologic carbon storage involves the separation and capture of CO_2 at the point of emissions, the transportation of CO_2, and the storage of CO_2 in deep, underground geologic formations. Terrestrial carbon storage involves the net removal of CO_2 from the atmosphere by plants during photosynthesis and its fixation in vegetative biomass and soils.

Geologic storage is defined as the placement of CO_2 into a subsurface formation such that it will remain permanently stored. DOE is investigating five types of underground formations for geologic carbon storage, each with unique challenges and opportunities: (1) saline formations; (2) oil and gas reservoirs; (3) unmineable coal areas; (4) organic-rich shales; and (5) basalt formations.

It is projected that many new power plants and fuel processing facilities will be built in the coming decades. These new facilities, along with existing plants, which have the potential to be appropriately retrofitted, will create ample opportunities for deploying efficient and cost-effective CO_2 capture technologies. DOE's CO_2 capture efforts seek to cost-effectively capture CO_2 using various advanced technologies.

The CCS process includes monitoring, verification, and accounting (MVA) and risk assessment at the storage site. DOE's MVA efforts focus on the development and deployment of technologies that can provide an accurate accounting of stored CO_2 and a high level of confidence that the CO_2 will remain permanently stored. Effective application of these MVA technologies will ensure the safety of storage projects, and provide the basis for establishing carbon credit trading markets for stored CO_2 should these markets develop. Risk assessment research focuses on identifying and quantifying potential risks to humans and the environment associated with carbon sequestration, and helping to identify appropriate measures to ensure that these risks remain low.





* American Recovery and Reinvestment Act of 2009

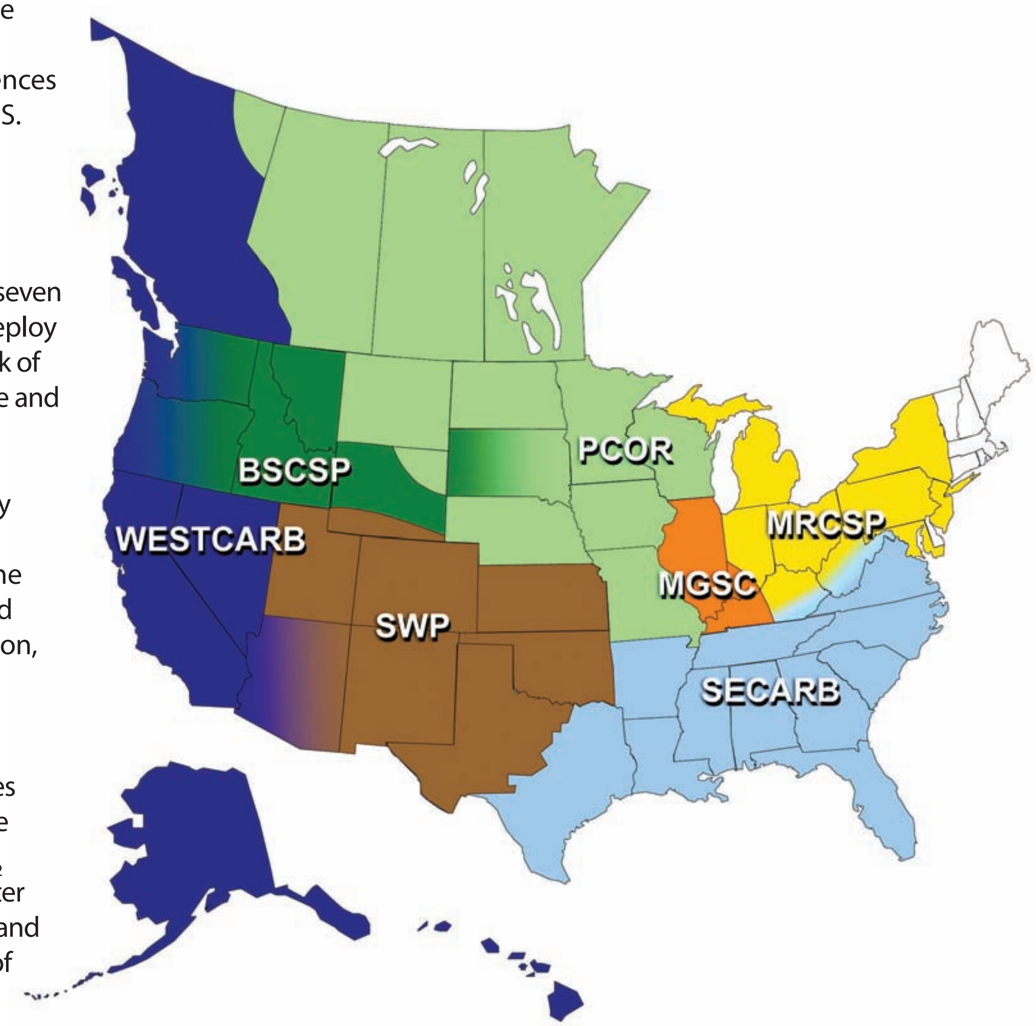
DOE's Carbon Sequestration Program

DOE's Carbon Sequestration Program is comprised of three key elements for CCS technology development and research: (1) Core R&D; (2) Infrastructure; and (3) Global Collaborations. The Core R&D element consists of five focal areas for CCS technology development: (1) Pre-Combustion Capture, (2) Geologic Storage, (3) Monitoring, Verification, and Accounting, (4) Simulation and Risk Assessment, and (5) CO_2 Utilization. The Core R&D element is driven by technology needs and is accomplished through applied laboratory and pilot-scale research aimed at developing new technologies for GHG mitigation. The primary component of the Infrastructure element is the Regional Carbon Sequestration Partnerships, a government/academic/industry cooperative effort tasked with characterizing, testing, and developing guidelines for the most suitable technologies, regulations, and infrastructure for CCS in different regions of the United States and several provinces in Canada. The Core R&D and Infrastructure elements provide technology solutions that support the Global Collaborations element. DOE participates and transfers technology solutions to international efforts that promote CCS, such as the Carbon Sequestration Leadership Forum (CSLF), the North American Energy Working Group (NAEWG), and several international demonstration projects.

DOE's Carbon Sequestration Program is developing a portfolio of technologies addressing various aspects of CCS that will aid in the reduction of GHG emissions. The Carbon Sequestration Program Goal is to demonstrate safe, cost-effective, and long-term carbon mitigation, management, and storage by 2020. Reaching this goal requires an integrated R&D program that will advance fundamental CCS technologies and prepare them for commercial-scale development. The Program works in concert with several programs within FE that are developing and demonstrating technologies integral to coal-fired power generation and coal conversion with potential for carbon capture, including Innovations for Existing Plants, Fuels, Clean Coal Power Initiative, Advanced Integrated Gasification Combined Cycle, Fuel Cells, Advanced Turbines, and Advanced Research. Projects that meet the Program Goal will result in large-scale units that come online around 2020. In the long-term, the program is expected to significantly contribute to the reduction of GHG emissions.

Regional Carbon Sequestration Partnerships

Initiated by DOE-FE, the Regional Carbon Sequestration Partnerships (RCSPs) (see map at right) are a public/private partnership tasked with developing guidelines and testing for the most suitable technologies, regulations, and infrastructure needs for CCS within seven different regions of the United States and Canada. Geographical differences in fossil fuel use and CO_2 storage potential across the United States and Canada dictate regional approaches to CCS. The seven RCSPs that form this network currently include more than 400 organizations, universities, and private companies, spanning 43 states, and 4 Canadian provinces.



The RCSPs' effort is being implemented in three phases: (1) Characterization Phase (2003–2005); (2) Validation Phase (2005–2011); and (3) Development Phase (2008–2018+). The Characterization Phase began in September 2003 with the seven RCSPs working to characterize storage potential and develop the necessary framework to validate and potentially deploy CCS technologies. At the end of the Characterization Phase, the RCSPs had succeeded in establishing a national network of companies and professionals working to support CCS deployments, creating a National Carbon Sequestration Database and Geographic Information System (NATCARB) and raising awareness and support for CCS as a GHG mitigation option.

The Validation Phase focuses on validating the most promising regional opportunities to deploy CCS technologies by building upon the accomplishments of the Characterization Phase. Two different CO_2 storage approaches are being pursued in this phase: geologic and terrestrial carbon storage. 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. The Validation Phase includes 20 geologic and 11 terrestrial CO_2 storage projects.

The Development Phase builds on the information generated in the Characterization and Validation Phases and involves the injection of 1 million tons or more of CO_2 by each RCSP into various regionally significant geologic formations. These large-volume injection tests are designed to demonstrate that CO_2 storage sites have the potential to store regional CO_2 emissions safely, permanently, and economically for hundreds of years. Development Phase projects will result in a better understanding of technical and non-technical aspects for commercial scale CCS projects, including regulatory, liability, and ownerships issues associated with these projects. These projects will provide a firm foundation for commercialization of large-scale CCS.

Regional Carbon Sequestration Partnership	Lead Organization	Member States/Provinces	Website
Big Sky Carbon Sequestration Partnership (BSCSP)	Montana State University	Western Montana, Idaho, South Dakota, Central Wyoming, Eastern Oregon and Washington, and adjacent areas in British Columbia and Alberta	http://www.bigskyco2.org/
Midwest Geological Sequestration Consortium (MGSC)	Illinois State Geological Survey	Illinois, Southwestern Indiana, and Western Kentucky	http://www.sequestration.org/
Midwest Regional Carbon Sequestration Partnership (MRCSP)	Battelle Memorial Institute	Eastern Indiana, Northeastern Kentucky, Maryland, Michigan, New Jersey, New York, Ohio, Pennsylvania, and Northwestern West Virginia	http://www.mrcsp.org/
Plains CO_2 Reduction (PCOR) Partnership	University of North Dakota, Energy and Environmental Research Center	Eastern Montana, Northeastern Wyoming, Nebraska, Eastern South Dakota, North Dakota, Minnesota, Wisconsin, Iowa, Missouri, Alberta, Saskatchewan, Manitoba, and Northeastern British Columbia	http://www.undeerc.org/PCOR/
Southeast Regional Carbon Sequestration Partnership (SECARB)	Southern States Energy Board	East Texas, Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Florida, Georgia, South Carolina, North Carolina, Virginia, Kentucky, and Southeastern West Virginia	http://www.secarbon.org/
Southwest Regional Partnership on Carbon Sequestration (SWP)	New Mexico Institute of Mining and Technology	Western Texas, Oklahoma, Kansas, Colorado, Utah, and Eastern Arizona, New Mexico, and Southern Wyoming	http://www.southwestcarbonpartnership.org/
West Coast Regional Carbon Sequestration Partnership (WESTCARB)	California Energy Commission	Alaska, Western Arizona, Western British Columbia, California, Hawaii, Nevada, Western Oregon, and Western Washington	http://www.westcarb.org/

Regional Carbon Sequestration Partnerships

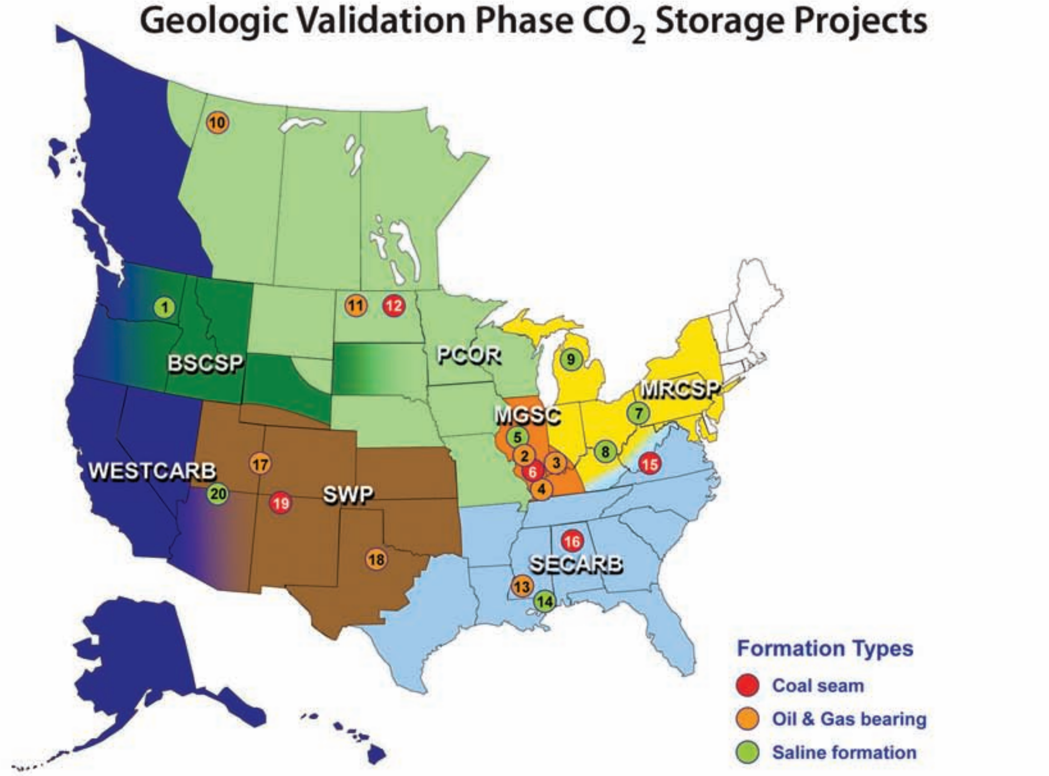
Validation Phase CO_2 Storage Projects

	Partnership	Geologic Province/ Location	Geologic: Total CO_2 Injection (metric tons CO_2)	Geologic: Approximate Depth (feet)	Terrestrial: Estimated CO_2 Storage Potential
1	Big Sky Carbon Sequestration Partnership	Columbia Basin	0	2,500 – 4,000	
A		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	Illinois Basin–Loudon Field	< 39	1,550	
3		Illinois Basin–Mumford Hills Field	3,375	1,551	
4		Illinois Basin–Sugar Creek Field	6,500	1,548	
5		Illinois Basin*	*	7,200	
6		Illinois Basin	91	1,000	
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	Alberta Basin–Zama Field	25,400	4,900	
11		Williston Basin–Norhwest Field	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–Cranfield	627,744	10,300–10,400	
14		Mississippi Coastal Plain	2,740	8,600	
15		Central Appalachian	907	1,600 – 2,300	
16		Black Warrior Basin	252	1,500 – 2,500	
17	SWP	Paradox Basin–Aneth Field	630,000	5,600 – 5,800	
18		Permian Basin–Sacroc Unit	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	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)

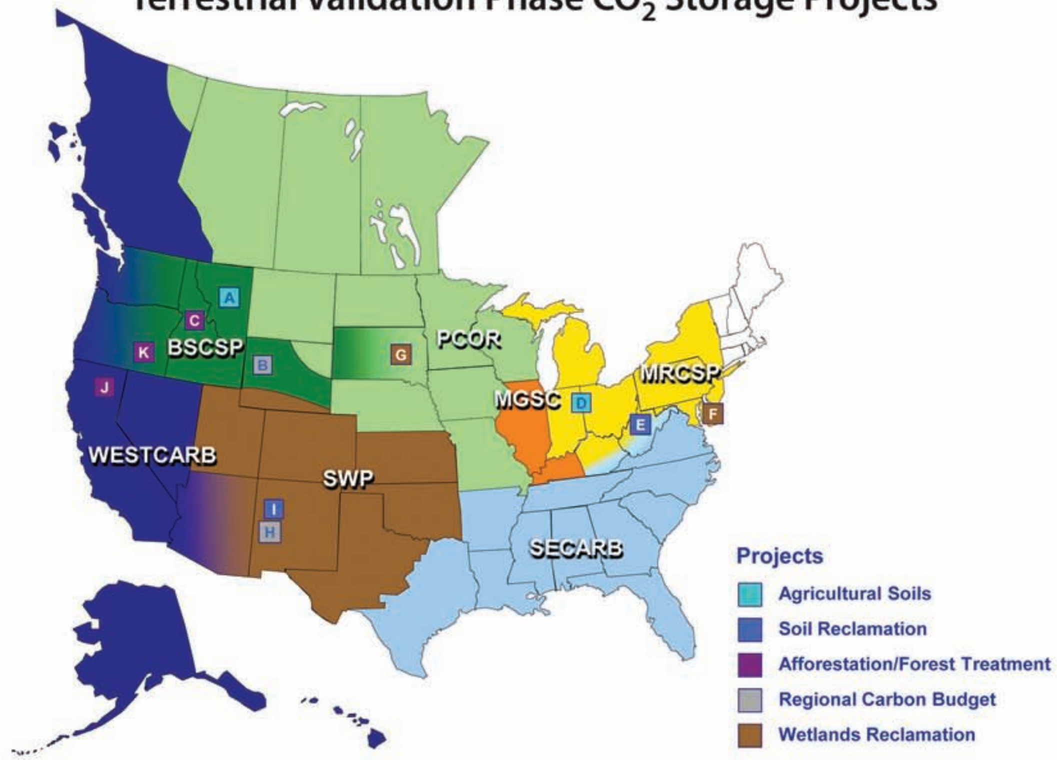
* Site was moved to Development Phase injection.

Information current as of June 2010

Geologic Validation Phase CO_2 Storage Projects



Terrestrial Validation Phase CO_2 Storage Projects



Regional Carbon Sequestration Partnerships

DOE's CCS Best Practices Manuals

The lessons learned during Validation Phase will result in a series of Best Practices Manuals (BPMs) that serve as the basis for the design and implementation of commercial CCS projects. These BPMs will provide recommended approaches for simulation and risk assessment; well construction, operations, and closure; terrestrial sequestration; MVA; public outreach and education; and site selection and characterization for future CCS commercial projects.

As of August 2010, FE's NETL has published three BPMs: (1) "Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations," (2) "Public Outreach and Education for Carbon Storage Projects," and (3) "Site Screening, Selection, and Characterization for Storage of CO_2 in Deep Geologic Formations."

