U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

Carbon Sequestration ATLAS of the United States and Canada

Disclaimer

Foreword

The Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) is proud to release the first *Carbon Sequestration Atlas of the United States and Canada*. Production of this Atlas is the result of cooperation and coordination among carbon sequestration experts from local, state, and government agencies, as well as industry and academia. This Atlas presents the first coordinated assessment of carbon capture and storage (CCS) potential across the majority of the U.S. and portions of western Canada. The Atlas also provides an introduction to the carbon storage (sequestration) process, summarizes the DOE's Carbon Sequestration Program, and gives information about the CCS contributions from each Regional Carbon Sequestration Partnership (RCSP) to date.

One of the key questions concerning CCS is: how much potential is there to effectively help address global climate change? As shown in this Atlas, CCS holds great promise as part of a portfolio of technologies that enables the U.S. and the rest of the world to address climate change while meeting the energy demands of an ever increasing global population. The Atlas includes the most current and best available estimates of potential carbon dioxide (CO_2) sequestration capacities determined by a methodology applied consistently across all of the RCSPs. All data were collected before December 2006. In the course of developing these CO_2 sequestration capacity estimates, it became clear that some areas had yielded more and better quality data than others. Therefore, it is acknowledged that these data sets are not comprehensive; it is, however, anticipated that CO_2 sequestration capacity estimates as well as geologic formation maps will be updated annually as new data are acquired and methodologies for CO_2 sequestration capacity estimates improve. Further, 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 sequestration capacity estimates.

About this Atlas

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 efforts in the CCS area, 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 all CO_2 sources in the U.S. and portions of Canada, as well as the areal extent and capacity of geologic CO_2 sequestration sites evaluated within the RCSP Regions. The National Perspectives section also contains a summary of the methodologies and assumptions employed to calculate the estimated CO_2 sequestration capacities of various geologic formations. (Appendix A contains the complete "Methodology for Development of Carbon Sequestration Capacity Estimates" document.) The Regional Perspectives section includes a detailed presentation of CO_2 sequestration capacity assessments for each RCSP based on these methodologies and assumptions.

DOE thanks the many people who contributed to this Atlas.

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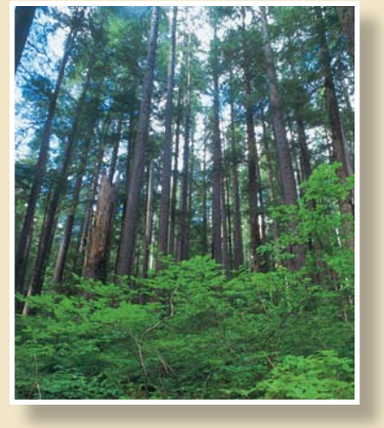
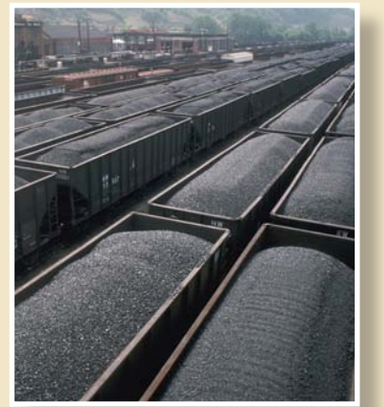




The Greenhouse Gas Effect

Greenhouse gases (GHGs) are gas phase components of the atmosphere that contribute to the greenhouse gas effect, the trapping of radiant heat from the sun within the Earth's atmosphere by various GHGs. One GHG of particular interest is carbon dioxide (CO_2) because it accounts for over 80 percent of total United States GHG emissions. CO_2 is a colorless, odorless, nonflammable gas . Atmospheric CO_2 originates from both natural and man-made sources. There are multiple natural sources including volcanic out-gassing, the combustion of organic matter, and the respiration processes of living aerobic organisms: man-made, or anthropogenic, sources of CO_2 are primarily the burning of various fossil fuels for power generation and transportation.

The GHG effect is a natural and important phenomenon of the Earth's ecosystem. However, GHG levels in the atmosphere have significantly increased above the pre-industrial level. Emissions of CO_2 from human activity have increased from an insignificant level two centuries ago to over 30 billion metric tons (33 billion tons) worldwide today. This increase of GHGs is considered by many scientists to contribute to the phenomenon of global warming and could cause unwelcome shifts in regional climates.

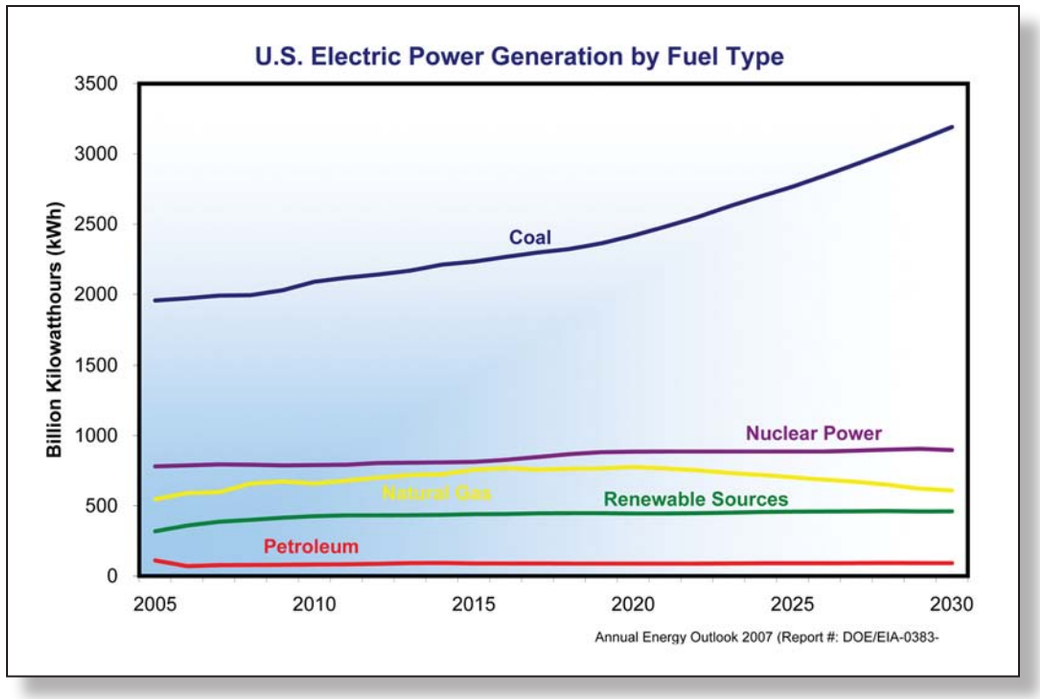
The U.S. is one of 189 countries which are signatories to the United Nations Framework Convention on Climate Change (UNFCC), a treaty which calls for stabilization of atmospheric GHGs at a level that would prevent anthropogenic interference with the world's climate. Conservation, renewable energy, and improvements in the efficiency of power plants, automobiles, and other energy consumption devices are important first steps in any GHG emissions mitigation effort. But those approaches cannot deliver the level of emissions reduction needed to stabilize the concentrations of GHGs in the atmosphere—especially against a growing global demand for energy. Technological approaches are needed that are effective in reducing atmospheric GHG concentrations yet, at the same time, have little or no negative impacts on energy use and economic growth and prosperity. Carbon capture and storage (CCS) efforts hold great promise as such GHG reduction technologies.

