



the **ENERGY** lab

## PROJECT FACTS

### Carbon Storage – RCSP

# Plains CO<sub>2</sub> Reduction Partnership— Validation Phase

## Background

The U.S. Department of Energy Regional Carbon Sequestration Partnership (RCSP) Initiative consists of seven partnerships. The purpose of these partnerships is to determine the best approaches for permanently storing carbon dioxide (CO<sub>2</sub>) in geologic formations. Each RCSP includes stakeholders comprised of state and local agencies, private companies, electric utilities, universities, and nonprofit organizations. These partnerships are the core of a nationwide network helping to establish the most suitable technologies, regulations, and infrastructure needs for carbon capture, utilization, and storage (CCUS). The RCSPs include more than 400 distinct organizations, spanning 43 states and four Canadian provinces, and are developing the framework needed to validate carbon storage technologies. The RCSPs are unique in that each one is determining which of the numerous CCUS approaches are best suited for their specific region of the country and are also identifying regulatory and infrastructure requirements needed for future commercial deployment. The RCSP Initiative is being implemented in three phases, the Characterization Phase, Validation Phase, and Development Phase. In September 2003, the Characterization Phase began with the seven partnerships working to determine the locations of CO<sub>2</sub> sources and to assess suitable locations for CO<sub>2</sub> storage. The Validation Phase (2005–2013) focused on evaluating promising CO<sub>2</sub> storage opportunities through a series of small scale field tests in the seven partnership regions. Finally, the Development Phase (2008–2020) activities are proceeding and will continue evaluating how CO<sub>2</sub> capture, transportation, injection, and storage can be achieved safely, permanently, and economically at large scales. These tests are providing tremendous insight regarding injectivity, capacity, and containment of CO<sub>2</sub> in the various geologic formations identified by the partnerships. Results and assessments from these efforts will assist commercialization efforts for future carbon storage projects in North America.

The primary objective of the DOE's Carbon Storage Program is to develop technologies to safely and permanently store CO<sub>2</sub> and reduce Greenhouse Gas (GHG) emissions without adversely affecting energy use or hindering economic growth. The Programmatic goals of Carbon Storage research are: (1) estimating CO<sub>2</sub> storage capacity in geologic formations; (2) demonstrating that 99 percent of injected CO<sub>2</sub> remains in the injection zone(s); (3) improving efficiency of storage operations; and (4) developing Best Practices Manuals (BPMs).

## NATIONAL ENERGY TECHNOLOGY LABORATORY

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## PARTNERS (2003 TO PRESENT)

Abengoa Bioenergy New Technology,  
Inc.

Air Products and Chemicals, Inc.