NETL's "Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations" BPM provides an overview of MVA techniques that are currently in use or are being developed; summarizes DOE's MVA R&D program; and presents information that can be used by regulatory organizations, project developers, and national and State policymakers to ensure the safety and efficacy of carbon storage projects. NETL's "Public Outreach and Education for Carbon Storage Projects" BPM is intended to assist project developers in understanding and applying best outreach practices for siting and operating CO_2 storage projects. It provides practical, experience-based guidance on designing and conducting effective public outreach activities. The purpose of NETL's latest BPM, titled, "Site Screening, Selection, and Characterization for Storage of CO_2 in Deep Geologic Formations," is to establish a framework and methodology for proper site screening, selection, and initial characterization of geologic storage sites that: (1) provides stakeholders with a compilation of best practices for site screening, selection, and characterization; (2) communicates the experience gained through DOE's RCSP Program in the Characterization and Validation Phases; and, (3) develops a consistent, industry-standard framework, terminology, and set of guidelines for project-related storage capacity and risk estimates.

NETL's BPMs are available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html.

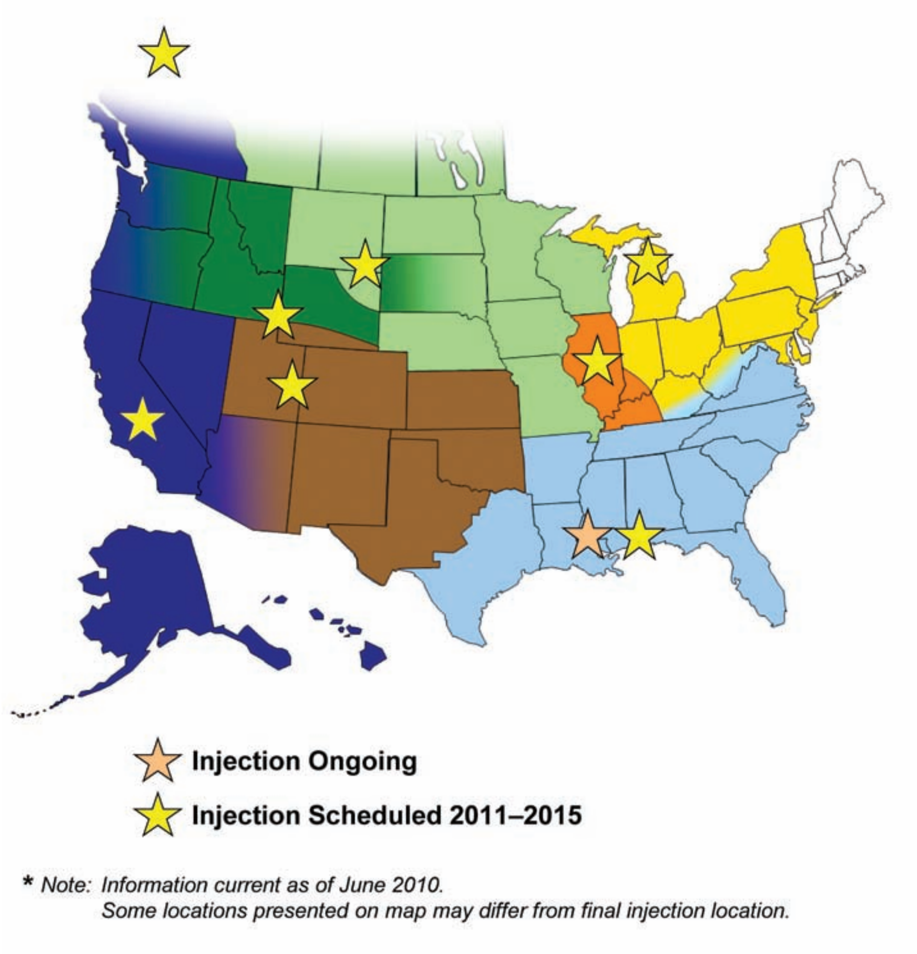
Best Practices Manual	Version 1 (Validation Phase)	Version 2 (Development Phase)	Final Guidelines (Post Injection)
Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations	2009	2017	2020
Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations	2010	2016	2020
Risk Assessment and Simulation for Geologic Storage of CO_2	2010	2017	2020
Drilling, Well Installation, Permitting, Operations, Mitigation, and Closure for CO_2 Storage in Deep Geologic Formations	2010	2017	2020
Public Outreach and Education for Carbon Storage Projects	2009	2016	2020
Terrestrial Sequestration of Carbon Dioxide	2010	**2016 – Post MVA Development Phase**	
Geologic Storage Formation Classification: *Understanding Its Importance and Impacts on CCS Opportunities in the United States*	2010		

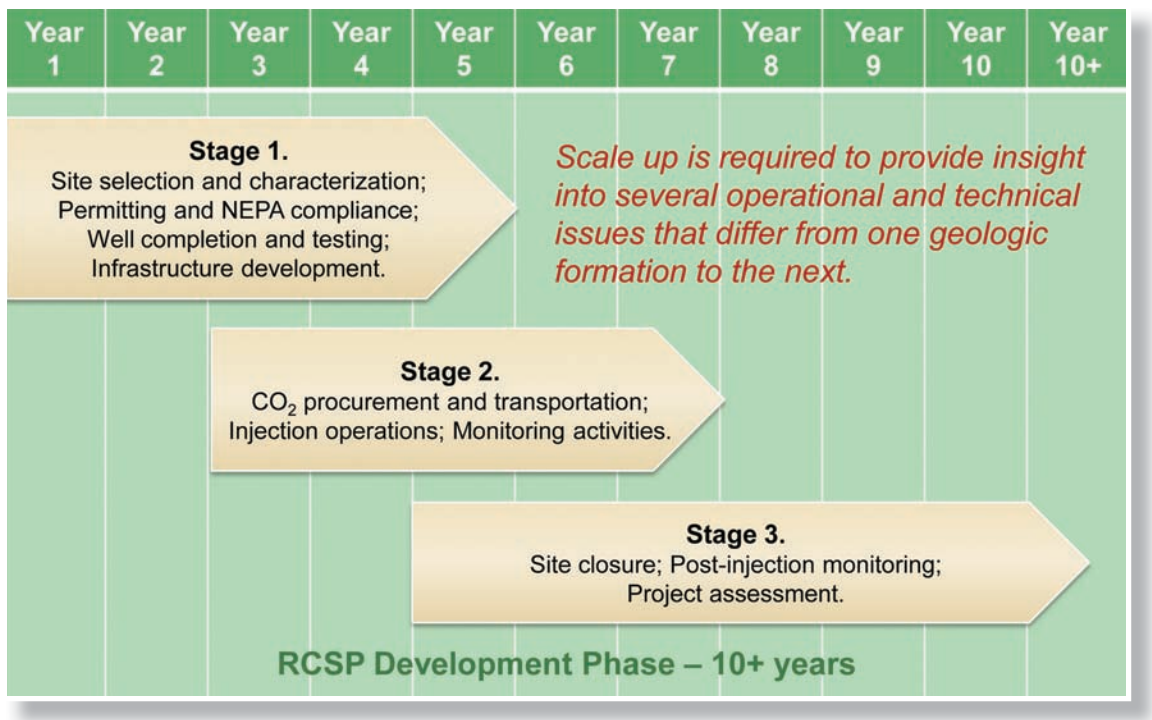
Regional Carbon Sequestration Partnerships

Development Phase CO_2 Storage Projects

The Development Phase (2008–2018+) builds on the experience obtained in the Characterization and Validation Phases and involves the injection of 1 million metric tons or more of CO_2 into regionally significant geologic storage formation environments. During this phase, the RCSPs will demonstrate that CO_2 capture, transportation, injection, and storage can be achieved safely, permanently, and economically at large scale. The geologic structures to be tested during these RCSP large-volume storage projects may become candidate sites for future near-zero emissions power plants. The primary goal of the Development Phase is to establish large-scale CCS projects across North America, where large volumes of CO_2 will be injected into a geologic storage formation to validate CO_2 storage potential (see map at bottom left). The RCSPs will design and explore various injection scenarios that fully utilize the infrastructure of their respective regions. Sources of CO_2 may include natural deposits, ethanol facilities, natural gas processing plants, and CO_2 captured from power plants. The Development Phase projects will be implemented in three stages, which will test key technologies during the project's life cycle (see graphic at bottom right). 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 large-scale projects.

Development Phase goals include: (1) collect physical data to confirm potential resource and injectivity estimates made during the Characterization Phase; (2) validate the effectiveness of simulation models to predict and MVA technologies to measure CO_2 movement within the geologic formations, confirm the integrity of the seals, and confirm indirect storage in terrestrial ecosystems; (3) develop guidelines for well completion, operations, and closure in order to maximize storage potential and mitigate potential release; (4) develop strategies for optimizing geologic storage for various reservoir types; (5) develop public outreach strategies and communicate the benefits of CCS to various stakeholders; and, (6) satisfy the regulatory and permitting requirements for CCS projects.





DOE's Global CCS Collaborations

The Global Collaborations portion of DOE's Carbon Sequestration Program involves participation in international CCS projects in Canada, Norway, Germany, Australia, Algeria, and China and other international efforts to promote CCS, such as the CSLF and the NAEWG. The table at right highlights DOE's global CCS project involvement.

The CSLF, established by DOE, 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 for the separation and capture of CO_2; transportation of CO_2; and, long-term, safe storage of CO_2. The purpose of the CSLF is to make these technologies available internationally and to identify and address wider issues relating to CCS, such as regulatory and policy options. For more information, visit http://www.cslf.org.

The NAEWG was established in 2001 by the Secretary of Energy of the United States, the Secretary of Energy of Mexico, and the Canadian Minister of Natural Resources. The goals of the NAEWG are to foster communication and cooperation among the governments and energy sectors of the three countries on energy-related matters of common interest, and to enhance North American energy trade and interconnections consistent with the goal of sustainable development. This trilateral process fully respects the domestic policies, divisions of jurisdictional authority, and existing obligations of each country.

As part of this trilateral effort, a joint CO_2 mapping initiative between the three countries called the North American Carbon Atlas Partnership (NACAP) was started. Additional information on NACAP can be found on page 19 of *Atlas III*.

DOE's Global CCS Project Involvement

Location/Project	Operations	U.S. Involvement	U.S. Participant(s)	Reservoir	Operator/Lead	International Recognition
North America, Canada – Saskatchewan Weyburn-Midale	1.8 MMt CO_2/yr Commercial 2000	2000–2011	Lawrence Livermore National Laboratory, Schlumberger, Fugro, University of Columbia	Oil field Carbonate Enhanced Oil Recovery	Cenovus, Apache	U.S. – Canada Clean Energy Dialogue, IEA GHG R&D Programme, CSLF
North America, Canada – Alberta Zama Oil Field	227,000 Mt CO_2, 82,000 Mt H_2S Demo	2005–2009	PCOR Partnership	Oil field Carbonate Enhanced Oil Recovery	Apache (RCSP)	CSLF
North America, Canada – British Columbia Fort Nelson	> 1 MMt CO_2/yr, 1.8 MMt acid gas/yr Large-scale Demo	2009–2015	PCOR Partnership	Saline Formation	Spectra Energy (RCSP)	CSLF
Europe, North Sea – Norway Sleipner	1 MMt 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 Snøhvit CO_2 Storage	700,000 Mt CO_2 Commercial 2008	2009–TBD	Lawrence Livermore National Laboratory	Marine Sandstone	StatoilHydro	—
Europe, Germany CO_2SINK, Ketzin	60,000 Mt CO_2 Demo 2008	2007–2010	Lawrence Berkeley National Laboratory	Saline Sandstone	GeoForschungsZentrum, Potsdam (GFZ)	CSLF, European Commission, IEA GHG R&D Programme
Europe, 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 Mt CO_2 Demo 2008	2005–2010	Lawrence Berkeley National Laboratory	Gas Field Sandstone	CO_2CRC	CSLF
Africa, Algeria In Salah Gas	1 MMt CO_2/yr Commercial 2004	2005–2010	Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory	Gas Field Sandstone	BP, Sonatrach, StatoilHydro	CSLF, European Commission
Asia, China Ordos Basin	Assessment Phase CCS	2008–TBD	Lawrence Livermore National Laboratory, West Virginia University	Ordos Basin	Shenhua Coal	—

Issue	Agency	Authority	What is Regulated	FE Involvement
CO_2 Geologic Storage				
Injection, Monitoring, Safety	EPA/Office of Water	Safe Drinking Water Act	Underground injection and environmental monitoring of CO_2; draft rule published 8/2008; final rule expected 12/2010	EPA and FE are actively engaged in CCS regulatory and technical development. This interaction has helped to inform EPA's regulatory development process.
Injection on Federal Lands	U.S. Department of Interior/ Bureau of Land Management (BLM)	Federal Land Policy and Management Act and Minerals Leasing Act	Underground injection of CO_2 on Federal lands	FE participated in the preparation of several BLM Reports to Congress (e.g., under EPACT Sec. 369 and EISA Sec. 714).
State Role	Interstate Oil and Gas Compact Commission (IOGCC) and Ground Water Protection Council (GWPC)	State and Federal Statutes	Storage, including injection	FE is working with the IOGCC to examine the legal and regulatory framework for CO_2 storage, and the GWPC on State regulatory program data management for carbon storage.
Offshore	IOGCC	State and Federal Waters	Transport and Storage	FE is sponsoring IOGCC to conduct assessment of gaps for offshore storage.
CO_2 Transport				
Pipeline Safety	U.S. Department of Transportation	Interstate Commerce Act and Hazardous Liquid Pipeline Act	CO_2 pipeline operations including technical specifications	FE is working with the IOGCC and National Association of Regulatory Utility Commissioners to examine the regulatory framework for CO_2 pipeline siting, operation, and tariffs.
Pipeline Tariff Rate and Access	Federal Energy Regulatory Commission (FERC) / Surface Transportation Board	No Authority under Natural Gas Act or Interstate Commerce Act to set tariffs	Rate and Access Regulation (no siting or eminent domain)	FE and FERC are participating in the IOGCC Pipeline Transportation Task Force on CO_2 pipelines for carbon storage.

* Information current as of June 2010.

DOE's Interagency CCS Collaborations

Regulatory authority over many aspects of CCS continues to be examined by numerous agencies. Most of the interagency activities to date have focused on CO_2 transport and geologic storage. FE is actively coordinating with States and other Federal agencies on CCS-related rulemaking activities and engaging industry stakeholders in preparation for future regulatory action. This includes interacting with the U.S. Environmental Protection Agency (EPA), the U.S. Department of Interior's (DOI) Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), 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. These regulatory activities are summarized in the chart to the left.

In addition, DOE is collaborating with the United States Geological Survey (USGS) and the DOI-BOEMRE on CCS site characterization and CO_2 geologic storage resource estimation for various geologic storage formations in the United States.

In 2007, the Energy Independence and Security Act (Public Law 110-140) authorized the USGS to conduct a national assessment of potential geologic storage resources for CO_2 in cooperation with the EPA and DOE. As a result of this legislation, the USGS developed a methodology that is being used by USGS geologists to assess the CO_2 storage potential in the United States at scales ranging from regional to sub-basinal. Storage assessment units are defined on the basis of common geologic and hydrologic characteristics. This methodology evaluates two types of storage processes (buoyant and residual) in saline formations at the individual storage assessment unit level. Results of the USGS assessment (2010–2013) will include illustrations and storage resource values.

The BOEMRE manages resources of the Outer Continental Shelf (OCS) pursuant to the Outer Continental Shelf Lands Act (OCSLA). Section 8(p)(1)(C) of the OCSLA authorizes the DOI to grant leases, easements, or rights-of-way on the OCS supporting the sub-seabed storage of CO_2 that is the byproduct of the production of electricity from sources other than oil and gas. The BOEMRE is currently developing regulations to implement its authority under Section 8(p)(1)(C). To support these regulations, BOEMRE is conducting research to develop best management practices for CO_2 sub-seabed storage on the OCS. The BOEMRE Resource Evaluation Division is investigating assessment methodologies that will enable it to estimate the potential total volume of CO_2 that could be stored in the OCS.

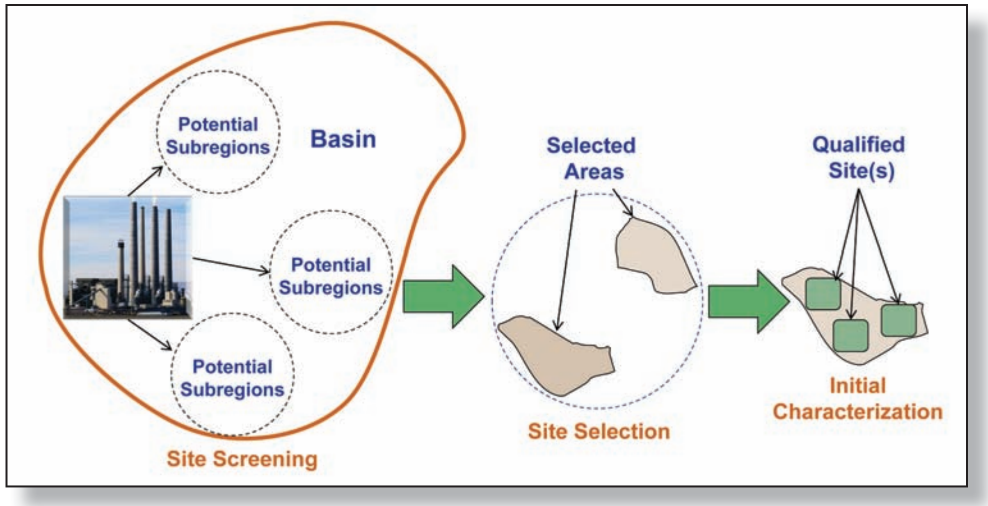
On February 3, 2010, President Obama sent a memorandum to the heads of 14 Executive Departments and Federal Agencies that established an Interagency Task Force on Carbon Capture and Storage. The Task Force's goal was to develop a comprehensive and coordinated Federal strategy to speed the commercial development and deployment of clean coal technologies. The Task Force, co-chaired by DOE and the EPA, was charged with proposing a plan to overcome the barriers to the widespread, cost-effective deployment of CCS within 10 years, with a goal of bringing 5 to 10 commercial demonstration projects online by 2016. The final report was published in August 2010 and is available at http://www.fe.doe.gov/programs/sequestration/ccstf/CCSTaskForceReport2010.pdf. For more information on the CCS Task Force, visit: http://www.whitehouse.gov/administration/eop/ceq/initiatives/ccs.