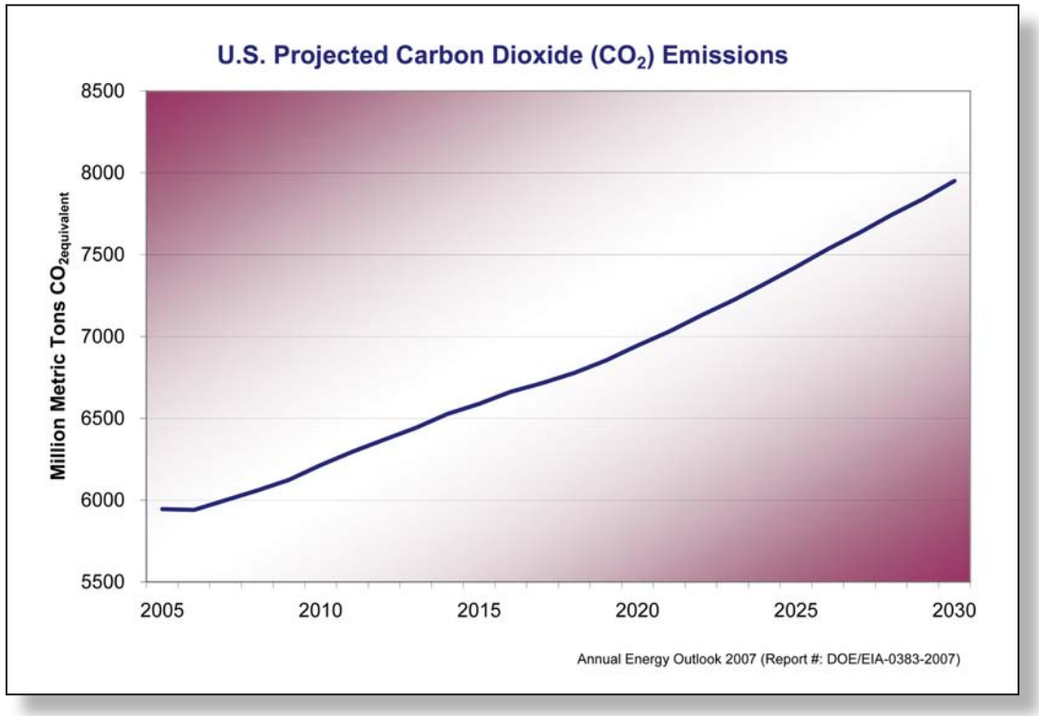
A Technology Approach to Reduce GHG Emissions