Alberta Department of Energy

Alberta Department of Environment



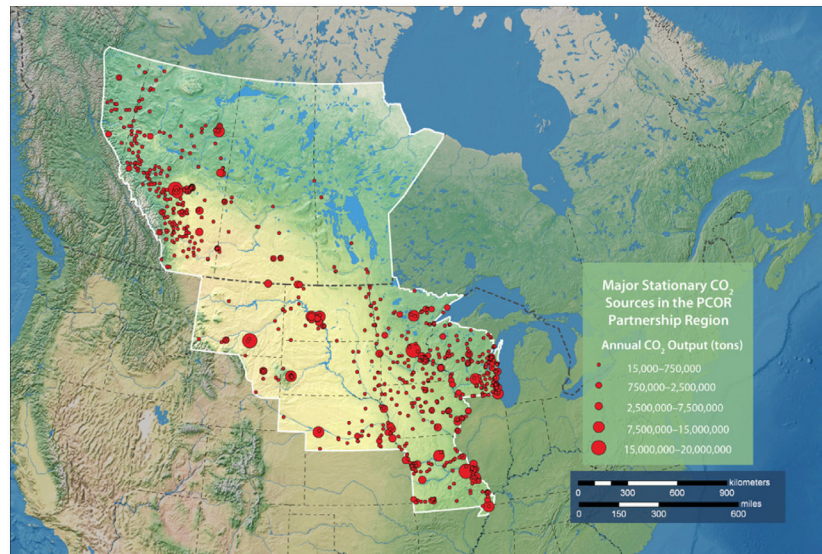
U.S. DEPARTMENT OF  
**ENERGY**

## PARTNERS (CONT.)

Alberta Innovates - Technology Futures  
ALLETE  
Ameren Corporation  
American Coalition for Clean Coal Electricity  
American Lignite Energy  
Apache Canada Ltd.  
Baker Hughes Incorporated  
Basin Electric Power Cooperative  
Bechtel Corporation  
Biorecro AB  
Blue Source, LLC  
BNI Coal, Ltd.  
British Columbia Ministry of Energy, Mines,  
and Petroleum Resources  
British Columbia Oil and Gas Commission  
Chicago Climate Exchange  
Computer Modelling Group, Inc.  
Dakota Gasification Company  
Denbury Onshore LLC  
Ducks Unlimited Canada  
Ducks Unlimited, Inc.  
Eagle Operating, Inc.  
Eastern Iowa Community College District  
Enbridge Inc.  
Encore Acquisition Company  
Energy & Environmental Research Center  
(University of North Dakota)  
Energy Resources Conservation Board/  
Alberta Geological Survey  
Environment Canada  
Excelsior Energy Inc.  
Great Northern Project Development, LP  
Great River Energy  
Halliburton  
Hess Corporation  
Huntsman Corporation  
Husky Energy Inc.  
Indian Land Tenure Foundation  
Interstate Oil and Gas Compact Commission  
Iowa Department of Natural Resources –  
Geological Survey  
Kiewit Mining Group  
Lignite Energy Council  
Manitoba Geological Survey  
Manitoba Hydro  
Marathon Oil Company  
MEG Energy Corporation  
Melzer Consulting  
Minnesota Pollution Control Agency  
Minnesota Power  
Minnkota Power Cooperative, Inc

## Description

The Plains CO<sub>2</sub> Reduction (PCOR) Partnership is a diverse group of public and private sector stakeholders working together to explore the technical and economic feasibility of capturing and storing CO<sub>2</sub> emissions from stationary sources in the central interior of North America. The PCOR Partnership is one of seven RCSPs funded by DOE and a broad range of project sponsors. It is led by the Energy & Environmental Research Center (EERC) at the University of North Dakota. The nine states in the PCOR Partnership region generate about 11 percent of the total U.S. CO<sub>2</sub> emissions from major stationary sources. Since its inception in 2003, the PCOR Partnership has included the support of approximately 100 public- and private-sector stake-holders from the central interior of North America and adjacent areas that have expertise in power generation; oil and gas exploration; and production, geology, engineering, the environment, agriculture, forestry, and economics. These partners are the backbone of the PCOR Partnership and provide data, guidance, and practical experience with the various facets of geologic and terrestrial storage of CO<sub>2</sub>.



*Major Stationary CO<sub>2</sub> Sources in the PCOR Partnership Region.*

The region has abundant geologic storage opportunities that can be used for storing CO<sub>2</sub>. During the PCOR Partnership Characterization Phase (2003–2005), key reservoir characterization data were gathered for over 1,900 oil fields in the oil-producing states and provinces of the region. Three saline formations that cover large portions of the region were also evaluated, and several more were identified for evaluation in the Validation Phase (2005 – 2009). The region's major coal fields have also been evaluated for CO<sub>2</sub> storage potential. In 2011, CO<sub>2</sub> storage estimates within the region's major oil and gas, saline, and unmineable coal formations were estimated at 25.8 billion metric tons, 417 billion metric tons, and 7.3 billion metric tons respectively.

The PCOR Partnership region also contains many opportunities for terrestrial storage of CO<sub>2</sub>. Terrestrial sinks include agricultural lands (e.g., croplands, grasslands, and rangelands), forestlands, wetlands, and peat bogs. Forested areas within the PCOR Partnership region total more than 302 million acres, agricultural lands (both farmland and rangeland) total more than 402 million acres, the Prairie Pothole Region (PPR) includes 30.9 million acres of wetlands, and the