Site Characterization for Geologic Storage Sites

The process of identifying and maturing suitable geologic storage sites involves a methodical and careful analysis of the technical and non-technical aspects of potential sites. This process is analogous to the methods used in the petroleum industry to mature a project through a framework of resource classes and project status subclasses until the project begins producing hydrocarbons. A CO_2 Geologic Storage Classification System would likely follow the same processes developed by the petroleum industry in a bottom up progression based on analyses conducted to reduce the project development risk. The proposed framework would contain three distinct phases of evaluation (Exploration Phase, Site Characterization Phase, and Implementation Phase) corresponding to each resource class and further subdivided into project subclasses.

The Exploration Phase evaluates resources classified as Prospective Storage Resources and is divided into three project subclasses (Potential Subregions, Selected Areas, and Qualified Sites). Each project subclass undergoes an evaluation process (Site Screening, Site Selection, and Initial Characterization) that builds on previous analyses to pare down larger Potential Subregions into Qualified Site(s). The three evaluation processes are discussed in more detail below:

- **Site Screening** involves analysis of three components (regional geologic data, regional site data, and social data) to develop and rank a list of Selected Areas within a Potential Subregion to elevate to the **Site Selection** evaluation. This analysis highlights the most promising Selected Areas for geologic storage, while eliminating those that do not meet a developer's criteria.
- **Site Selection** involves analysis of the most promising **Selected Areas** in more detail to ensure only those that meet critical technical and economic criteria advance for further evaluation. Analysis is conducted on five separate components, including subsurface geologic data, regulatory requirements, model data, site data, and social data. At the completion of this stage, the developer will have a list of potential **Qualified Site(s)** that can be assessed during the final evaluation stage.



Graphical Representation of "Project Site Maturation" through the Exploration Phase.

- **Initial Characterization** involves analysis of one or more of the higher ranked **Qualified Site(s)**. This stage includes analysis of several components, including baseline data, regulatory requirements, model data, social data, and a site development plan. Upon completion results from this stage should provide enough information to qualify discovered storage at the site as **Contingent Storage Resource**.

At the completion of the Exploration Phase, a **Qualified Site** moves into the **Site Characterization Phase**, classifying the storage as **Contingent Storage Resources** with three project subclasses: **Development Not Viable**, **Development Unclarified or on Hold**, or **Development Pending**. Once the appraised **Qualified Site** is considered commercial, the project would move into the **Implementation Phase**. The project would first be classified as **Justified for Development**. Once all necessary approvals and permits have been obtained and capital funds committed, the project elevates to **Approved for Development**, which would give way to **Active Injection**. The successful characterization of a site is one of the most important steps in ensuring the safe and economic operation of a geologic CO_2 storage site.

For more information, NETL's "Site Screening, Selection, and Characterization for Storage of CO_2 in Deep Geologic Formations" is available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-SiteScreening.pdf.

Petroleum Industry		CO_2 Geologic Storage
Reserves	Implementation	**Storage Capacity**
On Production		Active Injection
Approved for Development		Approved for Development
Justified for Development		Justified for Development
Contingent Resources	Site Characterization	**Contingent Storage Resources**
Development Pending		Development Pending
Development Unclarified or On Hold		Development Unclarified or On Hold
Development Not Viable		Development Not Viable
Prospective Resources	Exploration	**Prospective Storage Resources**
Prospect		Qualified Site(s)
Lead		Selected Areas
Play		Potential Subregions

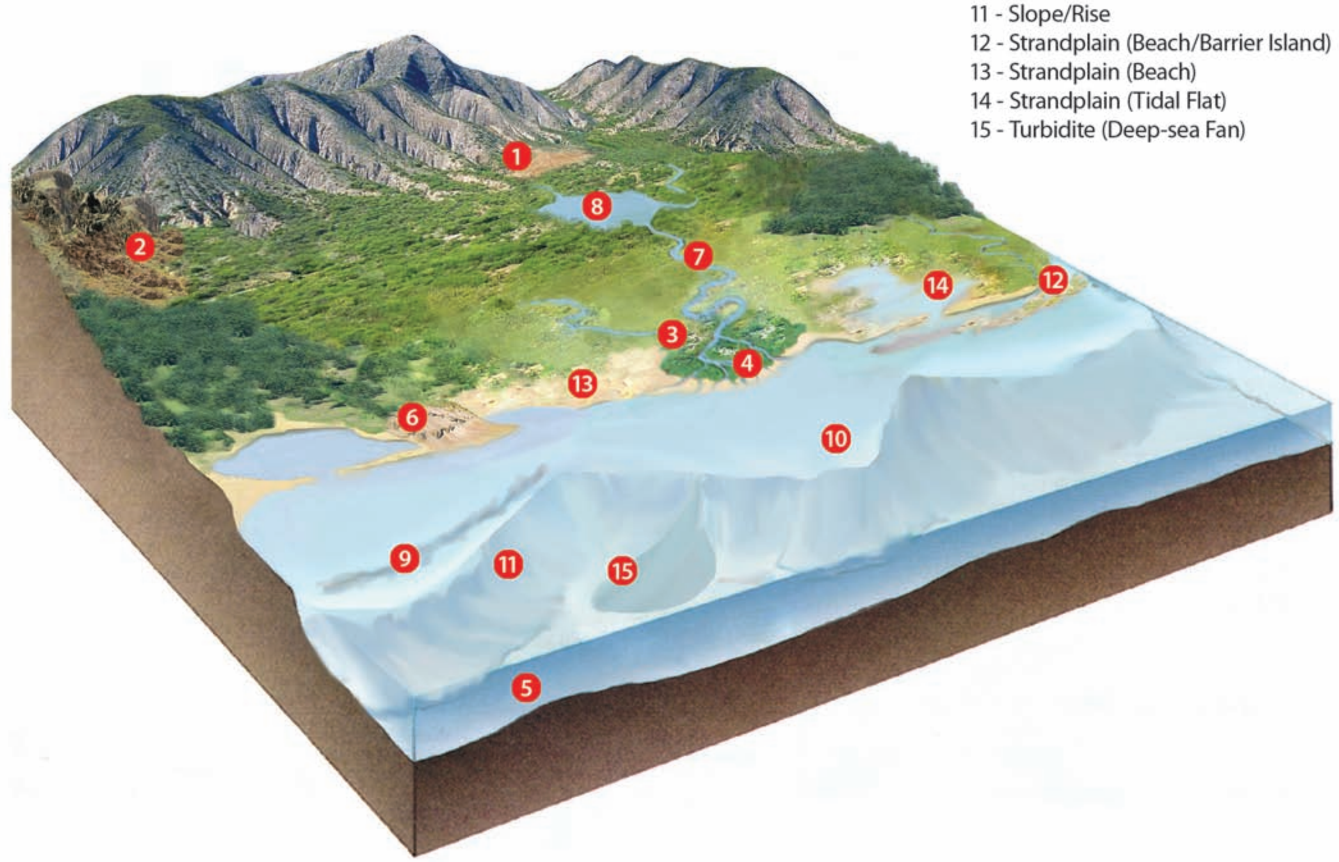
	Prospective Storage Resources	
Exploration	**Project Subclass**	**Evaluation Process**
	Qualified Site(s)	Initial Characterization
	Selected Areas	Site Selection
	Potential Subregions	Site Screening

Comparison of Petroleum Industry Classification and Proposed CO_2 Geologic Storage Classification. Adapted from SPE/WPC/AAPG/SPEE Resource Classification System. (© 2007 Society of Petroleum Engineers, Petroleum Resources Management System.)

(Note: this table should be read from the bottom to top)

Atlas III CO_2 Geologic Storage Estimates

Carbon dioxide geologic storage information in Atlas III was developed to provide a high level overview of CO_2 geologic storage potential across the United States and parts of Canada. Areal extents of geologic formations and CO_2 resource estimates presented are intended to be used as an initial assessment of potential geologic storage. *Atlas III* provides essential information about a potential site prior to an Exploration Phase evaluation.



1 - Alluvial (Alluvial Fan)
2 - Basalt (Lava Flow)
3 - Coal/Shale (Swamp)
4 - Deltaic (Delta)
5 - Deep Marine
6 - Eolian (Dunes)
7 - Fluvial (Stream)
8 - Lacustrine (Lake)
9 - Reef
10 - Shelf/Platform
11 - Slope/Rise
12 - Strandplain (Beach/Barrier Island)
13 - Strandplain (Beach)
14 - Strandplain (Tidal Flat)
15 - Turbidite (Deep-sea Fan)

Geologic Storage Formation Classes

Each type of geologic formation has different opportunities and challenges. While geologic formations are infinitely variable in detail, they are classified by geologists and engineers in the petroleum industry by their trapping mechanism, hydrodynamic conditions, lithology, and, more recently, by their depositional environment. The depositional environment, or the area where sediment was deposited over many years, influences how formation fluids are held in place, how they move, and how they interact with other formation fluids and solids (minerals). Certain geologic properties may be more favorable to long-term containment of liquids and gases, typically needed for CCS geologic storage reservoirs.

A primary goal of DOE's Carbon Sequestration Program is to classify the depositional environments of various formations known to have excellent reservoir properties that are amenable to geologic CO_2 storage. For fluid flow in porous media, knowledge of how depositional environments formed and directional tendencies imposed by the depositional environment can influence how fluid flows within these systems today and how CO_2 in geologic storage would be anticipated to flow in the future. Although the flow paths of the original depositional environment may have been degraded or modified by mineral deposition or dissolution since the geologic units were deposited, the basic stratigraphic framework created during deposition remains. Geologic processes working today also existed when the sediments were initially deposited. Analysis of modern day depositional analogs, evaluation of core, outcrops, and well logs from ancient subsurface formations provide an indication of how formations were deposited and how CO_2 within the formation is anticipated to flow.

There are three types of rocks: metamorphic, igneous, and sedimentary. Metamorphic rocks are not currently being evaluated for CO_2 storage. While igneous rocks comprise 95 percent of the Earth's crust, the only igneous rocks currently being evaluated for CO_2 storage are basalts. Most basalts have high amounts of calcium, which can react with CO_2 to form a mineral, calcite, resulting in permanent CO_2 storage. Sedimentary rocks are the most promising type of rock being evaluated for CO_2 storage. There are three types of sedimentary rocks: (1) clastic (broken fragments derived from preexisting rocks like sandstone); (2) chemical precipitates (such as carbonates [limestone] and rock salt); and (3) organics (plant or animal constituents that may form coal or limestone). At this time, most geologic storage reservoirs are either clastics or fractured carbonates (both precipitates and organic), where CO_2 is stored in the pore spaces between grains or fractures that are often filled with brine. In this type of CO_2 storage system impermeable layers are required to form a confining zone that prevents the upward migration of CO_2. For more information, NETL's "Geologic Storage Formation Classifications: Understanding Its Importance and Impacts on CCS Opportunities in the United States" is available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/Geologic_Storage.pdf.

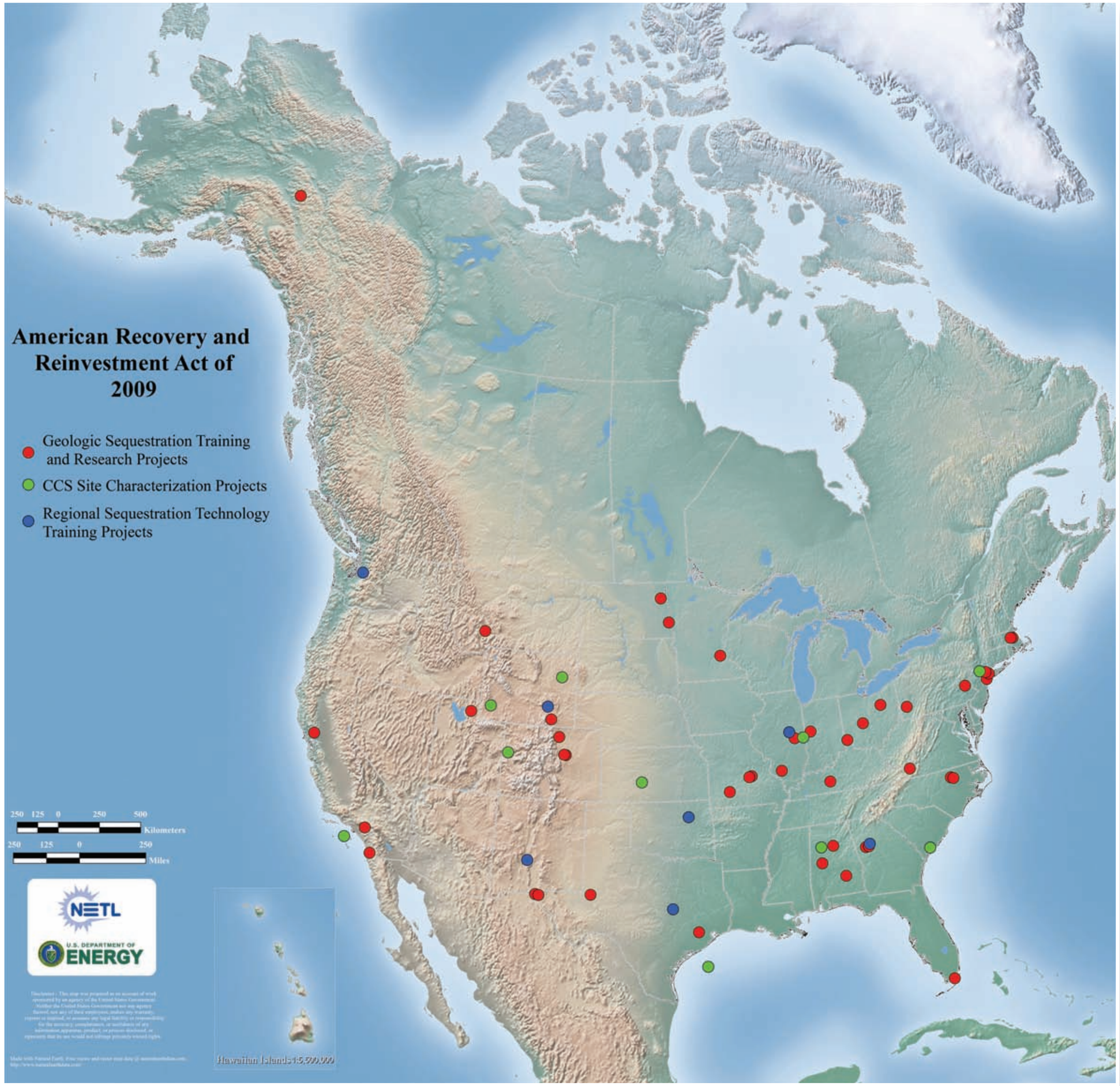
Matrix of NETL CO_2 Geologic Storage Projects and Geologic Formation Classes

Project Type	**High Potential Formations**					**Medium Potential Formations**				**Lower or Unknown Potential Formations**	
	Deltaic	Shelf Clastic	Shelf Carbonate	Strandplain	Reef	Fluvial Deltaic	Eolian	Fluvial & Aluvial	Turbidite	Coal	Basalt (LIP)
Large Scale	–	1	–	–	1	3	–	1	–	–	–
Small Scale	3	2	4	1	2	–	–	2	–	5	1
Characterization	1	–	8	6	–	3	3	2	2	–	1

* The number in the cell is the number of investigations by NETL per geologic formation class.
Source: NETL's "Understanding Geologic Storage Formations Classifications: Importance to Understanding and Impacts on CCS Opportunities in the United States" (DOE/NETL-2010/1420)