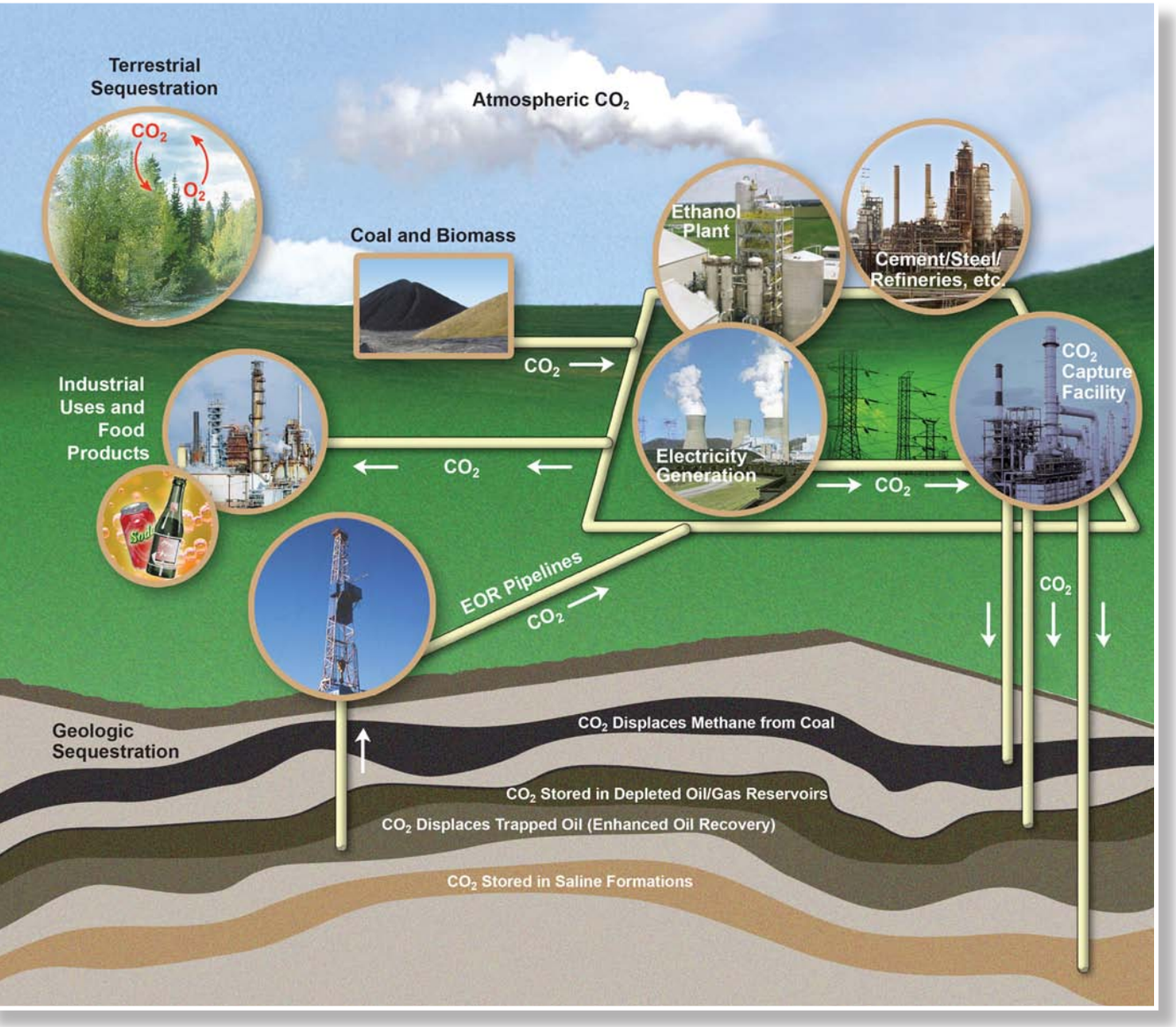
The U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) is engaged in a research and development (R&D) Carbon Sequestration Program focusing on CCS technologies with significant potential for reducing GHG emissions and controlling global climate change. The Program supports the UNFCC efforts to reduce GHG emissions as well as the National Energy Policy goals targeting the development of new technologies for reducing GHG emissions.

The graph "U.S. Electric Power Generation by Fuel Type", shown at top right, displays the *Annual Energy Outlook's* 2007 predictions of growth in energy generation by various fuel types. Coal is predicted to continue to dominate power generation for the next 25 years. Power generation from coal is one significant source of CO_2 emissions, making efforts to reduce these emissions a critical research need.

The Energy Information Administration's graph "U.S. Projected Carbon Dioxide (CO_2) Emissions", shown at bottom right, illustrates the projected increase in CO_2 emissions over the next 25 years. Assuming no action is taken to reduce these emissions, the U.S. will emit approximately 8,000 million metric tons (8,800 million tons) of CO_2 by 2030, increasing 2005 emission levels by more than 33 percent. The U.S. can work toward reducing GHG emissions with the development and implementation of appropriate CCS technologies.







What is Carbon Sequestration?

Carbon sequestration encompasses the processes of capture and storage of CO_2 that would otherwise reside in the atmosphere for long periods of time. DOE is investigating a variety of carbon sequestration options. Geologic sequestration involves the separation and capture of CO_2 at the point of emissions followed by storage in deep underground geologic formations. Terrestrial sequestration involves the net removal of CO_2 from the atmosphere by plants and microorganisms and its storage in vegetative biomass and in soils. There is significant opportunity to use terrestrial sequestration both to reduce CO_2 and to obtain the ancillary benefits such as habitat and water quality improvements that often result from such projects. The DOE is focusing its efforts for terrestrial sequestration on increasing carbon uptake through reforestation and amendment of minelands and other damaged soils. In addition, regional efforts are examining terrestrial sequestration through various land management techniques including no-till farming and wetland restoration.

It is expected that large numbers of new power plants and fuel processing facilities will be built in the coming decades, in both the developing world as well as in some areas of the developed world, such as the U.S. and Canada. These new facilities, along with existing plants having the potential for being 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 and purify CO_2 using post-combustion, pre-combustion, or oxy-combustion technologies for carbon capture.

Geologic sequestration is defined as the placement of CO_2 into an underground repository in such a way that it will remain permanently stored. DOE is investigating five types of underground formations for geologic sequestration, each with different challenges and opportunities for CO_2 sequestration: (1) mature oil and natural gas reservoirs, (2) deep unmineable coal seams, (3) deep saline formations, (4) oil- and gas-rich organic shales, and (5) basalt formations.