## PARTNERS (CONT.)

Missouri Department of Natural Resources  
Missouri River Energy Services  
Montana Department of Environmental Quality  
Montana-Dakota Utilities Company  
Montana Public Service Commission  
Murex Corporation  
National Commission on Energy Policy  
Natural Resources Canada  
Nebraska Public Power District  
Nexant, Inc.  
North American Coal Corporation  
North Dakota Department of Commerce  
Division of Community Services  
North Dakota Department of Health  
North Dakota Geological Survey  
North Dakota Industrial Commission  
Department of Mineral Resources, Oil and Gas Division  
North Dakota Industrial Commission  
Lignite Research, Development and Marketing Program  
North Dakota Industrial Commission Oil and Gas Research Council  
North Dakota Natural Resources Trust  
North Dakota Petroleum Council  
North Dakota Pipeline Authority  
North Dakota State University  
Otter Tail Power Company  
Oxand Risk & Project Management Solutions  
Petroleum Technology Research Centre  
Petroleum Technology Transfer Council  
Pinnacle, a Halliburton Service  
Prairie Public Broadcasting  
Pratt & Whitney Rocketdyne, Inc.  
Ramgen Power Systems, Inc.  
RPS Energy Canada Ltd  
Saskatchewan Ministry of Energy and Resources  
SaskPower  
Schlumberger Carbon Services  
Shell Canada Energy  
Spectra Energy  
Strategic West Energy Ltd.  
Suncor Energy Inc.  
TAQA North Ltd.  
Tesoro Refinery (Mandan)  
TGS Geological Products and Services  
U.S. Department of Energy  
U.S. Geological Survey Northern Prairie Wildlife Research Center

region contains more than 106 million acres of peat bogs. While the amount of carbon that can be stored in this manner is species or location-dependent, gross estimates of storage capacity can be made by applying known storage rates to the available acreages.

## Primary Project Goal

The overall goal of the PCOR Partnership Validation Phase was to develop a core of local technical expertise and experience to facilitate future CO<sub>2</sub> storage efforts in both subsurface and terrestrial settings in the Great Plains region, thus providing results and assessments from these efforts to assist commercialization efforts for future carbon storage projects in North America.

## Objectives

Objectives of the PCOR Partnership Validation Phase, which was completed in September 2009, were to:

- Continue to assess regional carbon storage opportunities.
- Develop and implement field tests; three geologic, and one terrestrial.
- Evaluate the feasibility of selected commercial-scale carbon storage technologies.
- Assess storage capacity, CO<sub>2</sub> permanence, economics, risk, public acceptance, and societal and monetary benefits.
- Provide outreach and education for CO<sub>2</sub> storage stakeholders and the general public.

Field validation tests have been completed and demonstrated four storage scenarios of significant scale. The PCOR Partnership Characterization Phase results have indicated enormous potential for carbon storage in strata suitable for enhanced oil recovery (EOR). EOR projects are especially compelling as field validation tests since the PCOR Partnership's regional opportunity for EOR is large, and the economics are favorable. The information generated on sink capacities and permanence; monitoring, verification, and accounting (MVA); CO<sub>2</sub> transport; economics; risk; public acceptance; and societal benefits that resulted from the storage /EOR tests, made them ideal activities.

## Field Projects

The PCOR Partnership conducted three geologic storage field tests and one terrestrial storage investigation. The field trials involved storage of CO<sub>2</sub> and comprehensive monitoring of depleted oil and natural gas reservoirs, unmineable coal seams, and wetland restoration and management. These activities, along with continued regional characterization and integration with other RCSPs, provided a firm technical foundation for the PCOR Partnership's large-scale Development Phase tests (initiated in September 2007) and for future commercial-scale deployment of CCUS in the region.

## PARTNERS (CONT.)

University of Alberta  
 University of North Dakota  
 Weatherford Advanced Geotechnology  
 Western Governors' Association  
 Westmoreland Coal Company  
 Williston Basin Interstate Pipeline Company  
 Wisconsin Department of Agriculture, Trade, and Consumer Protection  
 Wyoming Office of State Lands and Investments  
 Xcel Energy