American Recovery and Reinvestment Act of 2009

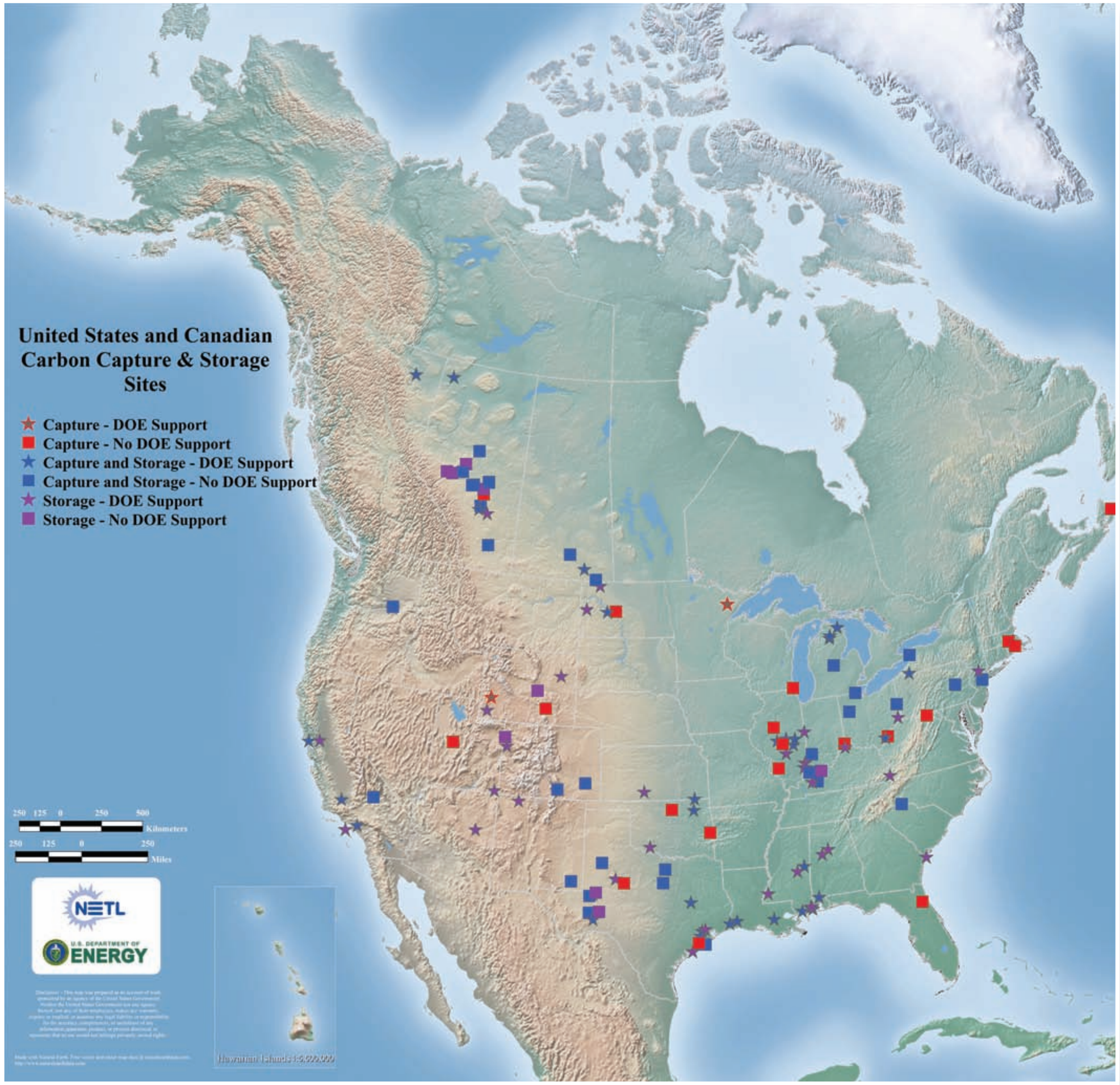
The American Recovery and Reinvestment Act (ARRA) of 2009 was passed on February 13, 2009, to (1) create new jobs and save existing ones; (2) spur economic activity and invest in long-term growth; and (3) foster unprecedented levels of accountability and transparency in Government spending. The primary objectives of the Fossil Energy portion of the Recovery Act are to: (1) demonstrate CCS technology to reduce GHG emissions from the electric power and industrial sectors of the U.S. economy; (2) become the world's leader in CCS science and technology; (3) implement projects to support economic recovery by creating new jobs in pursuit of a secure energy future. Within the funding appropriated by the Recovery Act, the Carbon Sequestration Program issued three Funding Opportunity Announcements. These included $50 million in DOE funding to support 10 CCS Site Characterization Projects; $7 million in DOE funding for Regional Sequestration Technology Training Projects; and almost $13 million in DOE funding for University-based Geologic Sequestration Training and Research Projects. The CCS Site Characterization Projects received and additional $50 million from ARRA Industrial Carbon Capture and Storage to characterize storage resources for industrial sources.



The objective of the CCS Site Characterization Projects is to characterize a minimum of 10 distinct "high-potential" geologic formations, including saline formations, depleting/depleted oil fields, and coal areas. Each project is focused on a minimum of one specific site, formation, or area not previously characterized with public data that represents a significant storage opportunity in a region with adequate seals that could be commercially developed in the future. The projects will increase understanding of the potential for these formations to safely and permanently store CO_2.

The objective of the Regional Sequestration Technology Training Projects is to facilitate development of a CCS workforce through regional CO_2 sequestration technology training in all aspects of long-term, underground CO_2 storage. Training is being accomplished through several activities, such as CCS short courses; regional CCS training conferences; targeted CCS training seminars; and transfer of the lessons learned from CO_2 storage projects.

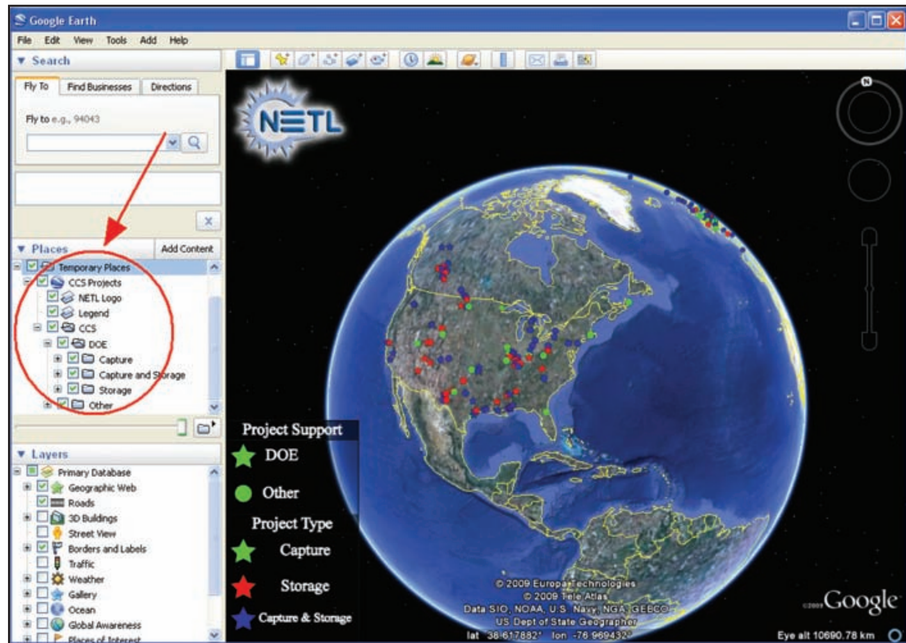
The objective of the University-based Geologic Sequestration Training and Research Projects is to provide training opportunities for graduate and undergraduate students that will provide the human capital and skills required for implementing and deploying CCS technologies. Training is being accomplished through fundamental research in the following areas: simulation and risk assessment; MVA; geological-related analytical tools; methods to interpret geophysical models; well completion and integrity for long-term CO_2 storage; and CO_2 capture.



NETL's CCS Worldwide Database

In November 2009, NETL launched its CCS Database, which includes active, proposed, canceled, and terminated CCS projects worldwide. This database provides the public with information regarding efforts by various industries, public groups, and governments towards development and eventual deployment of CCS technology. It lists technologies being developed for CO_2 capture, testing sites for CO_2 storage, project cost estimations, and anticipated dates of project completion. The database uses Google Earth to illustrate the location of projects and provide a link to further information. Project details are obtained from publically available information.

As of October 2010, the database contained 246 CCS projects worldwide. The 246 projects include 63 capture, 58 storage, and 125 for capture and storage in more than 20 countries across 5 continents. While most of the projects are still in the planning and development stage, or have recently been proposed, 8 are actively capturing and injecting CO_2. NETL will update the database as information regarding these projects is released to the public or new projects are announced.



NETL's CCS Database is available for download at: http://www.netl.doe.gov/technologies/carbon_seq/database/index.html. Access to the database requires use of Google Earth, as the NETL CCS database is a layer in Google Earth. Free downloadable software for Google Earth is available at http://earth.google.com/.

Public Outreach and Education for CCS Deployment

DOE charged the RCSPs with developing and implementing an outreach and education program that would (1) raise awareness and understanding of the general population in the RCSP regions with respect to long-term CO_2 storage in geologic formations for GHG reduction, and (2) educate communities in areas where CO_2 storage projects or long-term demonstrations are planned. Effective public outreach involves listening, sharing information, and addressing concerns through proactive community engagement. Conducting effective public outreach will not necessarily ensure project success, but underestimating its importance can contribute to delays, increased costs, and lack of community support.

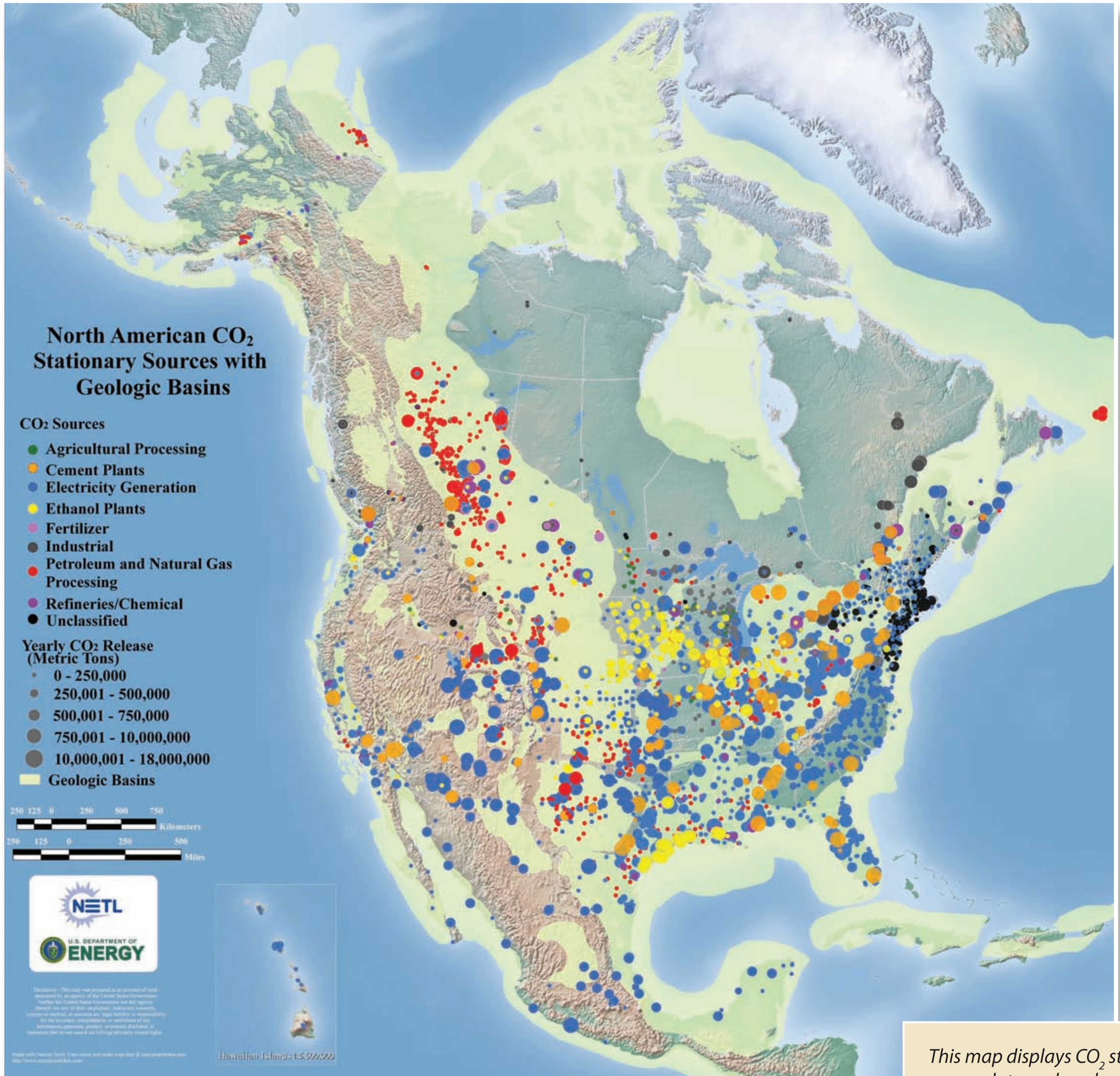
The RCSPs' concept of public outreach involves efforts to understand, anticipate, and address public perceptions and concerns about CO_2 storage in a community being considered for a project. Ideally, public outreach can lead to a mutually beneficial outcome where project developers and communities work together to implement a CO_2 storage project and then move ahead with the support of well-informed stakeholders who are comfortable with the project benefits and potential risks and trust the project team.

Public outreach begins at the onset of the project, continues through the close of the project, and involves each individual on the project team. In addition, public outreach encompasses an array of activities through which information about CO_2 storage projects is shared, and feedback is obtained from stakeholders. Stakeholders are defined as those parties who believe that they are affected by CO_2 storage project decisions.

As described in DOE's "Best Practices for Public Outreach and Education for Carbon Storage Projects," the RCSPs have identified the following best practices:

Physical Model Demonstration at a Midwest Geological Sequestration Consortium Open House. (Photo courtesy of Midwest Geological Sequestration Consortium.)

Best Practice	Description
Integrate Outreach with Project Management	By including outreach in the critical path of a CO_2 storage project, outreach activities will be more effective, in sync with other key project stages, and beneficial to the overall project; a key component is building in the time necessary to accomplish the various steps in advance of engaging the public.
Establish a Strong Team	It is essential to establish a clearly defined structure that delineates roles and responsibilities covering both internal and external communication and includes individuals who are knowledgeable about the technical details of the project, as well as individuals who have backgrounds in communication, education, and community relations.
Identify Key Stakeholders	Early CO_2 storage projects are being carried out in the context of national debates on climate change mitigation and, as a result, stakeholders may come from an area that extends beyond the project's location and regulatory jurisdiction. It is critical to identify all stakeholders in the project lifecycle. At the local level, these may include elected and safety officials, regulators, landowners, citizens, civic groups, business leaders, media, and community leaders. At the national level, these may include Government agencies, Congressional leaders, committee/subcommittee chairs and key staff, environmental groups, and the financial and legal community.
Conduct Social Characterization	Social characterization is an approach for gathering and evaluating information to obtain an accurate portrait of stakeholder groups, their perceptions, and their concerns about CO_2 storage. This approach can identify the factors that will likely influence public understanding of CO_2 storage within a specific community. The information gathered will enable the project team to develop better insights into the breadth of diversity among community members, local concerns and potential benefits, and assist in determining which modes of outreach and communication will be most effective.
Develop a Strategy and Communication Plan	The outreach strategy and communications plan ties together the information, planning, and preparation. The outreach strategy is tailored to the stakeholder needs and concerns of a particular CO_2 storage project. Specifics will include outreach objectives, outreach tasks, and events that coincide with the project stages, a timeline for outreach activities, and the roles and responsibilities of the outreach team. The outreach strategy will also identify key stakeholders and messages, and the timelines, roles, and responsibilities for producing outreach materials and managing outreach events. A component of the outreach strategy is a communications plan that focuses on representing the project directly to the public and through the media.
Develop Key Messages	CO_2 storage involves advanced science related to climate change, geology, and other fields of study; public policy related to energy, environment, and the economy; and issues related to risk, safety, and financial assurance. Therefore, identifying a set of key messages that can be consistently repeated in outreach activities and materials can help stakeholders develop a clearer understanding of the project and how their concerns will be addressed.
Develop Materials Tailored to Audiences	The development of outreach materials involves consideration of the intended audience. The amount of information and level of technical detail provided must be tailored to match the audience's degree of interest, education, and time constraints. Any concerns that have been identified, including perceived risks, should be addressed in language and formats suited to the intended audiences.
Proactively Manage the Program	Outreach programs should be actively managed to ensure that consistent messages are being communicated and that requests for information are fulfilled throughout the project lifecycle. The identification of an outreach leader or coordinator to manage, coordinate, and direct outreach is crucial for project success. The outreach lead will be supported in their efforts by the outreach team and other project team members. As a project unfolds, public perception will to be influenced by the extent to which the project and the project team are well coordinated and responsive.
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 the outreach activities. Monitoring can also help identify any misconceptions about the project or CO_2 storage and develop outreach strategies to correct them.
Refine the Program as Warranted	The outreach team must 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.



This map displays CO_2 stationary source data and geologic basins which were obtained from the RCSPs and other external sources and compiled by NATCARB. Each colored dot represents a different type of CO_2 stationary source with the dot size representing the relative magnitude of the CO_2 emissions (see map legend).

North American Carbon Atlas Partnership

A Joint CO_2 Mapping Initiative between the United States, Canada, and Mexico

The United States, Canada, and Mexico formed a joint CO_2 mapping initiative called the North American Carbon Atlas Partnership (NACAP). The goal of NACAP is for each country to identify, gather, and share data for CO_2 stationary sources and geologic storage sites in the United States, Canada, and Mexico and display these in a geographic information system (GIS) for North America. In order to achieve this goal, two working groups, the Information Technology Working Group and the Methodology Working Group, were formed within NACAP and tasked to develop sub-elements of a framework to achieve the goal. The map at left shows a preview of the data expected to be included in this NACAP Atlas. This data includes the magnitude and location of CO_2 stationary sources, and the areal extent of potential geologic CO_2 storage resource for various formations in each country.

Development of this GIS system supports FE's Carbon Sequestration Program, the objectives of the NAEWG, and current topics being discussed under the Canada-U.S. Clean Energy Dialogue. It is expected that this initiative will serve as a key opportunity to foster collaboration among the three countries in the area of CCS. Results of this initiative are expected to be published in a NACAP Atlas and made available in 2012.