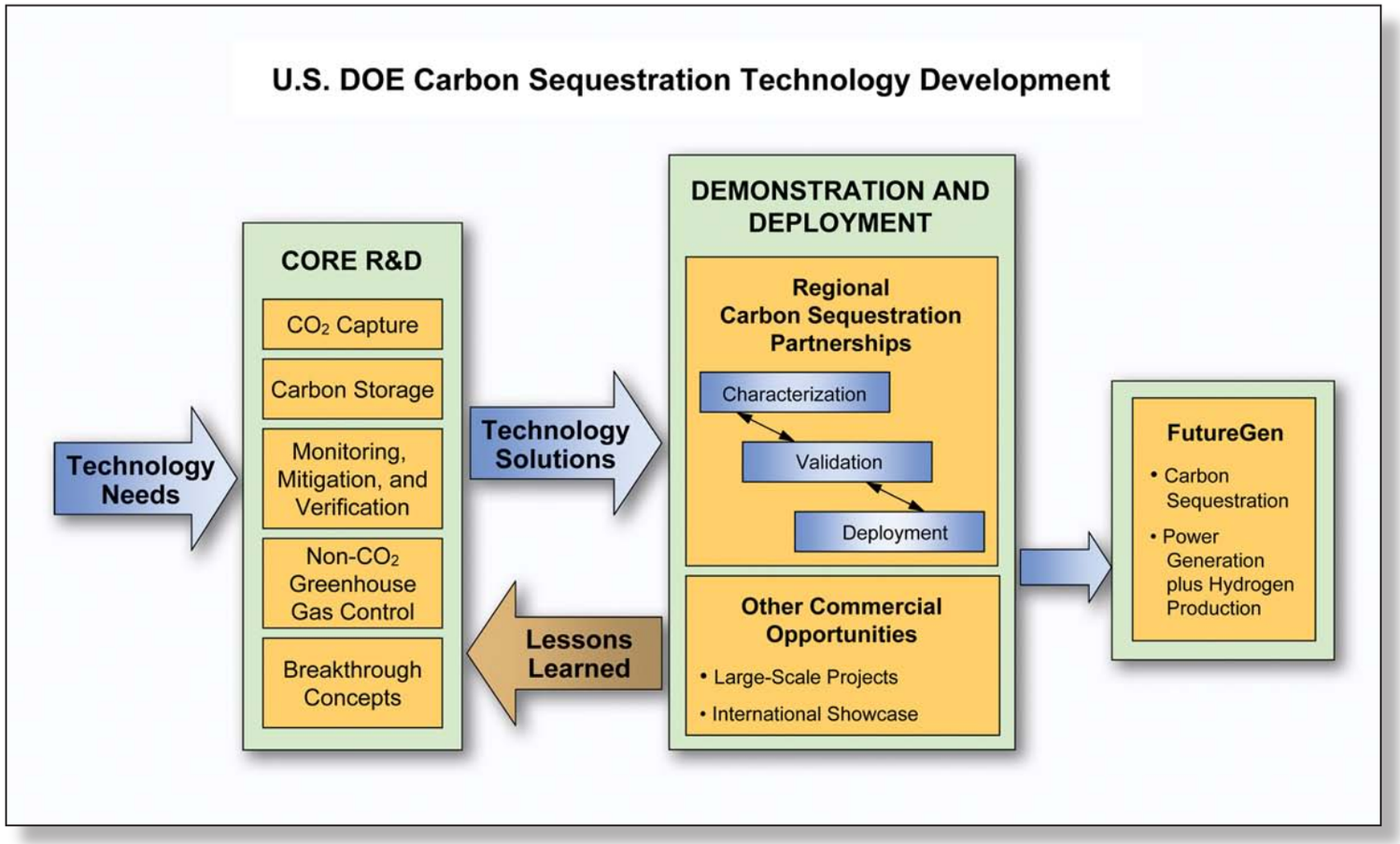
The process of CO_2 sequestration includes monitoring, mitigation, and verification (MM&V) as well as risk assessment at the sequestration site. DOE's MM&V efforts focus on development and deployment of technologies that can provide an accurate accounting of stored CO_2 and a high level of confidence that the CO_2 will remain permanently sequestered. Effective application of these MM&V technologies will ensure the safety of sequestration projects with respect to both human health and the environment, and provide the basis for establishing carbon credit trading markets for sequestered CO_2. Risk assessment research focuses on identifying and quantifying potential risks to humans and the environment associated with CO_2 sequestration and helping to ensure that these risks remain low.

DOE's Carbon Sequestration Program

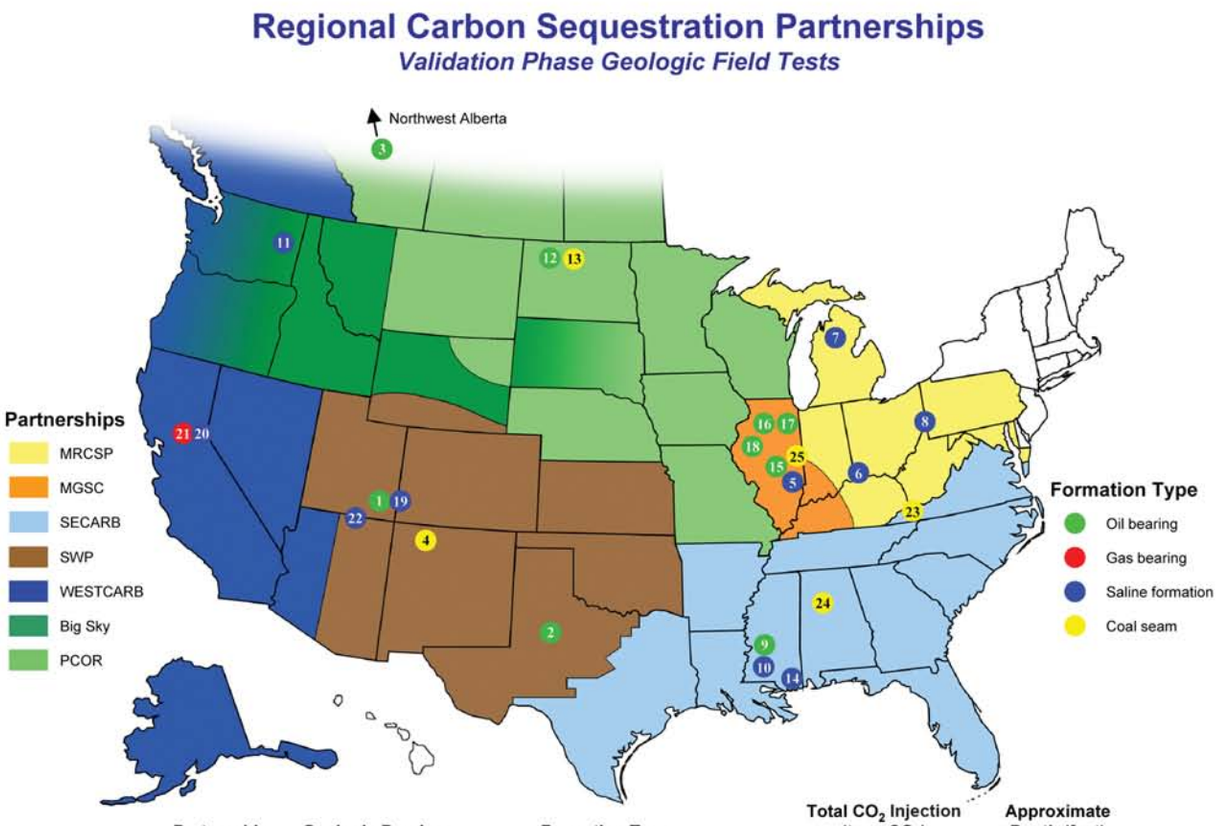
DOE's Carbon Sequestration Program involves two key elements for technology development: (1) Core R&D and (2) Demonstration and Deployment. The Core R&D element contains five focal areas for carbon sequestration technology development: (1) CO_2 Capture, (2) Carbon Storage, (3) Monitoring, Mitigation, and Verification, (4) Non-CO_2 Greenhouse Gas Control, and (5) Breakthrough Concepts. Core R&D is driven by industry's technology needs and is accomplished through laboratory and pilot-scale research aimed at developing new technologies and new systems for GHG mitigation. Core R&D provides technology solutions which support Demonstration and Deployment in the areas of Regional Carbon Sequestration Partnerships, FutureGen, and other commercial opportunities. Experiences with Demonstration and Deployment provide "lessons learned" which are used by Core R&D in developing further technology solutions.