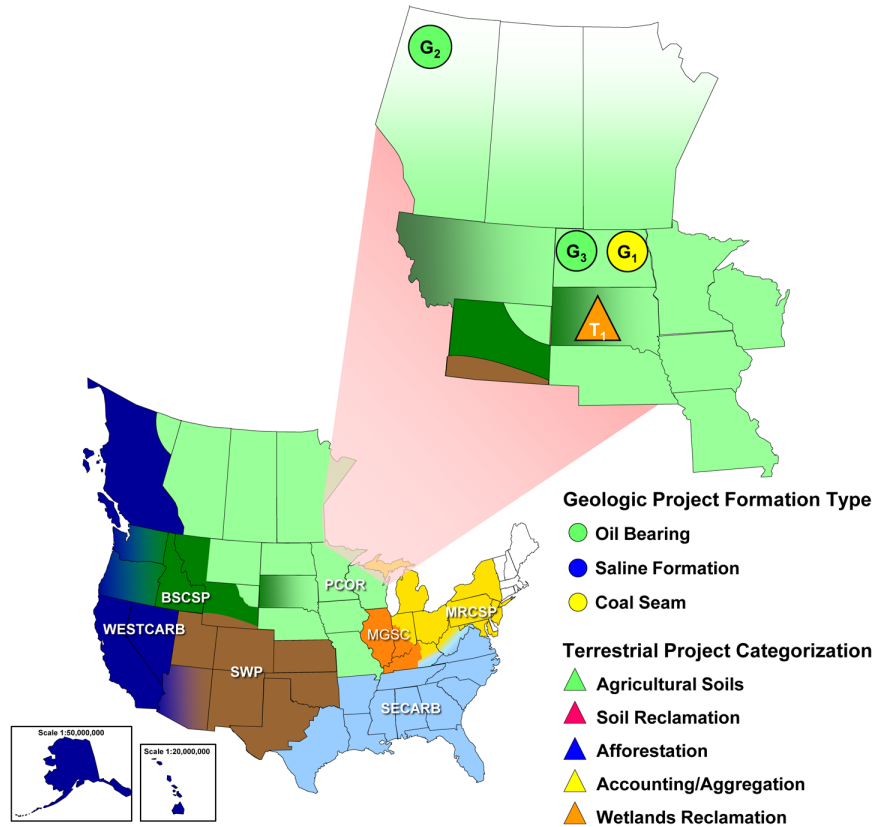
## COST

### Total Project Value

\$29,329,948

### DOE/Non-DOE Share

\$16,451,120 / \$12,878,828



Drilling an exploratory well in the Ft. Nelson Area

## Geologic Storage Opportunities

### Zama Field Validation Test (G1)

The field validation test conducted at Apache Canada's Zama oil field in Alberta, Canada evaluated the potential for geologic storage of CO<sub>2</sub> that utilized an acid gas stream that also includes high concentrations of hydrogen sulfide (H<sub>2</sub>S) for the concurrent purposes of CO<sub>2</sub> storage, H<sub>2</sub>S disposal, and EOR. Approximately 208,600 metric tons of CO<sub>2</sub> and 72,560 metric tons of H<sub>2</sub>S could be available for storage in the oil field over the lifetime of the commercial project at a drilling depth of 5,300 feet. The target formation is a carbonate pinnacle reef structure of the Middle Devonian Keg River Formation – one of the hundreds of such structures within the Zama sub-basin. The project provided insight regarding the impact of high concentrations of H<sub>2</sub>S within a CO<sub>2</sub> stream on sink integrity, MVA, and EOR productivity within a carbonate formation. A variety of research activities has been conducted at multiple scales of investigation in an effort to fully understand the ultimate fate of the injected acid gas. Geologic, geomechanical, geochemical, and engineering work has been used to fully describe the injection zone and adjacent strata in an effort to predict the long-term storage potential of this site. It is anticipated that the EOR operations for a five pinnacle scheme could yield 180,000 - 276,000 barrels of incremental oil recovery per year.

### Accomplishment Highlights:

- Conducted evaluations into the geological, hydrogeological, geochemical, and engineering aspects of an EOR project in an effort to provide an effective, yet low cost monitoring scheme at the site.

- Between December 2006 and May 2012, a total of 119,200 metric tons of acid gas (83,400 metric tons CO<sub>2</sub>) has been injected to produce more than 74,200 barrels of incremental oil. Over 36,000 metric tons of CO<sub>2</sub> is estimated to be stored in the reservoir during the injection period (December 2006 to May 2012).
- In March 2007, the Zama Field Validation Test was recognized by the Carbon Sequestration Leadership Forum for the MVA strategy employed at the site.
- Characterization activities in connection with current monitoring results suggest the Zama Field as an ideal candidate for consideration as a large-scale CO<sub>2</sub> storage location.
- Confirmation that sour gas could be successfully used for EOR operations in a previously untested geologic feature (i.e., carbonate pinnacle reefs – buildups of carbonate that can contain varying amounts of oil and natural gas); incremental oil production over the course of the project was greater than 70,000 barrels.