National Carbon Sequestration Database and Geographic Information System

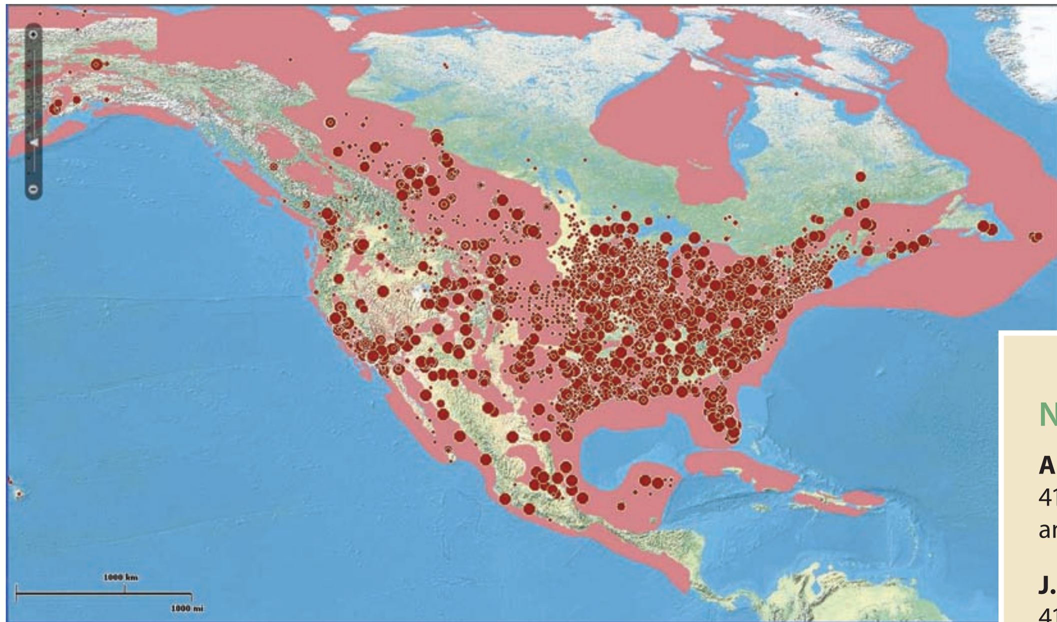
A National Look at Carbon Sequestration

The National Carbon Sequestration Database and Geographic Information System (NATCARB) provides Web-based data access to disparate data (CO_2 stationary sources, potential geologic CO_2, infrastructure, etc.) and analytical tools (pipeline measurement, storage resource estimation, cost estimation, etc.) required for addressing CCS deployment. Distributed computing solutions link the RCSPs and other publically accessible repositories of geologic, geophysical, natural resource, infrastructure, and environmental data. NATCARB, a first effort at a national carbon cyberinfrastructure, assembles the data required to address technical and policy challenges of CCS.

NATCARB online access is being modified to address the broad needs of all users. It includes not only GIS and database query tools for the high-end technical user, but also simplified displays for the general public, employing readily available Web tools, such as Google Earth™ and Google Maps™.

NATCARB organizes and enhances the critical information about CO_2 stationary sources and develops the technology needed to access, query and model, analyze, display, and distribute CO_2 storage resource data. Data are generated, maintained, and enhanced locally at each RCSP, or at specialized data warehouses and public servers (e.g., USGS-EROS Data Center, EPA, and the Geography Network), and assembled, accessed, and analyzed in real-time through a single geoportal.

All map layers and data tables used to construct the national estimates of CO_2 stationary sources and geologic storage resources are available for interactive display and download through the NATCARB website (http://www.netl.doe.gov/technologies/carbon_seq/natcarb/map_request.html).



In 2010, NATCARB will begin to provide CCS data covering all of North America for the general public, employing readily available Web tools like Google Earth™ and Google Maps™. This image shows the location of CO_2 stationary sources, inventoried and accessible through the NATCARB portal and displayed with a light-weight GIS viewer. At the same time, images of geologic basins that are potential areas for geologic CO_2 storage resources are displayed.

Close-up view of the American Electric Power integrated CCS project in West Virginia using NATCARB Google Earth™ viewer.

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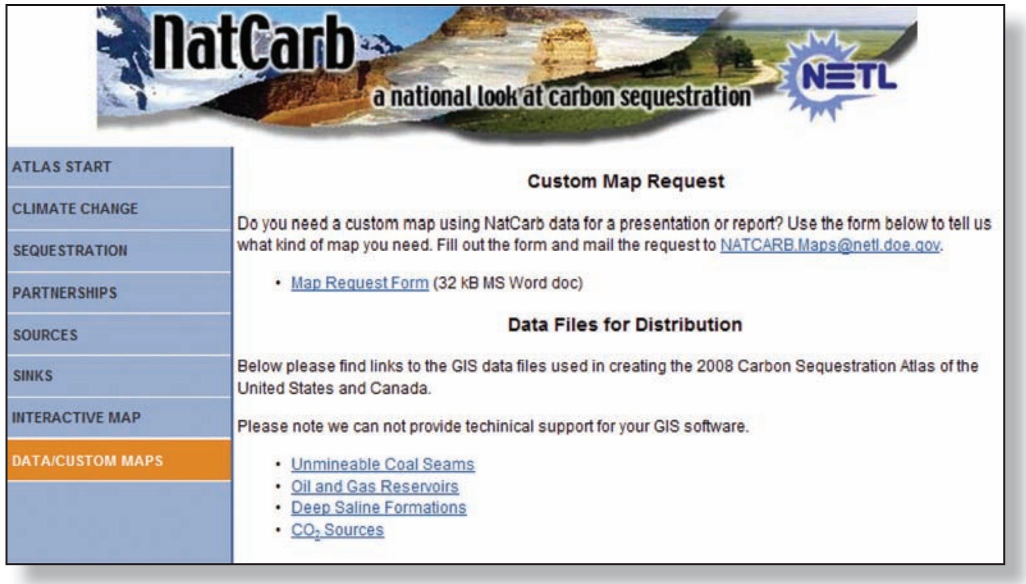
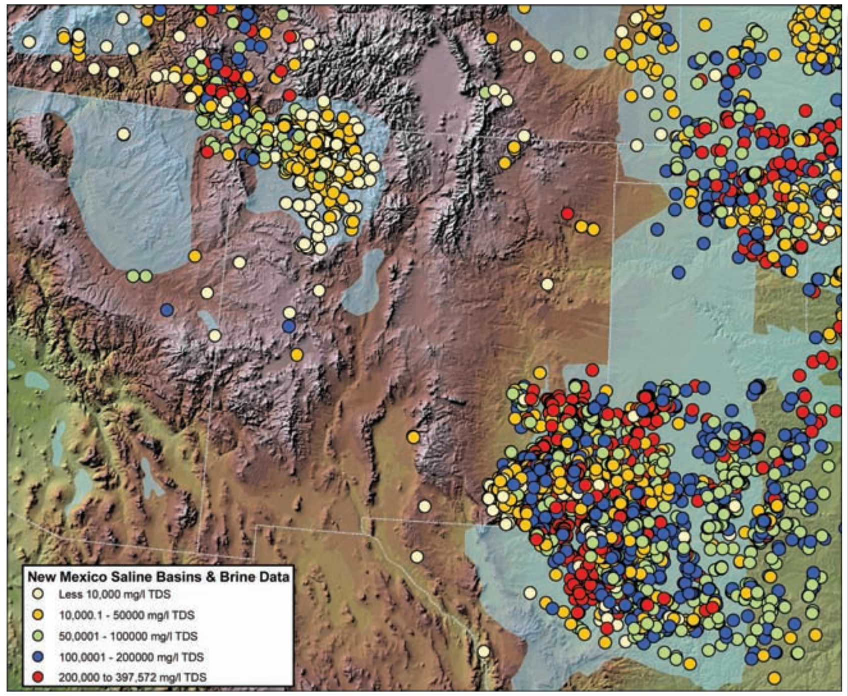
NATCARB Map and Data Requests

Please refer all NATCARB map and data requests to natcarb.maps@netl.doe.gov.

National Carbon Sequestration Database and Geographic Information System (cont'd)



NATCARB users have the ability to request custom maps and/or download data files from Atlas III.



This image shows the distribution of locations of over 10,000 brine samples in New Mexico. Data is categorized by total dissolved solids (TDS). Samples with less than 10,000 mg/l TDS are legally considered potential potable water and need to be protected (yellow dots). Formations containing TDS concentrations greater than 10,000 mg/l are potential sites that merit further evaluation for potential CO_2 storage (blue and red dots). Basins containing saline formations that have been evaluated are highlighted in blue. Data on brine geochemistry can be accessed and summarized with several additional online tools. All data were assembled as a custom map with a request through NatCarb.

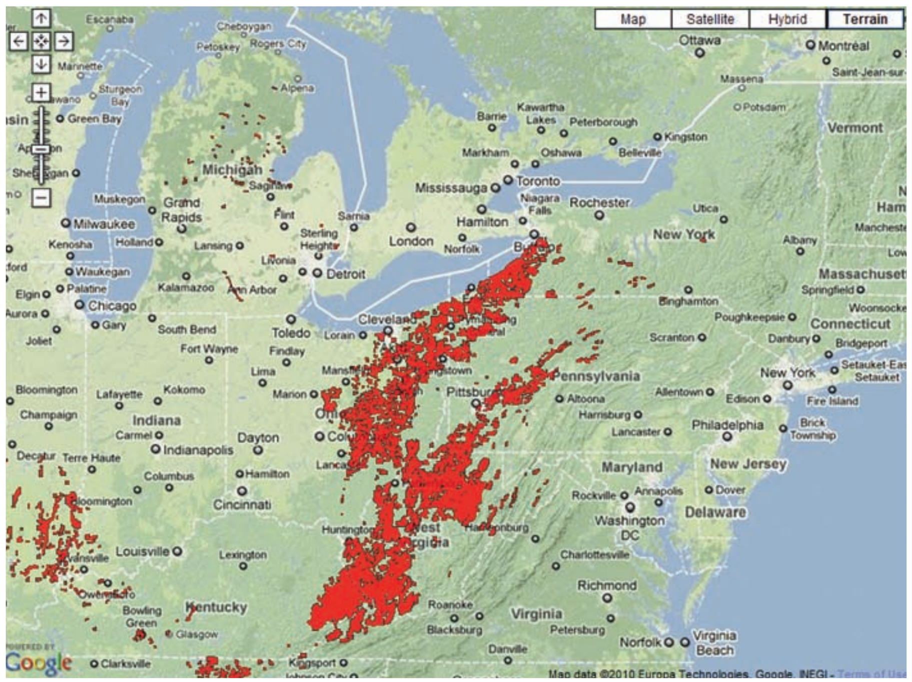
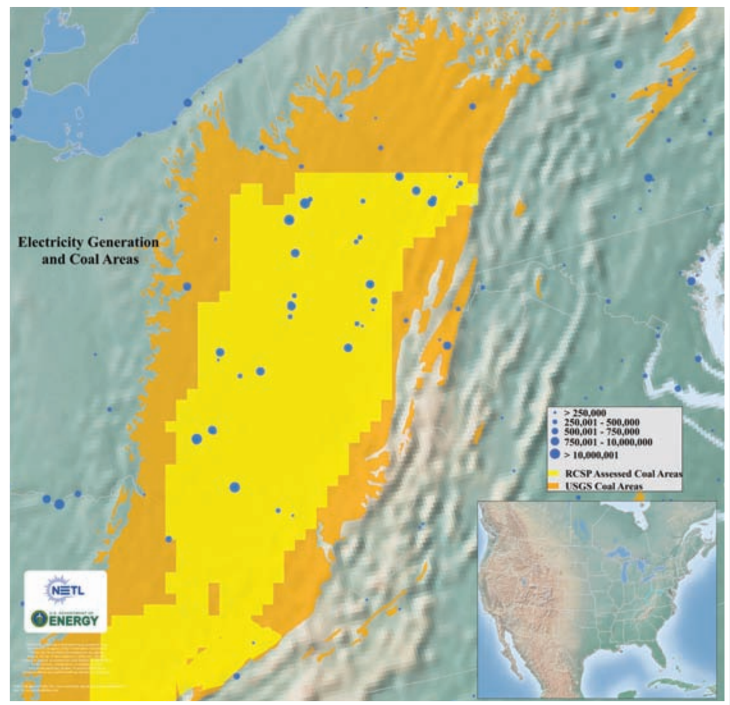


Image showing the extent of oil and gas reservoirs (red) in the northeastern United States. Similar data for saline formations and unmineable coal areas are accessible through NATCARB using Google Maps™.

Image showing the distribution of electric generation facilities ranked by metric tons of CO_2 emitted per year and the U.S. power distribution grid. The CO_2 stationary sources have been overlain on coal basins and assessed areas with unmineable coal areas that may serve as potential CO_2 storage sites.



CO_2 Stationary Source Emissions Summary

DOE's RCSPs have identified 4,507 CO_2 stationary sources with total annual emissions of more than 3,400 million metric tons (3,748 million tons) of CO_2. The RCSPs have documented the methods used to collect and calculate these emissions. A summary of those methods follows. For additional detail, refer to Appendix A "CO_2 Stationary Source Emissions Summary".

The CO_2 stationary sources documented by the RCSPs include power plants, ethanol plants, petroleum and natural gas processing facilities, cement and lime plants, agricultural processing facilities, industrial facilities, iron and steel production facilities, and fertilizer producing facilities. Estimation methods include the use of databases and emissions factors. Tables in Appendix A list the databases and emissions factors utilized for a particular CO_2 stationary source type. Not all databases or emissions factors were used by each of the RCSPs.

The documents used to identify each CO_2 stationary source, as well as the practical quantitative method (i.e., emission factors, continuous emissions-monitoring results, emission estimate equations, etc.) used to estimate CO_2 emissions from that source, are listed in Appendix A. In addition, the data sources to determine specific plant capacities, production outputs, or fuel usage data are listed by RCSP.

The approach to determine these methodologies was to identify CO_2 stationary sources within each RCSP region, and then assess the availability of CO_2 emission data or to apply an estimate of the CO_2 emissions based upon sound scientific and engineering principles. In each RCSP, the emissions were grouped by emission source and a methodology was established for each emission source category; then the methodology was utilized to estimate the CO_2 emissions from each emission source category. To summarize these efforts, nine tables containing CO_2 emission estimation methodologies and equations for the major CO_2 stationary source industries were created. During the RCSPs' Characterization Phase, each RCSP was responsible for developing GHG emission inventories and stationary source surveys within their respective boundary area.

Carbon dioxide stationary sources fall under one of the nine industry types. The table at right identifies the stationary sources included in various industry types.

For any stationary source within a given industry type, the RCSPs employed CO_2 emissions estimate methodologies that are based on the most readily available representative data for that particular industry type within the respective RCSP area. CO_2 emissions data provided by databases (for example, eGRID or ECOFYS) were the first choice for all of the RCSPs, both for identifying major CO_2 stationary sources and for providing reliable emission estimations. Databases are considered to contain reliable and accurate data obtained from direct emissions measurements via continuous emissions monitoring systems. When databases were not available, CO_2 stationary source facility production or fuel usage were coupled with CO_2 emissions factors to estimate annual CO_2 emissions from the production or fuel usage data. Emissions factors, fuel usage data, and facility production data were obtained from various databases, websites, and publications. Carbon dioxide stationary source spatial location data (latitude and longitude) were determined from a variety of sources. Some databases (eGRID) contain latitude and longitude information for each CO_2 stationary source. Where spatial location information was not available through an emissions database, other spatial location methods were utilized. These include the use of mapping tools (Google Earth™, TerraServer, and USGS Digital Orthophoto Imagery) equipped with geospatially defined data, along with web-based databases (Travelpost) containing latitude and longitude information for various U.S. locations.

A summary of the CO_2 stationary source emissions calculated and compiled by each RCSP appears in the "National Perspectives" section of Atlas III. Regional details of these CO_2 stationary source emissions appear in the "Regional Carbon Sequestration Partnerships Perspectives" section of Atlas III. Finally, a State summary of CO_2 stationary source emissions appears in Appendix C of Atlas III.

CO_2 Stationary Sources by Industry Category

Industry Type	CO_2 Stationary Sources Include
Electric Generating Plants	• Coal-, Oil-, and Natural Gas-Fired Power Plants
Ethanol Production Plants	• Ethanol Plants, Regardless of Feedstock Type
Agricultural Processing Facilities	• Sugar Production
Natural Gas Processing Facilities	• Natural Gas Processing Facilities
Industrial Facilities	• Aluminum Production Facilities • Soda Ash Production Facilities • Glass Manufacturing Facilities • Automobile Manufacturing Facilities • Iron Ore Processing Facilities • Compressor Stations • Paper and Pulp Mills
Iron and Steel Facilities	• Iron and Steel Producing Facilities
Cement and Lime Plants	• Lime Production Facilities • Cement Plants
Refineries and Chemical Facilities	• Petroleum Refinery Processing • Ethylene Production Facilities • Ethylene Oxide Production • Hydrogen Production Facilities
Fertilizer Production	• Ammonia Production

Methodology for Development of Geologic Storage Estimates for Carbon Dioxide

DOE's RCSPs were charged with providing a high-level, quantitative estimate of CO_2 storage resource available in subsurface environments of their regions. Environments considered for CO_2 storage were categorized into five major geologic systems: oil and gas reservoirs, saline formations, unmineable coal areas, shale, and basalt formations. Where possible, CO_2 storage resource estimates have been quantified for oil and gas reservoirs, saline formations, and unmineable coal areas; shale and basalt formations are presented as future opportunities and not assessed in *Atlas III*.

Carbon dioxide storage resource estimates in *Atlas III* are defined as the fraction of pore volume of sedimentary rocks available for CO_2 storage and accessible to injected CO_2. Storage resource assessments do not include economic or regulatory constraints. *Atlas III* estimates are based on the assumption that in situ fluids will either be displaced by the injected CO_2 or managed by means of fluid production, treatment, and/or disposal in accordance with current technical, regulatory, and economic guidelines. In addition, storage resource estimates are screened by criteria such as isolation from potable groundwater, isolation from other strata, TDS concentrations of 10,000 ppm or more, and maximum allowed injection pressure to avoid fracturing. Resource estimates do take into account geologic-based physical considerations, such as vertical thickness, fraction of porosity available for CO_2 storage, and fraction of the total area accessible to injected CO_2. In these CO_2 storage resource estimates, only physical trapping of CO_2 is considered.