In addition, DOE is part of an international collaboration in the area of carbon sequestration, participating in the Carbon Sequestration Leadership Forum (CSLF). The CSLF is an international climate change initiative that is focused on the development of improved, cost-effective technologies for the separation and capture of CO_2 and for its transport and long-term safe storage. The purpose of the CSLF is to make these technologies available internationally and to identify and address wider issues relating to carbon capture and storage.

DOE's Carbon Sequestration Program is developing a portfolio of technologies with great potential to reduce GHG emissions. The Carbon Sequestration Program's primary concentration is on dramatically lowering the cost and energy requirements of pre- and post-combustion CO_2 capture. The goal is to have a technology portfolio by 2012 for safe, cost-effective and long-term carbon mitigation, management and storage, which will lead to substantial market penetration after 2012. In the long-term, the Program is expected to contribute significantly to the President's goal of developing technologies to substantially reduce GHG emissions.



Artist rendition of FutureGen—a billion-dollar, 10-year project to create the world's first coal-based, near zero emission electricity plant with carbon capture and sequestration.



Partnership	Geologic Province	Formation Type	Total CO_2 Injection (tons CO_2)	Approximate Depth (feet)
1 SWP	Paradox Basin, Aneth Field	Oil-bearing	450,000 – 750,000	5,600 – 5,800
2 SWP	Permian Basin	Oil-bearing	900,000	5,800
3 PCOR	Keg River Formation	Oil-bearing	250,000 tons CO_2 w/90,000 tons H_2S	5,000
4 SWP	San Juan Basin	Coal seam	75,000	3,000
5 MGSC	Illinois Basin	Saline formation	10,000	7,000 – 8,600
6 MRCSP	Cincinnati Arch	Saline formation	1,000 – 3,000	3,200 – 3,500
7 MRCSP	Michigan Basin	Saline formation	3,000 – 20,000	3,200 – 3,500
8 MRCSP	Appalachian Basin	Saline formation	1,000 – 3,000	5,900 – 8,300
9 SECARB	Gulf Coast	Oil-bearing	>800,000/yr	10,066
10 SECARB	Gulf Coast	Saline formation	30,000	10,300
11 Big Sky	Columbia Basin	Saline formation (basalt/mafic)	3,000	3,255 – 3,335 & 3,600 – 3,755
12 PCOR	Duperow Formation	Oil-bearing	5,000	10,000 – 10,500
13 PCOR	Williston Basin	Coal seam	<1,000	1,600 – 1,800
14 SECARB	Mississippi Salt Basin	Saline formation	3,000	8,600
15 MGSC	Illinois Basin	Oil-bearing – Heavy	300	1,550
16 MGSC	Illinois Basin	Oil-bearing – Well Conversion	300	1,549
17 MGSC	Illinois Basin	Oil-bearing – Pattern Flood I	300	1,548
18 MGSC	Illinois Basin	Oil-bearing – Pattern Flood II	300	1,551
19 SWP	Paradox Basin, Aneth Field	Saline formation	20,000	6,900
20 WESTCARB	Thorton Gas Field	Saline formation	1,000	3,400 – 3,500
21 WESTCARB	Thorton Gas Field	Gas-bearing	500	3,050
22 WESTCARB	Colorado Plateau	Saline formation	2,000	5,000
23 SECARB	Central Appalachian	Coal seam	1,000	1,600 – 2,300
24 SECARB	Black Warrior Basin	Coal seam	1,000	1,500 – 2,500
25 MGSC	Illinois Basin	Coal seam	750	1,000

Regional Carbon Sequestration Partnerships

Formed by DOE, the Regional Carbon Sequestration Partnerships (RCSPs) are a government/industry effort tasked with determining the most suitable technologies, regulations, and infrastructure needs for carbon capture and sequestration in different regions of the U.S. and Canada. The energy sectors of both countries are very closely related. Geographical differences in fossil fuel use and sequestration potential across the U.S. and Canada dictate regional approaches to sequestration of CO_2 and other GHGs. The seven RCSPs that form this network currently include more than 350 state agencies, universities, and private companies, spanning 40 states, three Indian nations, and four Canadian provinces. In addition, agencies from six member countries of the CSLF are participating.