*Apache Canada Zama gas plant and oil production facility.*

## **Lignite in North Dakota Field Validation Test (G2)**

Approximately 90 metric tons of CO<sub>2</sub> was injected into unmineable lignite seams of the Williston Basin at a drilling depth of approximately 1,100 feet to determine the suitability of these strata for both CO<sub>2</sub> storage and coal-bed methane production. The test was located in Burke County, North Dakota, and attempted to determine whether long-term contact with CO<sub>2</sub> affects the physical stability and gas storage capacity properties of lignite and the hydrodynamic properties of the seam. Lignite coal seams in North Dakota may have the theoretical capacity to store 544 million metric tons of CO<sub>2</sub> and the theoretical potential to produce 0.56 trillion cubic feet (Tcf) of methane.

### **Accomplishment Highlights:**

- Completed drilling of one CO<sub>2</sub> injection well and four monitoring wells in a five-spot pattern during the summer of 2007.
- Retrieved a 30-foot core (including 20 feet of cap rock) for geophysical and geochemical analysis.
- Completed site characterization revealing the existence of multiple coal seams with sufficient areal extent and low-permeability clay layers above and below the target seam. The targeted coal seam (~1,100 ft) was selected as the best candidate for CO<sub>2</sub> injection.
- CO<sub>2</sub> was injected in March 2009 providing 90 metric tons over a 16 day period. Injectivity of 1.4 gpm was achieved below 720 psi for a completion thickness of 10 feet.

- Seismic imaging revealed the extent of the CO<sub>2</sub> plume, and enabled estimation of CO<sub>2</sub> migration and occupation within the coal.
- Down-hole instruments proved to be a successful monitoring technique to corroborate seismic data and logging results which enhanced the determination for the fate of the injected CO<sub>2</sub>.
- Indications are that the injected CO<sub>2</sub> migrates along the path of the coal and was contained within the expected injection zone for the duration of the approximately 3-month monitoring period. This validation test affirmed that CO<sub>2</sub> can be safely injected and stored in an unmineable lignite seam.



*Lignite test site with rig set up at injection well, showing five-spot configuration*



*CO<sub>2</sub> Injection Rig for Lignite Injection Test*

### **Williston Basin EOR Field Test (G3)**

The Williston Basin demonstration test evaluated the potential for geological storage of CO<sub>2</sub> in a deep carbonate reservoir for the dual purpose of CO<sub>2</sub> storage and EOR. Characterization studies indicated that the oil fields of the Williston Basin may have over one billion metric tons of CO<sub>2</sub> storage resources. Additionally, the volume of incremental oil that could be produced from Williston Basin oil fields was estimated to be approximately one billion barrels. With the Development Phase project now underway, results of the Validation Phase activities are being used to support the large-scale deployment project. A total of 400 metric tons of CO<sub>2</sub> was injected into a single well in the Mississippian Madison Group of the Northwest McGregor Oil Field at 8,050 feet using a huff 'n' puff approach. The CO<sub>2</sub> was allowed to "soak" for a two-week period and then produced again. Dynamic response to the injection zone was evaluated for changes over the duration of the project using reservoir saturation tool (RST) and vertical seismic profiling (VSP) logging, reservoir fluid sampling, and formation and injection well pressure monitoring.

## Accomplishment Highlights:

- Eagle Operating and the EERC conducted a CO<sub>2</sub> "Huff n' Puff" in the Northwest McGregor Oil Field on the Nesson Anticline in Williston County, North Dakota. A total of 400 tonnes of CO<sub>2</sub> was injected into the Madison formation over two days in July 2009.
- Petrophysical models, which provide a more detailed evaluation of the injection zone, sealing formations, and other zones of porosity, were developed. Pre-injection predictions regarding CO<sub>2</sub> behavior in the target reservoir both during and after injection were compared to monitored post-injections conditions obtained over the project duration. Reservoir modeling closely matched the field observations and with no evidence of CO<sub>2</sub> migration outside of the target zone.
- The oil productivity of the well more than doubled over the course of a three month production period following the injection. The oil production rate increased from a baseline of 1.5 stock tank barrels (STB) per day to 3, and then to 7 STB per day.
- The results of the RST and VSP indicated that the CO<sub>2</sub> migrated approximately 300 ft (90 m) horizontally and 50 ft (15 m) vertically into the reservoir and suggest that the RST and VSP technologies may be effective MVA tools for deep carbonate reservoirs.
- Project results indicated that CO<sub>2</sub>-based huff 'n' puff operations may be a viable option to increase oil recovery in deep carbonate reservoirs.