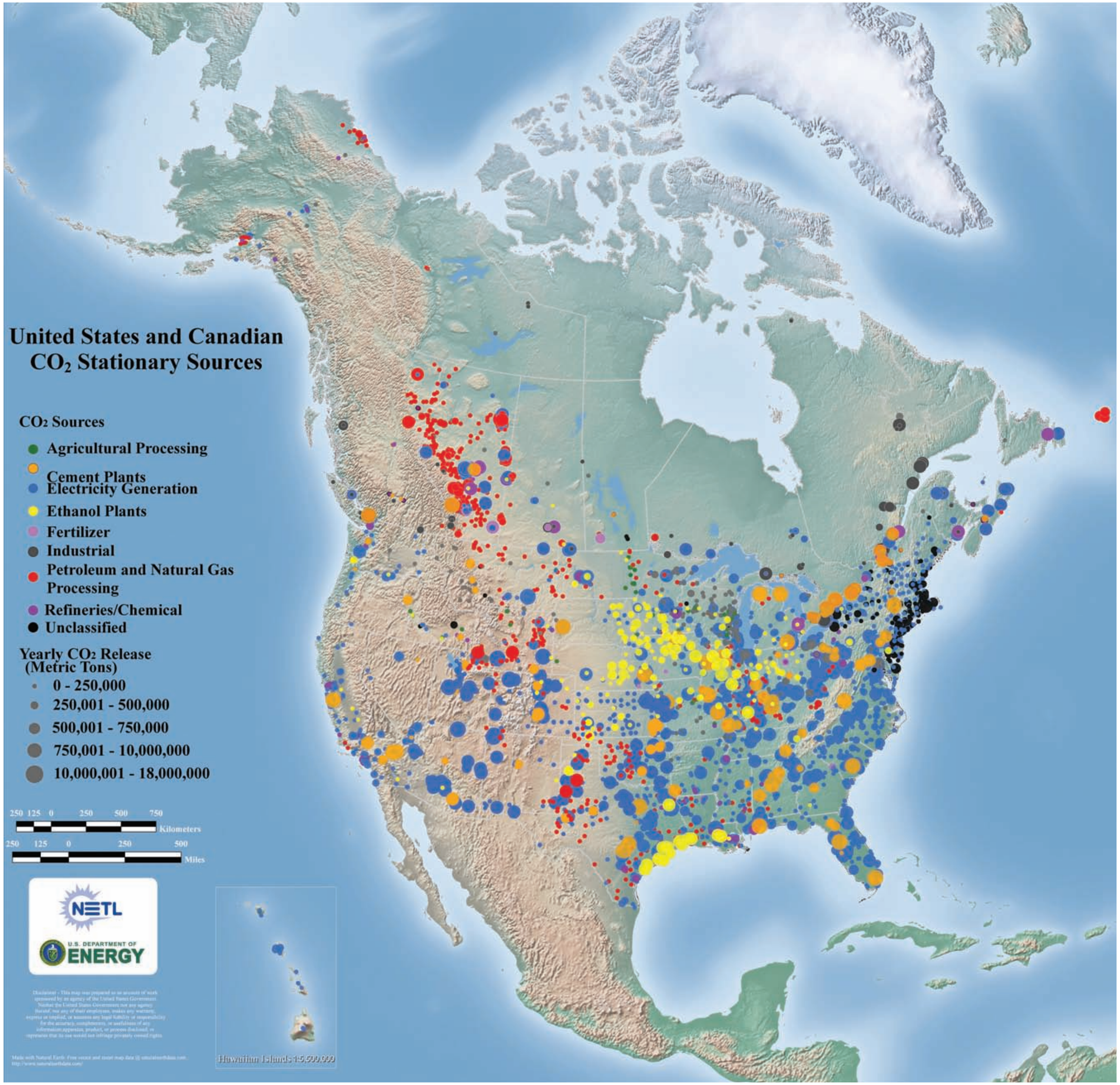
The methodologies used for estimating CO_2 geologic storage resource potential in *Atlas III* were designed to integrate results from all seven RCSPs and were based on volumetric methods for estimating subsurface volumes, in situ fluid distributions, and fluid displacement. Estimating subsurface volumes depends on geologic properties (area, thickness, and porosity of formations) and storage efficiency (the fraction of the accessible pore volume that will be occupied by the injected CO_2). Storage efficiency was determined using Monte Carlo simulation, which included efficiency terms to account for variations in a formation's geologic properties and displacement properties of in situ fluids and injected CO_2.

A summary of the national CO_2 storage resource estimates computed by each RCSP and compiled by NATCARB appears in the "National Perspectives" section of *Atlas III*. Regional details of these CO_2 storage resource estimates appear in the "Regional Carbon Sequestration Partnership Perspectives" section of *Atlas III*. A State summary of CO_2 storage resource estimates appears in Appendix C of *Atlas III*.

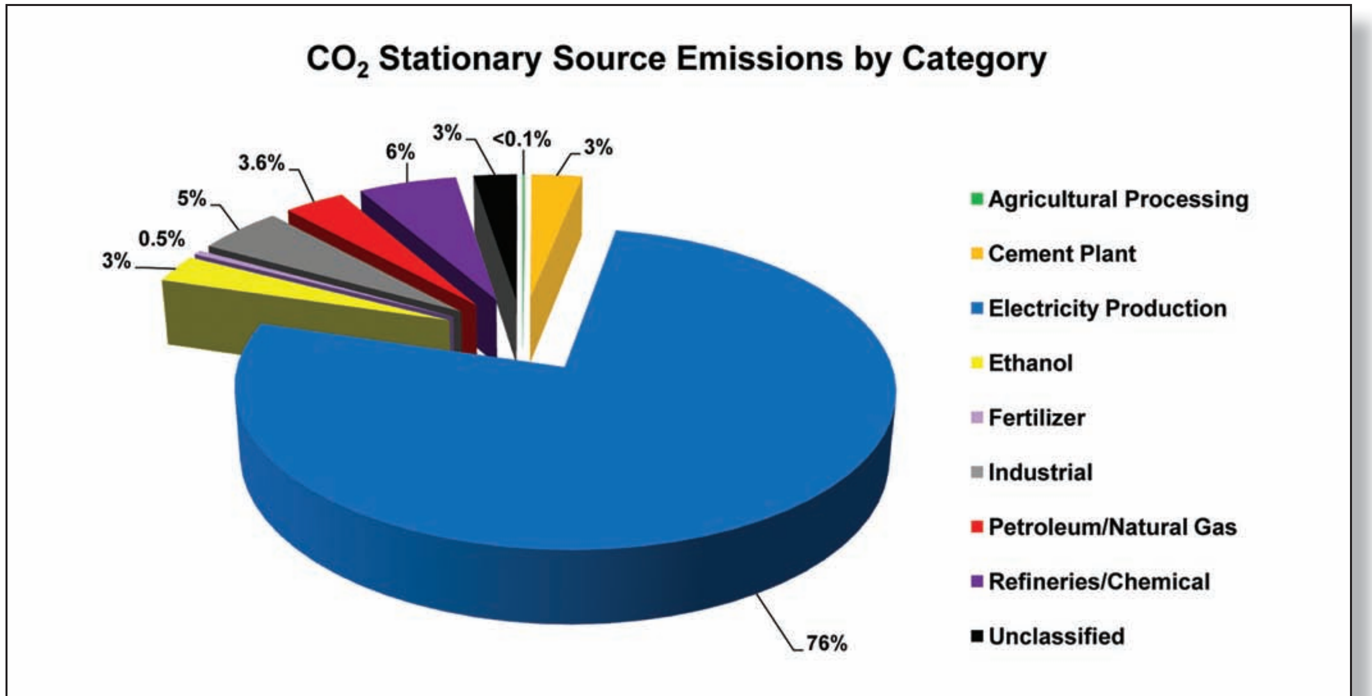
For additional information on the methodologies used by the RCSPs for the CO_2 resource estimates in *Atlas III*, please refer to the 2010 "Methodology for Development of Geologic Storage Estimates for Carbon Dioxide" in Appendix B of *Atlas III*.

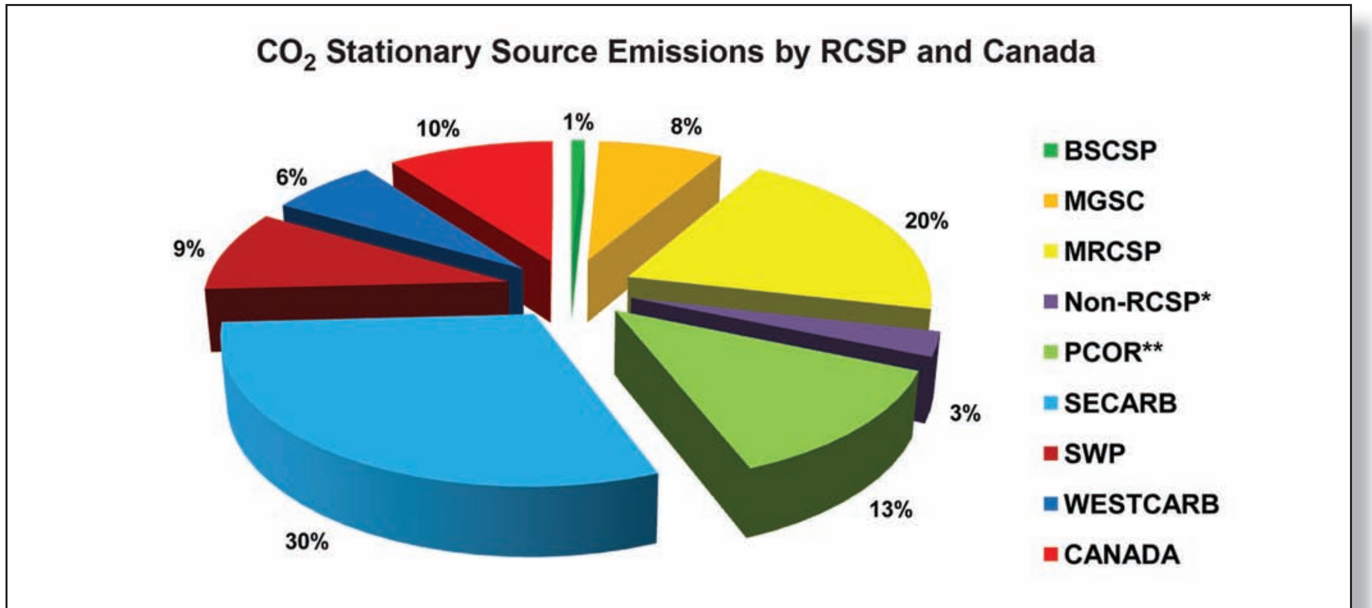
Regional CO_2 Storage Resource Estimates to Site-Specific CO_2 Storage Resource Estimates

Methodologies used in *Atlas III* are intended to produce high-level, regional and national scale CO_2 resource estimates of potential geologic storage in the United States and Canada. At this scale, the estimates of CO_2 geologic storage have a high degree of uncertainty. One reason for this uncertainty is the lack of wells penetrating the potential storage formation, resulting in undefined rock properties and heterogeneity of the formation. Because of this uncertainty, estimates from *Atlas III* are not intended to be used as a substitute for site-specific characterization and assessment. As CO_2 storage sites move through the site characterization process (see page 14 of *Atlas III*), additional site-specific data is collected and analyzed, reducing uncertainty. This data includes, but is not limited to, site-specific lithology, porosity, and permeability. Incorporation of this site-specific data allows for the refinement of CO_2 storage resource estimates and development of CO_2 storage capacities by future potential commercial project developers.



This map displays CO_2 stationary source data which were obtained from the RCSPs and other external sources and compiled by NATCARB. Each colored dot represents a different type of CO_2 stationary source with the dot size representing the relative magnitude of the CO_2 emissions (see map legend).





* As of November 2010, "Non-RCSP" states include Connecticut, Delaware, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

** Canadian Sources previously included in the PCOR Partnership have been assigned to Canada.

CO_2 Sources

There are two types of CO_2 emission sources: stationary sources and non-stationary sources. Carbon dioxide stationary source emissions come from a particular, identifiable, source, such as a power plant, while non-stationary source emissions include CO_2 emissions from the transportation sector and other diffuse sources. Carbon dioxide emissions from stationary sources can be separated from stack gas emissions and subsequently transported to a geologic storage injection site. The "United States and Canadian CO_2 Stationary Sources" map at left displays the location and relative magnitude of a variety of CO_2 stationary sources.

According to the EPA, total U.S. GHG emissions were estimated at 6,960 million metric tons (7,670 million tons) CO_2 equivalent in 2008.[1] This estimate includes CO_2 emissions, as well as other GHGs, such as methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Annual GHG emissions from fossil fuel combustion, primarily CO_2, were estimated at 5,570 million metric tons (6,140 million tons) with 3,780 million metric tons (4,170 million tons) from stationary sources.

The "CO_2 Stationary Source Emissions by Category" pie chart contains values, gathered by the RCSPs and NATCARB (illustrated on the "United States and Canadian CO_2 Stationary Sources" map), showing that CO_2 stationary source emissions result largely from power generation, energy use, and industrial processes. While not all potential GHG sources have been examined, NETL's RCSPs have documented the location of 4,507 CO_2 stationary sources with total annual emissions of 3,470 million metric tons (3,825 million tons) of CO_2 in the United States. In Canada, the locations of CO_2 stationary sources with total annual emissions of 350 million metric tons (385 million tons) of CO_2 were also identified. The "CO_2 Stationary Source Emissions by RCSP and Canada" pie chart displays the amount of CO_2 stationary source emissions identified by each RCSP. For details on CO_2 stationary sources by State, see Appendix C.

1 EPA's 2010 U.S. Greenhouse Gas Inventory Report (April 2010), available at http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_Report.pdf.

Sedimentary Basins

DOE's RCSPs have identified and examined the location of potential CO_2 injection formations in different sedimentary basins throughout the United States and Canada. These sedimentary basins collected sediments that lithified to become sedimentary rocks. If these sedimentary rocks are porous or fractured, they can be saturated with brine (water with a high TDS concentration), oil, or gas. If the sedimentary rock is permeable (e.g., many sandstones), it could be a target for injection of CO_2. If it is impermeable (e.g., many shales) it could act as a seal to prevent migration of CO_2. Necessary conditions for a CO_2 storage site are the presence of both a reservoir with sufficient injectivity and a seal to prevent migration.

Brine is water that contains appreciable amounts of salts that have either been leached from the surrounding rocks or from sea water that was trapped when the rock was formed. The EPA has determined that a saline formation used for CO_2 storage must have at least 10,000 ppm of TDS. Total dissolved solids is a measure of the amount of salt in water. Most drinking water supply wells contain a few hundred ppm or less of TDS.

Oil and gas reservoirs are often saline formations that have proven traps and seals allowing oil and gas to accumulate over millions of years. Many oil and gas fields containing stacked formations (different reservoirs) have characteristics that make them excellent target locations for geologic storage, including good porosity.

Supercritical CO_2

It is common to hear CCS experts talk about storage of CO_2 in the "supercritical" condition. Supercritical CO_2 means that the CO_2 is at a temperature in excess of 31.1 °C and a pressure in excess of 72.9 atm (about 1,057 psi); this temperature and pressure defines the critical point for CO_2. At such temperatures and pressures, the CO_2 has some properties like a gas and some properties like a liquid. In particular, it is dense like a liquid but has viscosity like a gas. The main advantage of storing CO_2 in the supercritical condition is that the required storage volume is hugely less than if the CO_2 were at "standard" (room) pressure conditions. This reduction in volume is illustrated in the figure at right. The blue numbers show the volume of CO_2 at each depth compared to a volume of 100 at the surface.

Temperature naturally increases with depth in the Earth's crust, as does the pressure of the fluids (brine, oil, or gas) in the rocks. At depths below about 800 meters (about 2,600 feet), in most places on Earth, the natural temperature and fluid pressures are in excess of the critical point of CO_2. This means that CO_2 injected at these temperatures and pressures will be in the supercritical condition. The pressure of CO_2 must be greater than the naturally existing fluid pressure in order to get the CO_2 into the reservoir. Large temperature differences between the injected CO_2 and the surrounding rock are not recommended, but, the CO_2 will take on the temperature of the surrounding rock as it moves into the reservoir. Hence, even if not injected under supercritical conditions, it will—in most cases—end up in the supercritical condition in the reservoir.