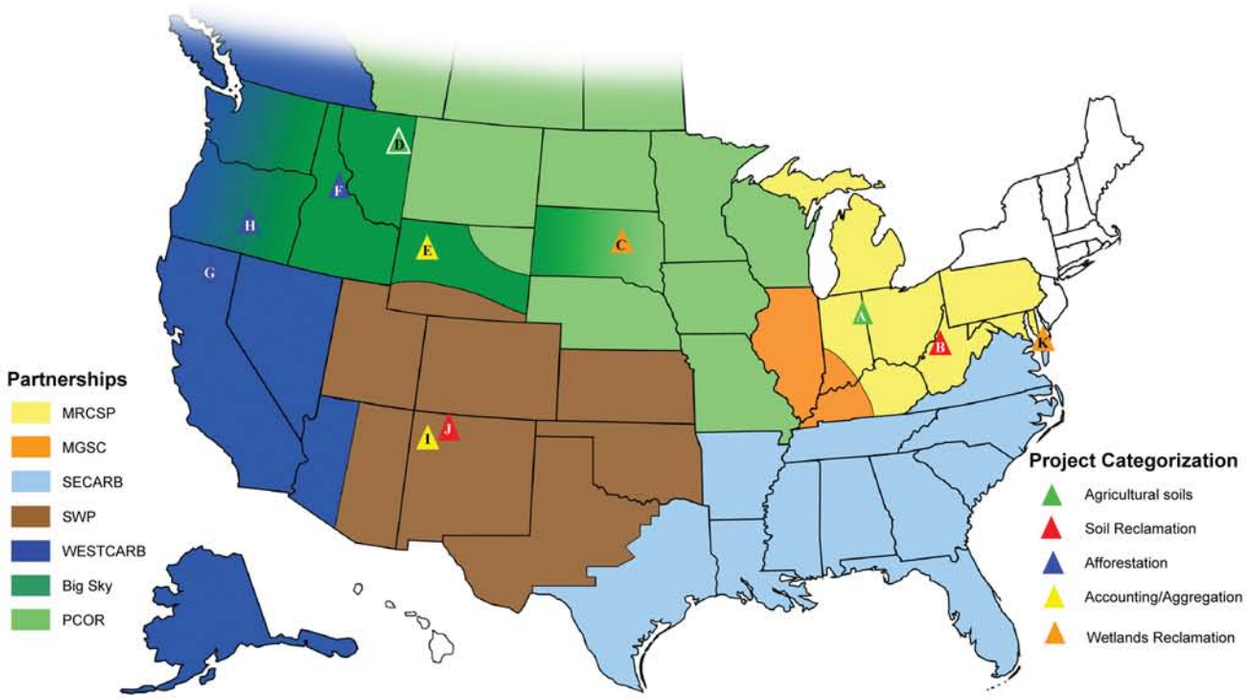
The RCSPs' effort has three distinct phases: (1) Characterization Phase (2003-2005); (2) Validation Phase (2005-2009); and (3) Deployment Phase (2008-2017). The Characterization Phase began in September 2003 with seven RCSPs working to develop the necessary framework to validate and potentially deploy carbon sequestration technologies. At the end of the Characterization Phase, the RCSPs had succeeded in establishing a national network of companies and professionals working to support sequestration deployments, creating a National Carbon Sequestration Database and Geographic Information System (NATCARB), and raising awareness and support for carbon sequestration as a GHG mitigation option.

The Validation Phase focuses on validating the most promising regional opportunities to deploy sequestration technologies by building upon the Characterization Phase accomplishments. Two different sequestration approaches are being pursued in this phase: geologic and terrestrial sequestration. Efforts are being made to validate and refine current reservoir simulation for CO_2 injection; collect physical data to confirm capacity and injectivity estimates; demonstrate the effectiveness of MM&V technologies; develop guidelines for well completion, operations, and abandonment; and develop strategies to optimize the storage capacity of various sink types.

The Deployment Phase will consist of several large-volume sequestration tests. These tests are designed to demonstrate that sequestration sites have the potential to store hundreds of years of regional CO_2 emissions. The large-volume sequestration tests in this phase will be conducted to address issues such as sustainable injectivity, well design for both integrity and increased capacity, and formation behavior with respect to prolonged injection.

Regional Carbon Sequestration Partnerships

Validation Phase Terrestrial Field Tests



Partnership	Project Location	Land Categorization	Project Summary	Estimated CO_2 Capacity
A MRCSP	Region-wide	**Agricultural**	Demonstrating carbon sequestration on existing farm lands. Determine rate of sequestration and potential for different tillage practices to increase storage.	250 Mt over 20 years
B MRCSP	Region-wide	**Mineland**	Demonstrating carbon sequestration in reclaimed mine soils. Determine reclamation and land management practices that increase storage.	100 Mt over 20 years
C PCOR	Great Plains wetlands complex (PPR)	**Wetlands**	Sequestration demonstration in wetlands/grasslands that will provide carbon offsets, develop protocols and standards, and provide a market-based carbon sequestration strategy.	14.4 Mt
D Big Sky	North Central MT	**Agricultural**	Objectives are to (1) quantify and determine cropland management practices that optimize carbon sequestration and (2) develop MMV protocols to evaluate carbon sequestration for enrolled farms.	60 Mt over 20 years
E Big Sky	Eastern WY	**Rangeland**	To determine the sequestration effects of (1) grazing intensity and seasonality of grazing on native northern mixed grass prairie and (2) improvement practices on degraded northern mixed-grass prairie.	30 Mt over 10 years
F Big Sky	Region-wide	**Forest**	Identify strategies for maintaining or increasing sequestration in forests through understanding the effects of forest management on different carbon pools in forests.	640-1,040 Mt over 80 years
G WESTCARB	Shasta County, CA	**Forest and Rangelands**	Validation of forest growth potential for rangelands; Change in forest management; Fuels management to reduce risk of uncharacteristically severe wildfire and prevent emissions	4,600 Mt over 80 years (CA)
H WESTCARB	Lake County, OR	**Forest and Rangelands**	Afforestation using fast-growing tree species Fuels management to reduce risk of uncharacteristically severe wildfire and prevent emissions	900 Mt over 80 years (OR)
I SWP	Region-wide	**Multiple**	Develop a carbon reporting and monitoring system that functions consistently across hierarchical scales and is compatible with the existing technology underlying the 1605b reporting system. Project will develop improved technologies and systems for direct measurement.	TBD
J SWP	San Juan Basin Coal Fairway (Navajo City, NM)	**Rangeland/ Riparian**	Desalinate produced water from the ECBM pilot and use the water for irrigating a riparian restoration project. Reintroducing woody plant species along riparian areas and reestablishing native grasses and shrubs in upland areas. Project represents a combined ECBM-terrestrial sequestration project.	TBD
K MRCSP	Cambridge, MD	**Wetlands**	Develop estimates of carbon sequestration rates in marshes over time. Understand influences of carbon management practices on sequestration rates. Develop sampling protocol for sequestration validation.	TBD