*CO<sub>2</sub> Injection Rig for Williston Basin EOR Field Test*

## Terrestrial Storage Opportunities

### PCOR Terrestrial Field Validation Test (T1)

This project demonstrated optimal practices for terrestrially storing CO<sub>2</sub> at multiple sites located in the Prairie Pothole Region (PPR) of North America. A terrestrial field validation test was initiated to develop the technical capacity to systematically identify, develop, and apply alternate land-use management practices to the Prairie Pothole ecosystem (at both local and regional scale) that results in net GHG reductions and marketable carbon offsets. Soil and gas samples were collected from various age cohorts of restored grasslands, native prairie, cropland, and wetlands throughout Montana, North and South Dakota, Minnesota, and Iowa. In addition to carbon uptake and storage measurements, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) gas fluxes were also measured to estimate the net GHG flux of each management practice. These data have been instrumental in advancing terrestrial carbon credits from the PCOR Partnership region into the marketplace.

## Accomplishment Highlights:

- Gas emissions were collected from 17 wetlands in north-central South Dakota on a biweekly basis (11,625 individual gas flux samples collected).
- Soil samples were collected on 14,250 acres of native grassland, restored grassland, and cropland (2,850 soil samples collected). Sample sites are located in North and South Dakota, Montana, Iowa, and Minnesota.
- An Oracle software-based carbon-tracking database was officially launched for use in May 2008. This database provides carbon transaction information complete with serial numbers for unique carbon units and tons and includes business requirements generated for calculating, inventorying, and tracking offsets.
- Project results have supported the accreditation of an Avoided Grassland Conversion project with Climate, Community, and Biodiversity Standard (CCBS 2008). This project was the first to be certified by the standard in the United States and is the first Avoided Grassland Conversion project in the world.
- An economic model was constructed to examine land units affected by various wetland restoration actions. This model, along with another that predicts the probability that a parcel of land will remain in a particular land use (with varying commodity prices and subsidy and conservation payments), was used in a “price point” and/or “willingness to sell/convert” analysis on private lands in the PCOR Partnership region.

Results from this project have provided the science and business processes framework needed for project developers and investors to advance emission reduction targets as well as achieve financial returns in this rapidly emerging market. With the launch of the Ducks Unlimited Carbon Credit Program, landowners are provided with a revenue stream novel to the agricultural economy of the plains, stored carbon.

## Benefits

This Validation Phase initiative benefited the United States by providing a comprehensive assessment of the sources and potential storage options for CO<sub>2</sub> in the central interior of North America. The data collected from this research effort will further CO<sub>2</sub> storage capacity estimates, better demonstrate CO<sub>2</sub> storage permanence, and allow for more efficient CO<sub>2</sub> storage operations in the future. Project specific data was integrated with data from other partnerships to provide a database covering the entire nation. The project promoted cooperation among stakeholders and helped promote public acceptance of CO<sub>2</sub> storage. Analysis of existing EOR projects in the region also provided valuable data to increase the understanding of this option for CO<sub>2</sub> storage.

The PCOR Partnership Validation Phase projects demonstrated that geologic storage is not just an option for the distant future, but is now being implemented on a large scale for both environmental and commercial reasons. The PCOR Partnership estimates additional oil recovery through regional EOR applications of over 1.4 billion barrels, with a value of approximately \$100 billion at U.S. \$50 per barrel. Overall, based on the current geological formations characterized, the PCOR Partnership region has the potential to geologically store 417 billion metric tons of CO<sub>2</sub> in saline formations, 2.9 billion metric tons in depleted oil and natural gas fields, and 7.3 billion metric tons in unmineable coal seams.



*A drake pintail rests in a prairie pothole.*



*Wetland Catchment*