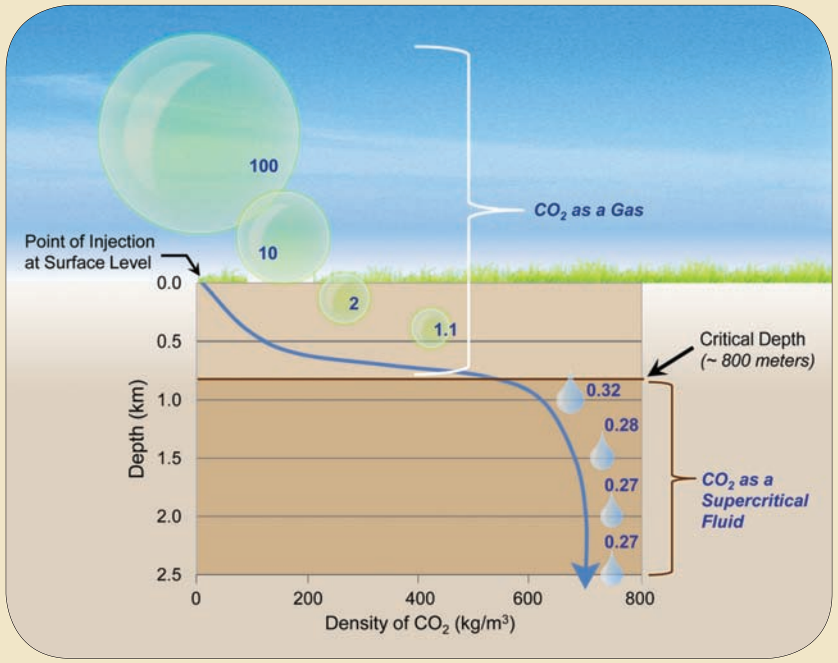
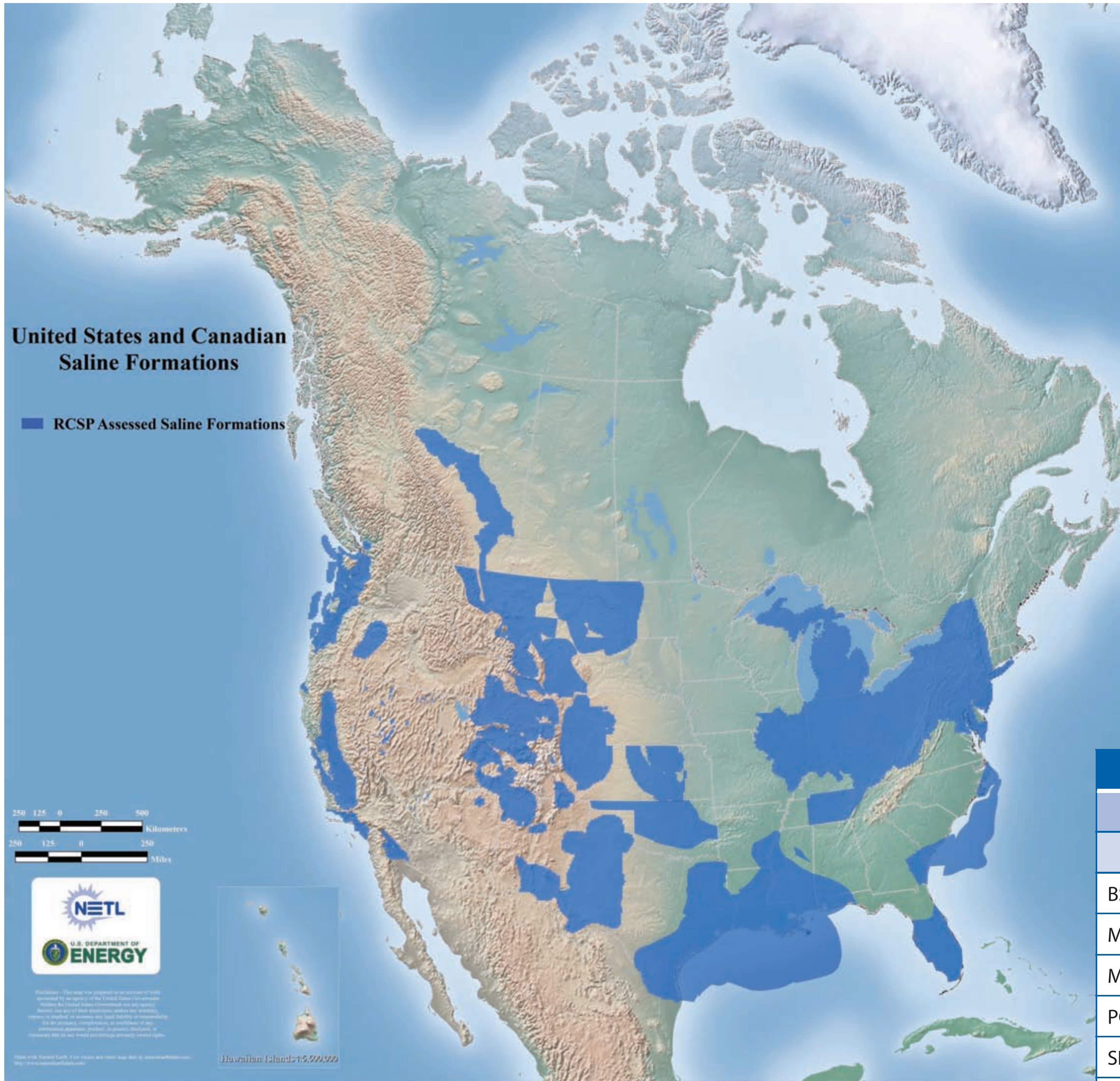


Illustration of Pressure Effects on CO_2 (based upon image from CO_2CRC)



This map displays saline formation data that were obtained by the RCSPs and other sources and compiled by NATCARB. Carbon dioxide geologic storage information in Atlas III was developed to provide a high-level overview of CO_2 geologic storage potential across the United States and parts of Canada. 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 CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please refer to page 14 for additional information on this level of assessment. Please note that saline formation data resulting in a straight edge in the map above is indicative of an area lacking sufficient data and is subject to future investigation.

Saline Formations

Saline formations are layers of porous rock that are saturated with brine. They are much more extensive than coal areas or oil- and gas-bearing rock and represent an enormous potential for CO_2 geologic storage. However, less is known about saline formations because they lack the characterization experience that industry has acquired through resource recovery from oil and gas reservoirs and coal seams. Therefore, there is an amount of uncertainty regarding the suitability of saline formations for CO_2 storage.

While not all saline formations in the United States have been examined, the RCSPs have documented the locations of saline formations with an estimated CO_2 storage resource ranging from 1,653 billion metric tons to more than 20,213 billion metric tons (from 1,822 billion tons to more than 22,281 billion tons) of CO_2. At current CO_2 emission rates, calculations indicate more than 450 years of storage potential in assessed saline formations. For details on saline formation CO_2 storage resource by State, see Appendix C.

CO_2 Storage Resource Estimates for Saline Formations by RCSP

	Low		High	
RCSP	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	221	244	3,041	3,352
MGSC	12	13	160	176
MRCSP	46	51	183	202
PCOR	165	182	165	182
SECARB	908	1,001	12,527	13,809
SWP	219	241	3,013	3,321
WESTCARB	82	90	1,124	1,239
Total	**1,653**	**1,822**	**20,213**	**22,281**

Oil and Gas Reservoirs

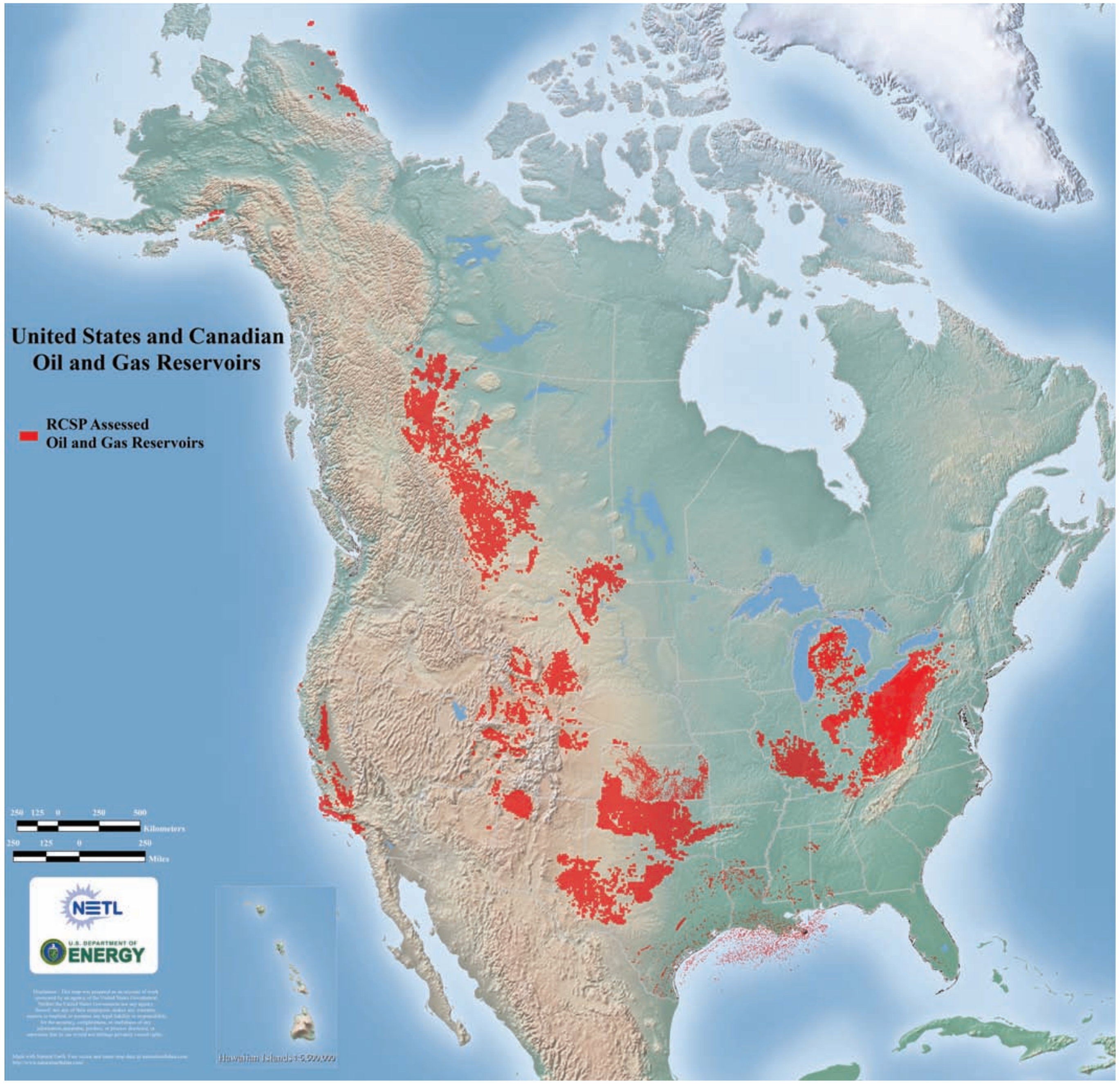
Mature oil and gas reservoirs have held crude oil and natural gas over millions of years. They consist of a layer of permeable rock (usually sandstone, but sometimes carbonates) with a layer of nonpermeable rock also called caprock (usually shale) above, such that the caprock forms a seal that holds the hydrocarbons in place. The characteristics that have held the oil and gas in the reservoirs for millions of years make them excellent target locations for geologic storage of CO_2. An added benefit of oil and gas reservoirs is that they have been extensively explored, which generally results in a wealth of data available to plan and manage proposed CCS efforts.

As a value-added benefit, CO_2 injected into a mature oil reservoir can enable incremental oil to be recovered. A small amount of CO_2 will dissolve in the oil, increasing the bulk volume and decreasing the viscosity, thereby facilitating flow to the wellbore. Typically, primary oil recovery and secondary recovery via a water flood produce 30–40 percent of a reservoir's original oil in place (OOIP). A CO_2 flood allows recovery of an additional 10–15 percent of the OOIP. NETL's work in this area is focused on increasing the amount of CO_2 that remains in the ground as part of CO_2-enhanced oil recovery (CO_2-EOR).

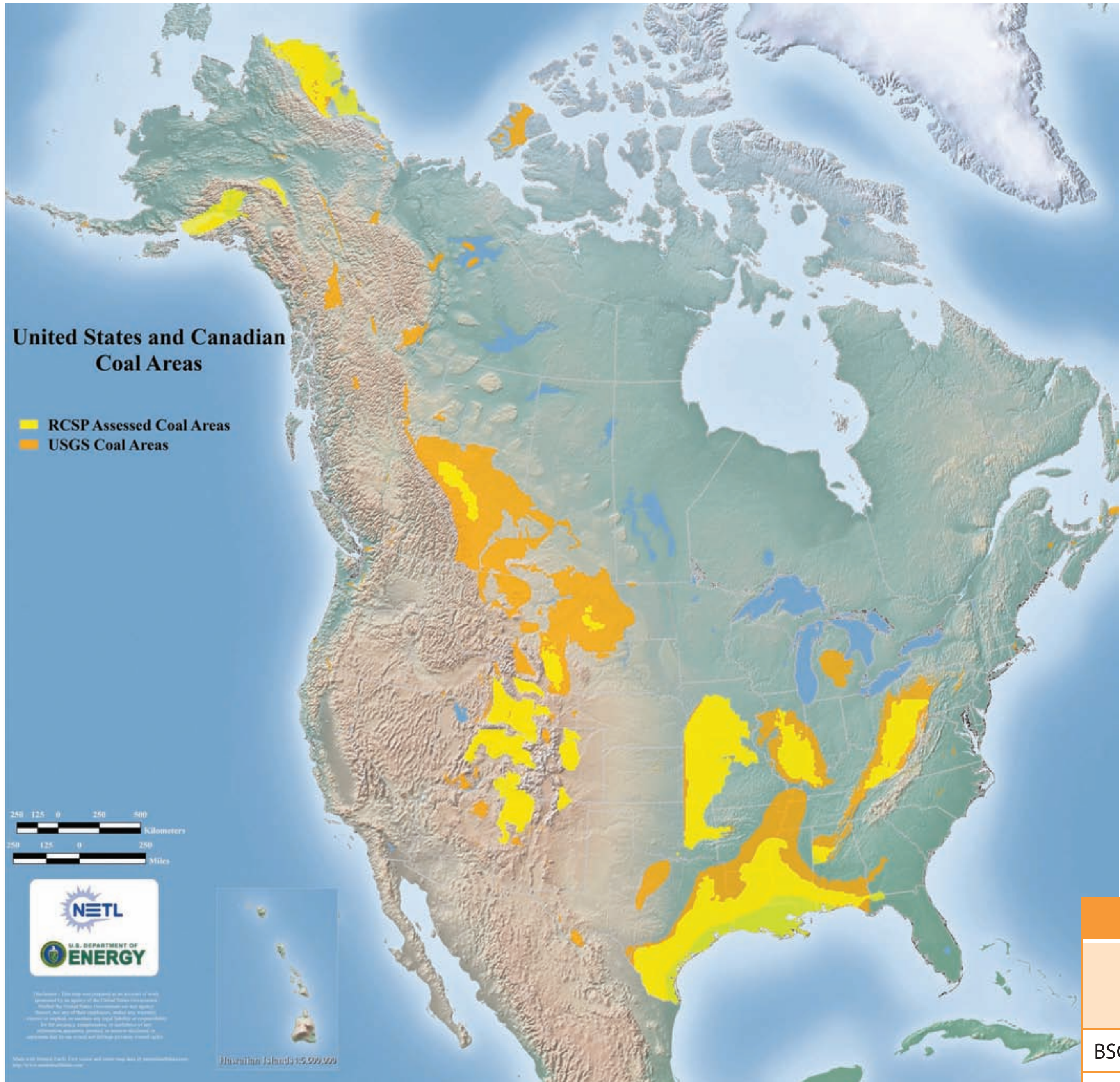
While not all potential mature oil and gas reservoirs in all States and provinces have been examined, the RCSPs have documented the location of almost 143 billion metric tons (155 billion tons) of CO_2 storage resource in 29 States and 4 provinces. At current CO_2 emission rates, calculations indicate more than 40 years of storage potential in assessed oil and gas reservoirs. For details on oil and gas CO_2 storage resource by State, see Appendix C.

CO_2 Storage Resource Estimates for Oil and Gas Reservoirs by RCSP

RCSP	Billion Metric Tons	Billion Tons
BSCSP	2	2
MGSC	1	1
MRCSP	17	19
PCOR	25	26
SECARB	32	35
SWP	62	68
WESTCARB	4	4
Total	**143**	**155**



This map displays oil and gas reservoir data that were obtained by the RCSPs and other sources and compiled by NATCARB. Carbon dioxide geologic storage information in Atlas III was developed to provide a high-level overview of CO_2 geologic storage potential across the United States and parts of Canada. 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 CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please refer to page 14 for additional information on this level of assessment.



This map displays unmineable coal area data that were obtained by the RCSPs and other sources and compiled by NATCARB. Carbon dioxide geologic storage information in Atlas III was developed to provide a high-level overview of CO_2 geologic storage potential across the United States and parts of Canada. 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 CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please refer to page 14 for additional information on this level of assessment. Please note that unmineable coal area data resulting in a straight edge in the map above is indicative of an area lacking sufficient data and is subject to future investigation.

Unmineable Coal Areas

Coal seams that are too deep or too thin to be economically mined are viable for CO_2 storage. All coals have varying amounts of methane adsorbed onto pore surfaces. Wells can be drilled into unmineable coalbeds to recover this coalbed methane (CBM). Initial CBM recovery methods, such as dewatering and depressurization, leave a considerable amount of methane in the formation. Additional recovery can be achieved by sweeping the coalbed with CO_2. Depending on coal rank, 3 to 13 molecules of CO_2 are adsorbed for each molecule of methane released, thereby providing an excellent storage site for CO_2 along with the additional benefit of enhanced coalbed methane (ECBM) recovery. The adsorption process bonds the CO_2 to the coals, causing the CO_2 to be physically and permanently trapped on the coal provided sufficient pressure is maintained. The adsorption process coupled with the recovery of economically valuable methane gas makes unmineable coal seams attractive options for CCS.

While not all unmineable coal areas have been examined, the RCSPs have documented the location of 60 billion to 117 billion metric tons (65 billion to 128 billion tons) of potential CO_2 storage resource in unmineable coal areas distributed over 21 States and 1 province. At current CO_2 emission rates, calculations indicate more than 15 years of storage potential in assessed coal areas. For details on unmineable coal area CO_2 storage resource by state, see Appendix C.