Regional Carbon Sequestration Partnerships

BIGSKYCARBON SEQUESTRATION PARTNERSHIP	Montana State University **http://www.bigskyco2.org/**
MGSC	Illinois State Geological Survey **http://www.sequestration.org/**
MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP	Battelle Memorial Institute **http://www.mrcsp.org**
The Plains CO_2 Reduction Partnership PCOR Partnership	University of North Dakota, Energy & Environmental Research Center **http://www.undeerc.org/pcor/**
Southeast Regional Carbon Sequestration Partnership	Southern States Energy Board **http://www.secarbon.org/**
SWP SOUTHWEST PARTNERSHIP CO_2 SEQUESTRATION	New Mexico Institute of Mining and Technology **http://www.southwestcarbonpartnership.org/**
WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP westcarb.org	California Energy Commission **http://www.westcarb.org/**

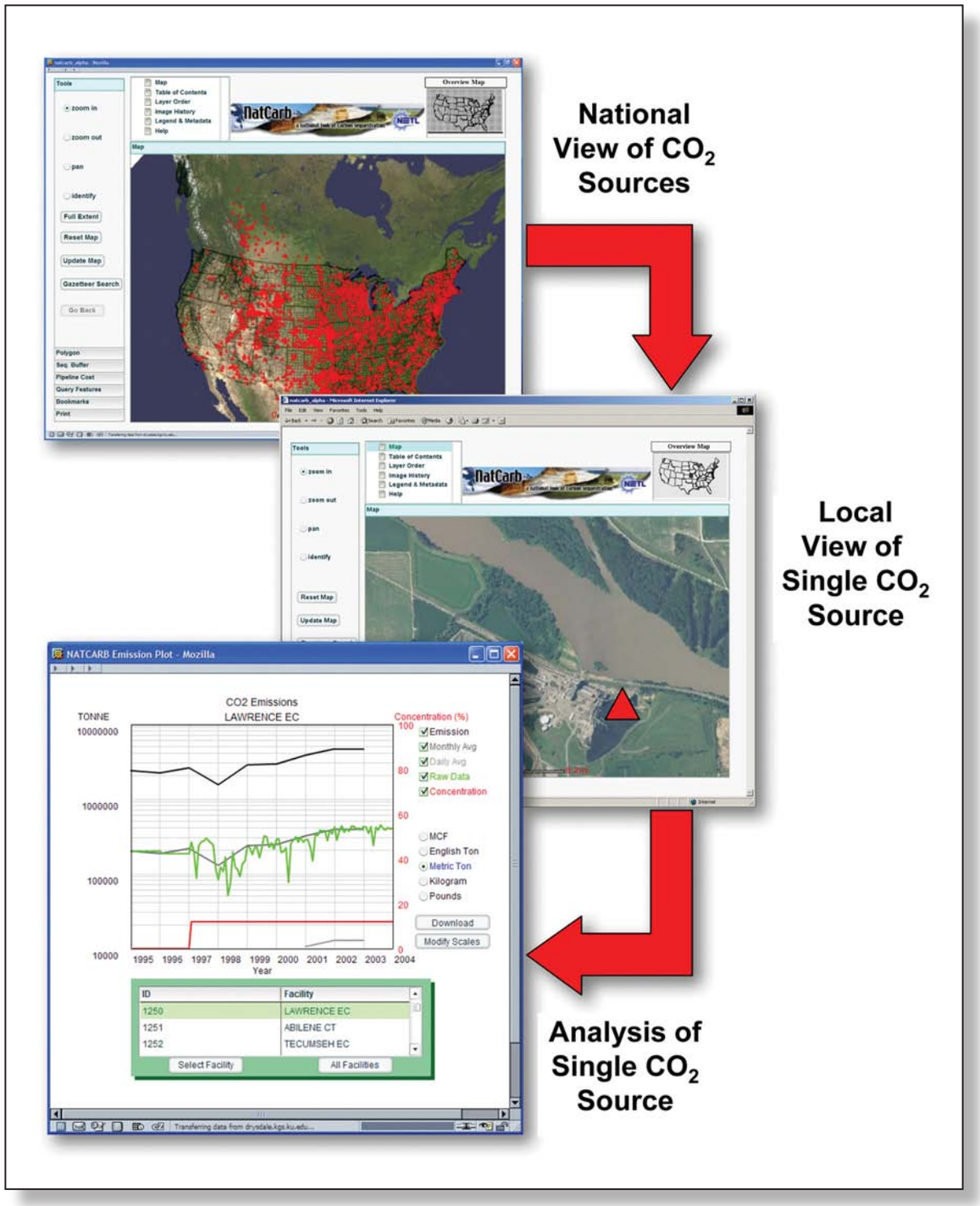
National Carbon Sequestration Database and Geographical Information System

A National Look at Carbon Sequestration

The DOE's Regional Carbon Sequestration Partnerships generated data for this *Atlas*. These key geospatial data (carbon sources, potential sequestration sites, transportation, land use, etc.) are required for efficient implementation of carbon sequestration on a broad scale. NATCARB is a relational database and geographic information system (GIS) that integrates carbon sequestration data from the RCSPs and various other sources. The purpose of NATCARB is to provide a national view of the carbon sequestration potential in the U.S. and Canada. The digital spatial database allows users to estimate the amount of CO_2 emitted by sources (such as power plants, refineries and other fossil-fuel-consuming industries) in relation to geologic formations that can provide safe, secure sequestration sites over long periods of time. The NATCARB project will provide stakeholders with improved online tools for the display and analysis of CO_2 sequestration data.

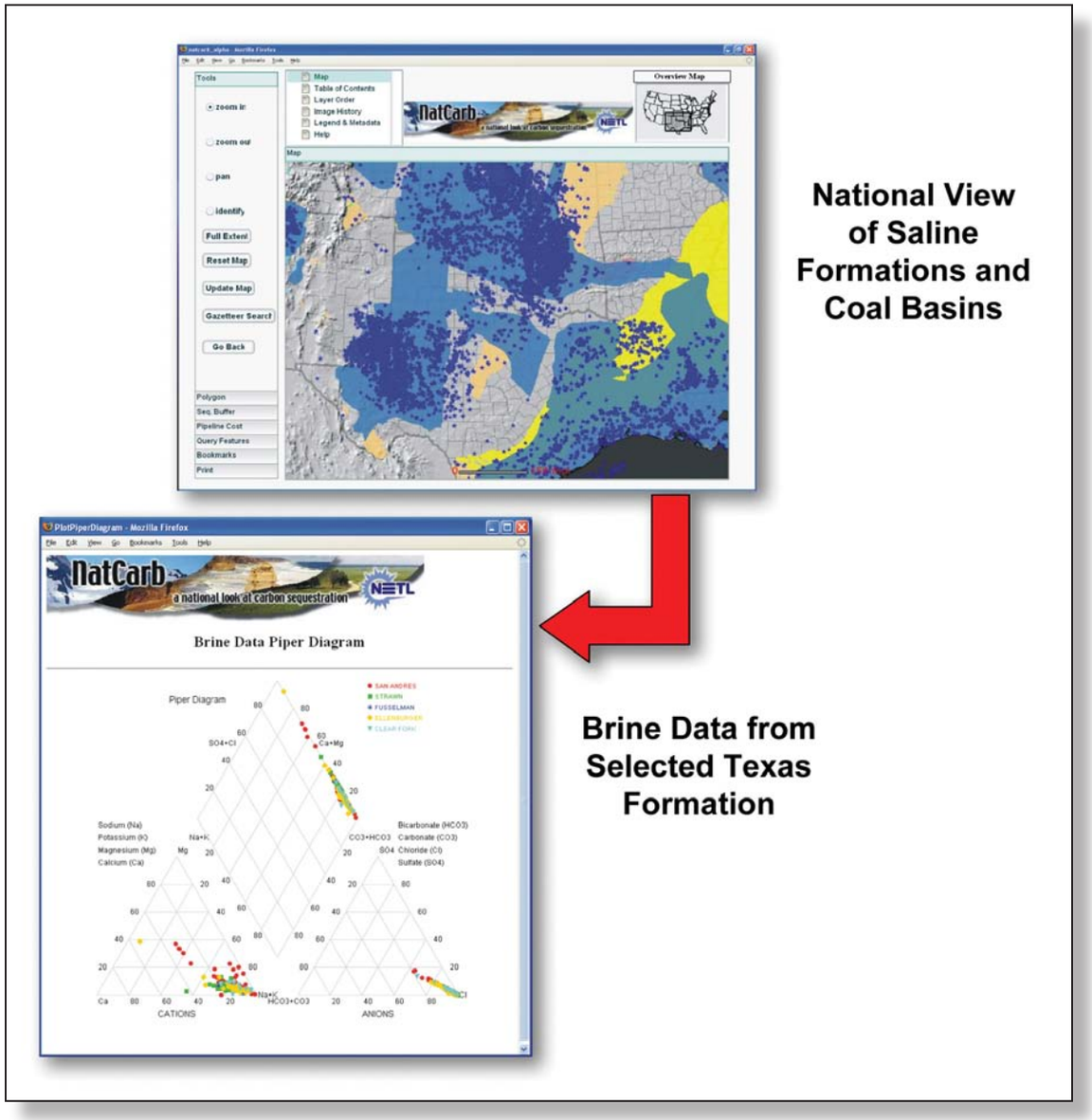
NATCARB is organizing and enhancing the critical information about CO_2 sources and developing the technology needed to access, query, model, analyze, display, and distribute natural resource data related to carbon management. These data are maintained and enhanced locally at the RCSP level, or at specialized data warehouses, and assembled, accessed, and analyzed through a single geoportal. NATCARB is a functional demonstration of distributed data-management systems that cross the boundaries between institutions and geographic areas. It forms the first step toward a functioning national carbon cyber infrastructure. NATCARB can provide access to the necessary information regarding the costs, economic potential, and societal issues of CO_2 capture and storage, including public perception and regulatory aspects.

Not only is NATCARB connected to all the RCSPs, but data are also pulled from public servers including the U.S. Geological Survey-EROS Data Center and from the Geography Network. Data for major CO_2 sources have been obtained from U.S. Environmental Protection Agency (EPA) databases, and data on major coal basins and coalbed methane wells were obtained from the Energy Information Administration (EIA).



CO_2 Sources

NATCARB (**www.natcarb.org**) is a digital mapping site that allows users to display and analyze CO_2 sources and potential sequestration sites. As seen in these images, this analysis can be done at the national, regional, and local level. The CO_2 Source example shows all the large stationary sources of CO_2 across the RCSPs Regions and detailed image and display of CO_2 emissions from a single source. The CO_2 sequestration site example shows saline formations and coal basins from a national view to detailed analysis.



CO_2 Sequestration Site