CO_2 Storage Resource Estimates for Unmineable Coal Areas by RCSP

RCSP	Low		High	
	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	12	13	12	13
MGSC	2	2	3	3
MRCSP	1	1	1	1
PCOR	1	1	1	1
SECARB	33	36	75	83
SWP	1	1	2	2
WESTCARB	10	11	23	25
Total	**60**	**65**	**117**	**128**

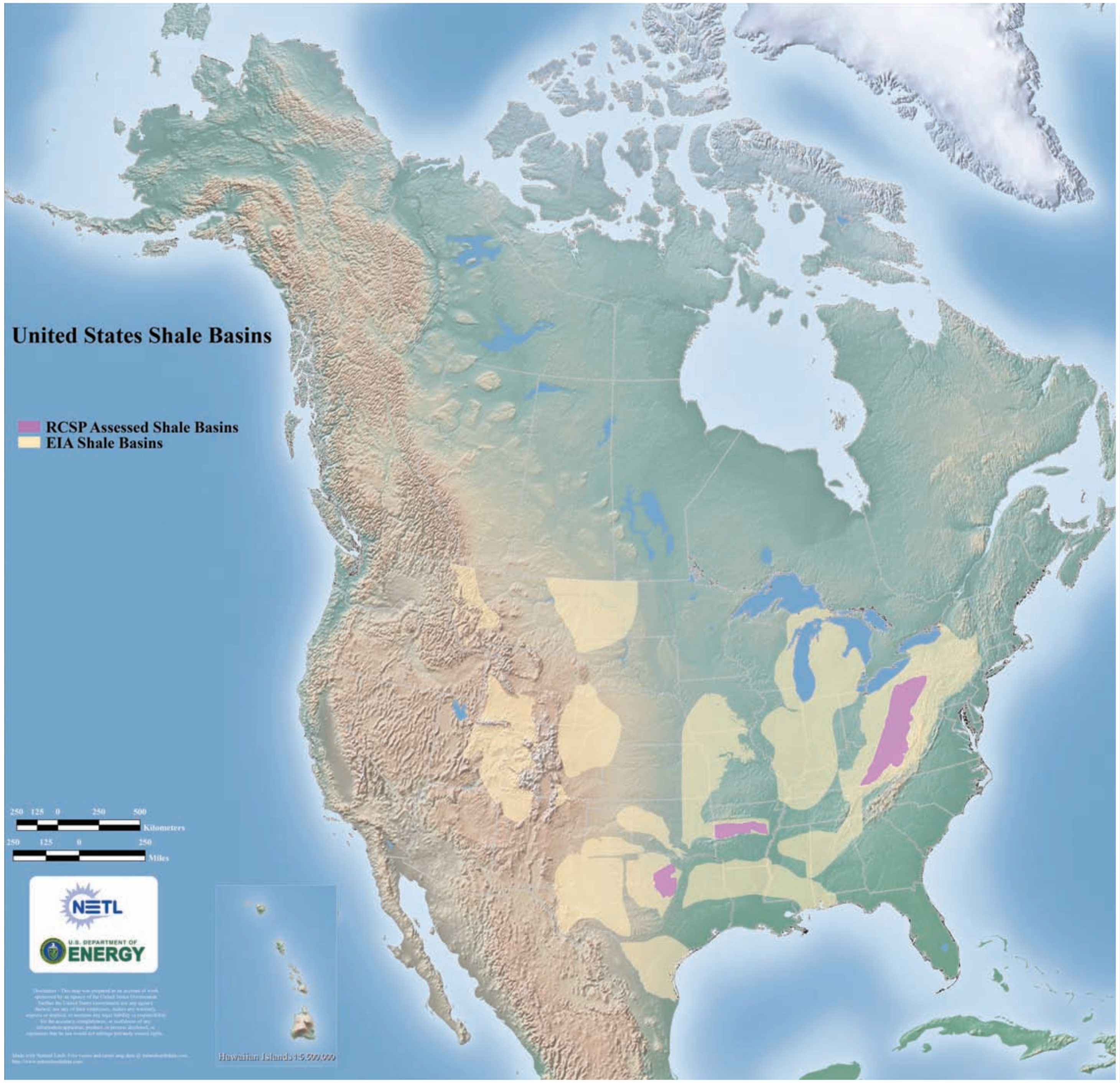
Basalt Formations

Another potential CO_2 storage option DOE is investigating is basalt formations. The relatively large amount of potential storage resource in basalts, along with their geographic distribution, make them an important formation type for possible CO_2 storage, particularly in the Pacific Northwest and the Southeastern United States. Basalt formations are geologic formations of solidified lava. These 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. Some key factors affecting the capacity and injectivity of CO_2 into basalt formations are effective porosity of flow top layers and interconnectivity. DOE's current efforts are focused on enhancing and utilizing the mineralization reactions and increasing CO_2 flow within basalt formations.

The chemistry of basalts potentially allows the injected CO_2 to react with magnesium and calcium in the rocks to form the stable carbonate mineral forms of calcite and dolomite. This mineralization process shows promise of being a valuable tool for CCS since the mineralization process permanently locks carbon in the solid mineral structure. Thus, basalts may offer one of the safest options for the long-term isolation of CO_2 from the atmosphere because of the unique capacity for permanent incorporation of injected CO_2 into carbonates via mineralization. However, more research is needed to understand the time frames and actual chemical inputs and outputs of a basalt CO_2 injection.

Columbia River Basalt.

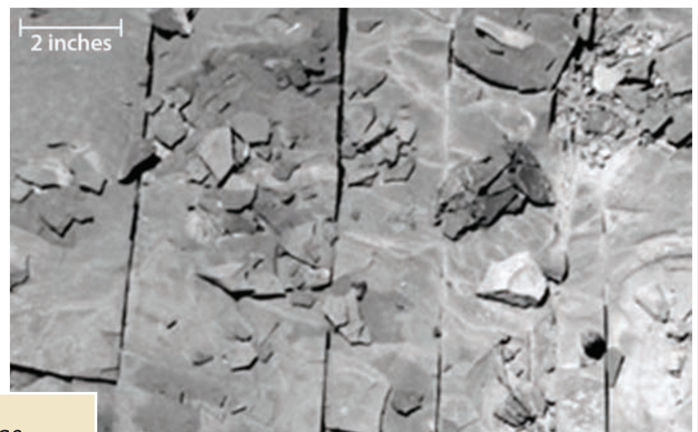
This map displays basalt formation data that were obtained by the RCSPs and other sources and compiled by NATCARB. Carbon dioxide geologic storage information in Atlas III was developed to provide a high-level overview of CO_2 geologic storage potential across the United States and parts of Canada. Areal extents of geologic formations presented are intended to be used as an initial assessment of potential geologic storage. This information provides CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please refer to page 14 for additional information on this level of assessment. Carbon dioxide storage in basalt formations is an area of current research. Before basalt formations can be considered viable storage targets, a number of questions relating to the basic geology, the CO_2 trapping mechanisms and their kinetics, and monitoring and modeling tools need to be addressed. As such, Atlas III presents a map of these potential future storage opportunities, but provides no CO_2 storage resource values for basalt formations.



Organic-Rich Shale Basins

As CCS moves toward commercialization, additional CO_2 storage options may be explored. One option already under consideration is the possibility of utilizing organic-rich shales. Shales are formed from silicate minerals that are degraded into clay particles that accumulate in areas of still water over millions of years. The plate-like structure of these clay particles causes them to accumulate in a flat manner, resulting in rock layers with extremely low permeability in the vertical direction. Therefore, shales are most often used in a geologic storage system as a confining seal or caprock.

If the horizontal permeability in shales is preferentially increased through engineering, CO_2 storage becomes feasible. Recent technological advances in the form of horizontal drilling and hydraulic fracturing have increased interest in organic-rich shales in the energy sector for natural gas production. With horizontal drilling and hydraulic fracturing, operators are basically engineering the porosity and permeability into organic-rich shales to create flow pathways. These technologies, coupled with the fact that CO_2 is preferentially adsorbed over methane, will improve the feasibility of using CO_2 for enhanced gas recovery in much the same way as ECBM recovery. While additional engineering of the rocks would add to the cost, the potential for hydrocarbon production could potentially offset the cost.



Natural fractures "joints" in Devonian-age shale, typical of fractures in Marcellus Shale. (Image from www.geology.com)

This map displays organic-rich shale basins data that were obtained by the RCSPs and other sources and compiled by NATCARB. Carbon dioxide geologic storage information in Atlas III was developed to provide a high-level overview of CO_2 geologic storage potential across the United States and parts of Canada. Areal extents of geologic formations presented are intended to be used as an initial assessment of potential geologic storage. This information provides CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please refer to page 14 for additional information on this level of assessment. Carbon dioxide storage in organic-rich shale basins is an area of current research. Before organic-rich shale basins can be considered viable storage targets, a number of questions relating to the basic geology, the CO_2 trapping mechanisms and their kinetics, and monitoring and modeling tools need to be addressed. As such, Atlas III presents a map of these potential future storage opportunities, but provides no CO_2 storage resource values for organic-rich shale basins.

Federal Lands

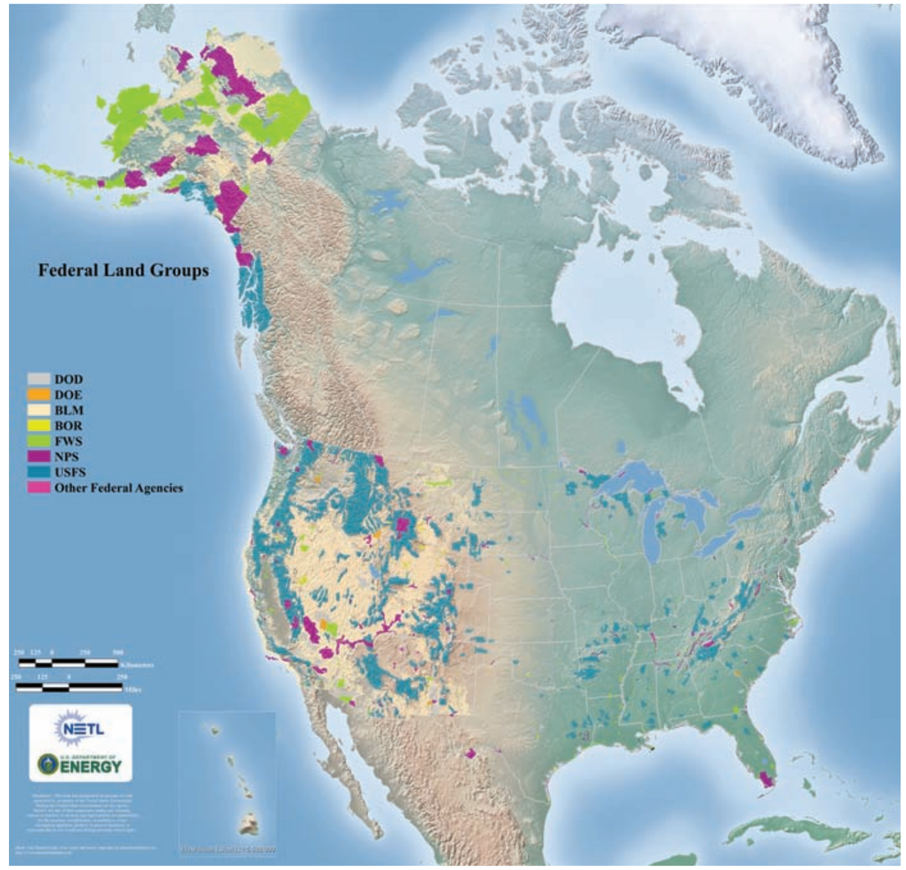
Land Management

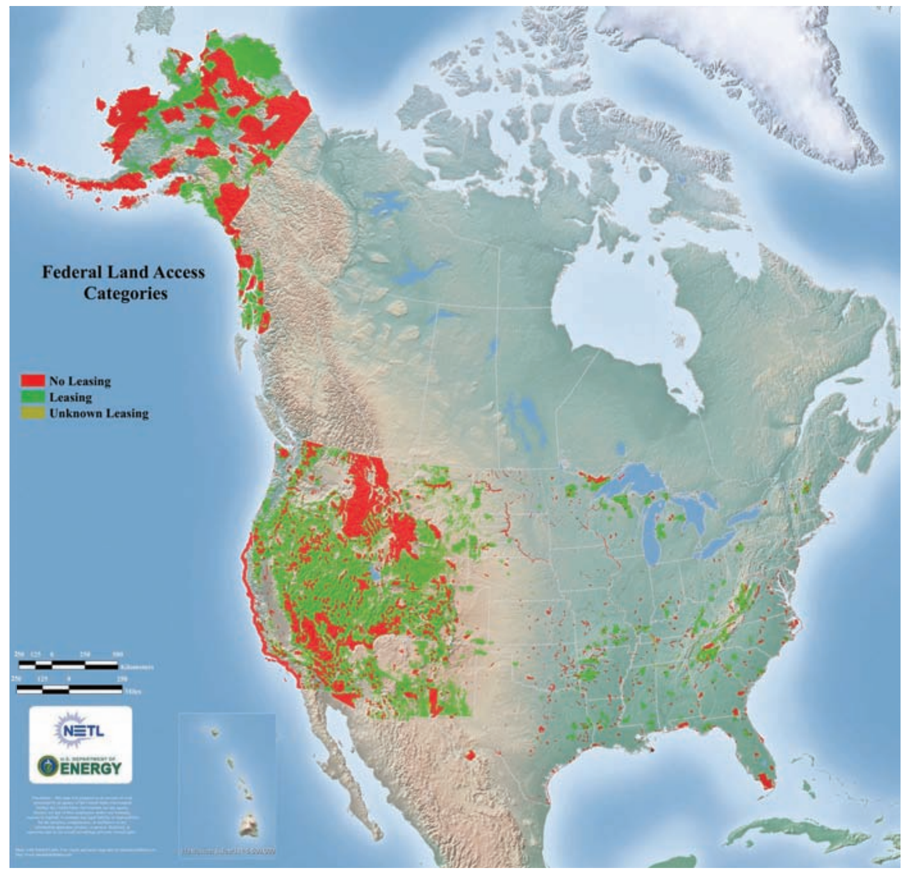
The Federal Government owns about 2.91 million km^2 (1.13 million miles^2) of land, almost 30 percent of the total U.S. land mass. A recent study used USGS spatial data to identify lands owned and/or administered by the Federal Government. The source dataset categorizes Federal landholdings under 65 separate Government bodies. However, to obtain a manageable description of Federal landholdings, these 65 categories were reorganized into 8 land groups according to common Department or Agency ownership (bottom left): (1) Department of Defense (DOD); (2) DOE; (3) Bureau of Land Management (BLM); (4) Bureau of Reclamation (BOR); (5) U.S. Fish and Wildlife Service (FWS); (6) National Park Service (NPS); (7) U.S. Forest Service (USFS); and (8) other Federal agencies. The BLM and the FWS, both in the DOI, and the USFS, of the Department of Agriculture (DOA), manage the vast majority of Federal acreage—about 2.45 million km^2 (0.95 million miles^2).

An assessment of Federal leases with respect to oil and gas resources, per Section 364 of the Energy Policy and Conservation Act (EPCA) of 2005, was completed by the DOI. Utilizing this study, it was recognized that certain agencies do not lease or are restricted from leasing lands under their management—for example NPS or FWS lands—and a net value of 1.62 million km^2 (0.63 million miles^2) was derived (bottom middle).

The BLM and USFS manage almost 99 percent of the leasable lands, 1.60 million km^2 (0.62 million miles^2), the vast majority of which is located in the Rocky Mountain States and further west. Potentially leasable lands from the BLM and USFS are listed in the table at bottom right. Additional restrictions may be added for the protection of wildlife and ecosystems.

The advantage of using Federal Lands for CO_2 storage projects in the western states is the ability to assemble sufficient land from a single owner. Federal Lands east of the Mississippi River occur in smaller, more widely distributed blocks, and CCS utilization in the Eastern United States will most likely be on non-Federal Lands.





Leasable Federal Lands (million km^2)			
RCSP	BLM	USFS	Total
BSCSP	0.11	0.00	0.11
MGSC	0.00	0.01	0.01
MRCSP	0.00	0.04	0.04
PCOR	0.03	0.08	0.11
SECARB	0.00	0.08	0.08
SWP	0.17	0.16	0.33
WESTCARB	0.64	0.28	0.92
TOTAL	**0.95**	**0.65**	**1.60**

Federal Lands (cont'd)

Federal Lands CO_2 Storage Potential and CO_2 Stationary Sources				
RCSP	Percent of Leasable Acreage	Percent of Average Storage	Number of CO_2 Stationary Sources	Annual CO_2 Emissions
BSCSP	6.9	57.8	111	26
MGSC	0.0	0.2	182	247
MRCSP	0.0	0.7	260	559
PCOR	0.1	0.6	487	315
SECARB	0.1	11.3	638	1,004
SWP	0.2	21.1	223	310
WESTCARB	0.6	8.3	295	218
TOTAL			2,196	2,679

CO_2 Storage Resource

The estimated CO_2 geologic storage resource beneath leasable Federal Lands ranges from 266 billion to 3,172 billion metric tons (292 billion to 3,497 billion tons). This is about 15 percent of the onshore CO_2 storage resource presented in *Atlas III*.

Carbon dioxide geologic storage resource beneath Federal Lands and CO_2 stationary sources on Federal Lands are listed by RCSP in the table at left. The majority of leasable Federal Land is found in the WESTCARB region, while the majority of CO_2 storage resource beneath Federal Lands is found in the BSCSP and the SWP regions.

The RCSPs have identified 4,507 total CO_2 stationary sources in the United States and Canada (please refer to pages 24 and 25 for more information). Of those, 3,474 are within 100 miles of Federal Lands (77 percent of the total CO_2 stationary sources identified by the RCSPs). Of those, 2,196 emit over 10,000 metric tons per year and are included in the table at left.

The distribution of CO_2 storage resource beneath Federal Lands for saline formations, oil and gas reservoirs, and unmineable coal areas is displayed below (bottom left, middle, and right below, respectively).

CO_2 Storage Resource Estimates for Saline Formations Beneath Federal Lands by RCSP				
RCSP	Low		High	
	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	133	147	1,834	2,022
MGSC	0	0	6	6
MRCSP	4	5	16	18
PCOR	6	7	6	7
SECARB	26	28	353	390
SWP	48	53	662	730
WESTCARB	19	21	257	284
TOTAL	237	261	3,136	3,457

CO_2 Storage Resource Estimates for Oil and Gas Reservoirs Beneath Federal Lands by RCSP				
RCSP	Low		High	
	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	1	2	1	2
MGSC	0	0	0	0
MRCSP	1	1	1	1
PCOR	4	5	4	5
SECARB	0	0	0	0
SWP	7	8	7	8
WESTCARB	1	1	2	2
TOTAL	15	16	16	18

CO_2 Storage Resource Estimates for Unmineable Coal Areas Beneath Federal Lands by RCSP				
RCSP	Low		High	
	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	9	10	9	10
MGSC	0	0	0	0
MRCSP	0	0	0	0
PCOR	0	0	0	0
SECARB	3	3	7	7
SWP	0	0	1	1
WESTCARB	1	1	3	3
TOTAL	14	15	20	22

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Please note for all maps: