PCOR Partnership Members at the 2007 Annual Meeting.

The Plains CO_2 Reduction Partnership

The Plains CO_2 Reduction (PCOR) Partnership is investigating and demonstrating various sequestration technologies to provide a safe, effective, and efficient means of managing CO_2 emissions across central North America.

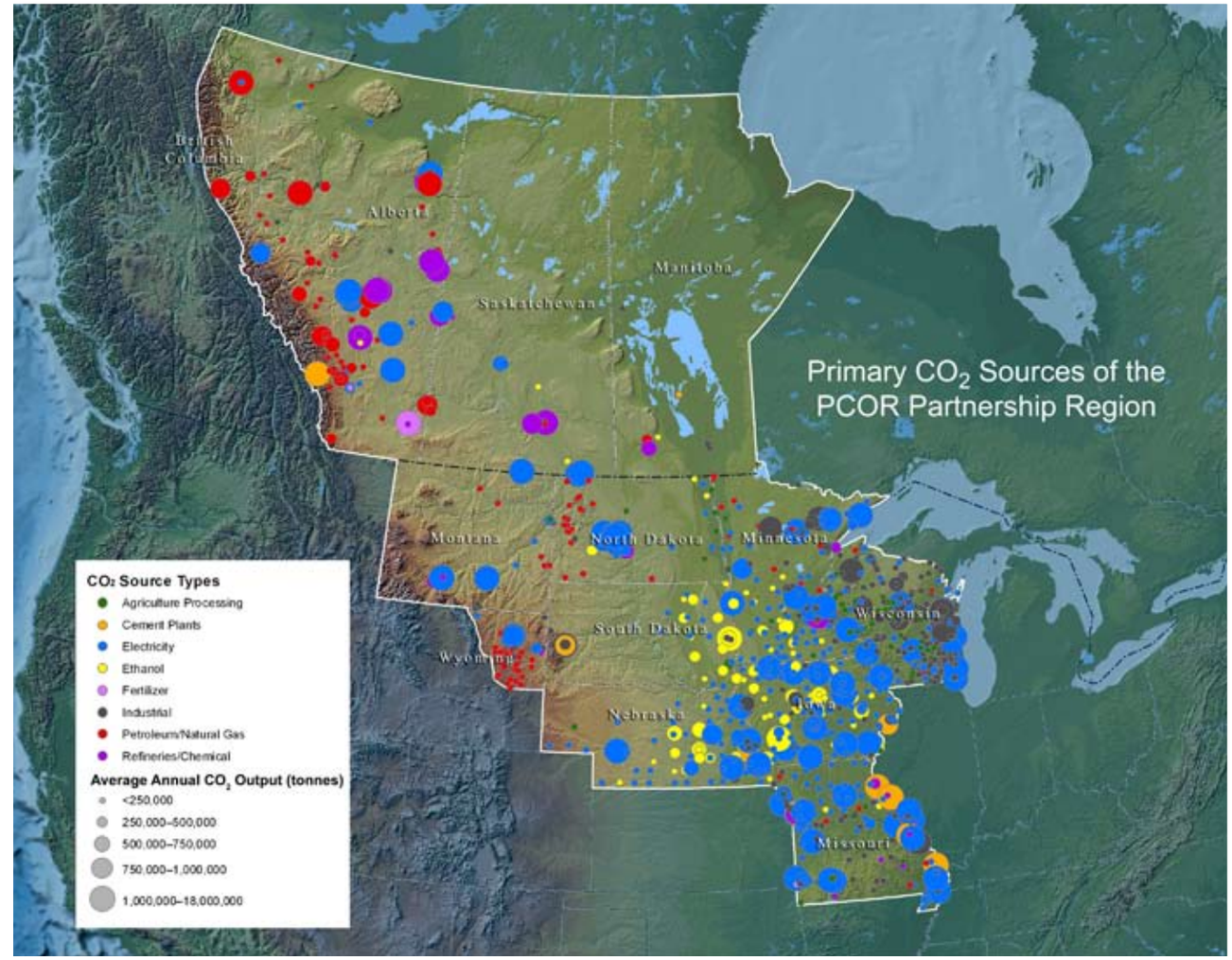
The regional characterization activities conducted by PCOR Partnership confirmed that while numerous large stationary CO_2 sources are present, the Region also has tremendous potential for CO_2 sequestration. The varying natures of the sources and sequestration sites reflect the geographic and socioeconomic diversity across this nearly 3.6 million km^2 (1.4 million mi^2) of central North America. In the upper Mississippi River Valley and along the shores of the Great Lakes Michigan and Superior, large coal-fired electrical generators power the manufacturing plants and breweries of St. Louis, Minneapolis, and Milwaukee. To the west, the prairies and badlands of the north-central United States and central Canada are home to coal-fired power plants, natural gas-processing plants, ethanol plants, and refineries that further fuel the industrial and domestic needs of cities throughout North America. The PCOR Partnership Region is also rich in agricultural lands that hold tremendous potential for terrestrial sequestration. The Prairie Pothole Region (PPR) that stretches from northwestern Iowa, across the Dakotas, and into Saskatchewan and Alberta holds promise as an area that can provide a significant terrestrial CO_2 sequestration site.

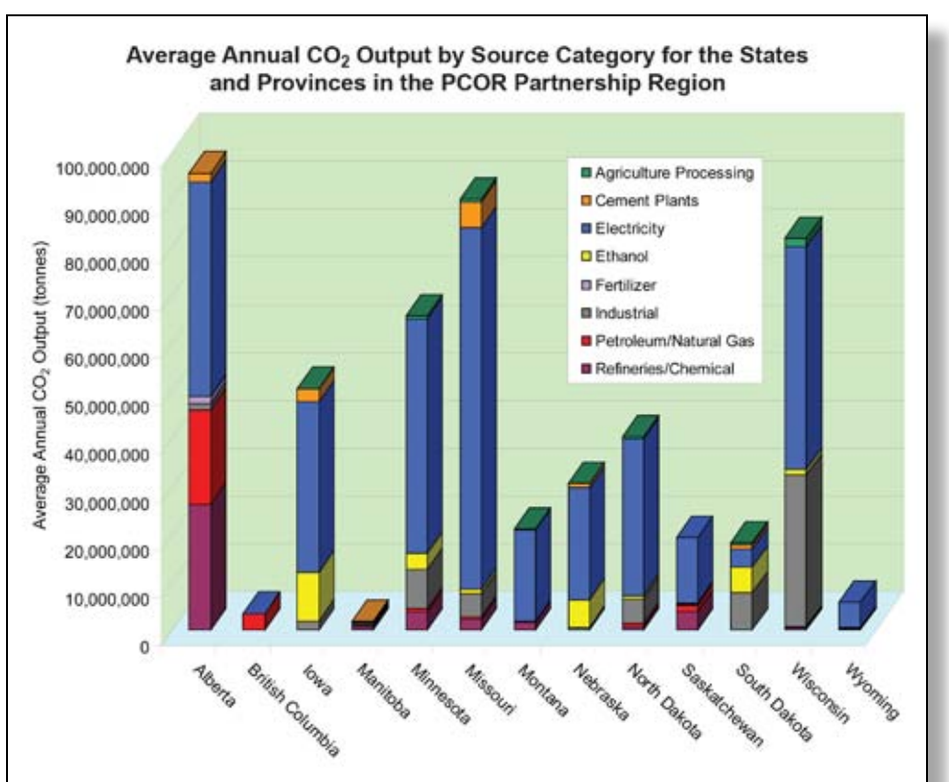
Deep beneath the surface of the region lie geologic formations that hold tremendous potential to store CO_2. Oil fields, already considered to be capable of sequestering CO_2, can be found in roughly half the region, while formations of limestone, sandstone, and coal suitable for CO_2 storage exist in basins that, in some cases, extend over thousands of square miles. In many cases, large sources in the Region are proximally located to large-volume sequestration sites, and in some cases, key infrastructure is already in place. The PCOR Partnership is a collaboration of more than 75 public- and private-sector stakeholders 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. The partners are the backbone of the PCOR Partnership and provide data, guidance, and practical experience with direct and indirect sequestration, including value-added projects.

PCOR Partnership: CO_2 Sources

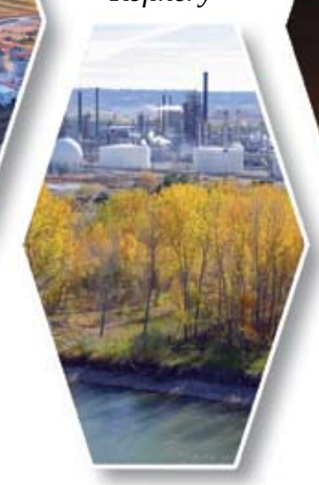
The PCOR Partnership project has identified, quantified, and categorized 1,545 stationary CO_2 sources in the Region. These stationary sources have a combined annual CO_2 output of nearly 522 million metric tons (575 million tons). And, although not a target source of CO_2 for direct sequestration, the transportation sector contributes nearly 202 million metric tons (223 million tons) of additional CO_2 to the atmosphere every year.

The annual output from the various stationary sources ranges from 9 million to 16 million metric tons (10 to 18 million tons) for the larger coal-fired electric generation facilities, to under 4,500 metric tons (5,000 tons) for industrial and agricultural processing facilities. In some cases, the distribution of the sources with the largest CO_2 output coincides with the availability of fossil fuel resources, namely, coal, natural gas, and oil. This relationship is significant with respect to geologic sequestration opportunities. Many of the smaller sources are concentrated around more heavily industrialized metropolitan regions such as southeastern Minnesota, southeastern Wisconsin, and eastern Missouri.





Ethanol Plant

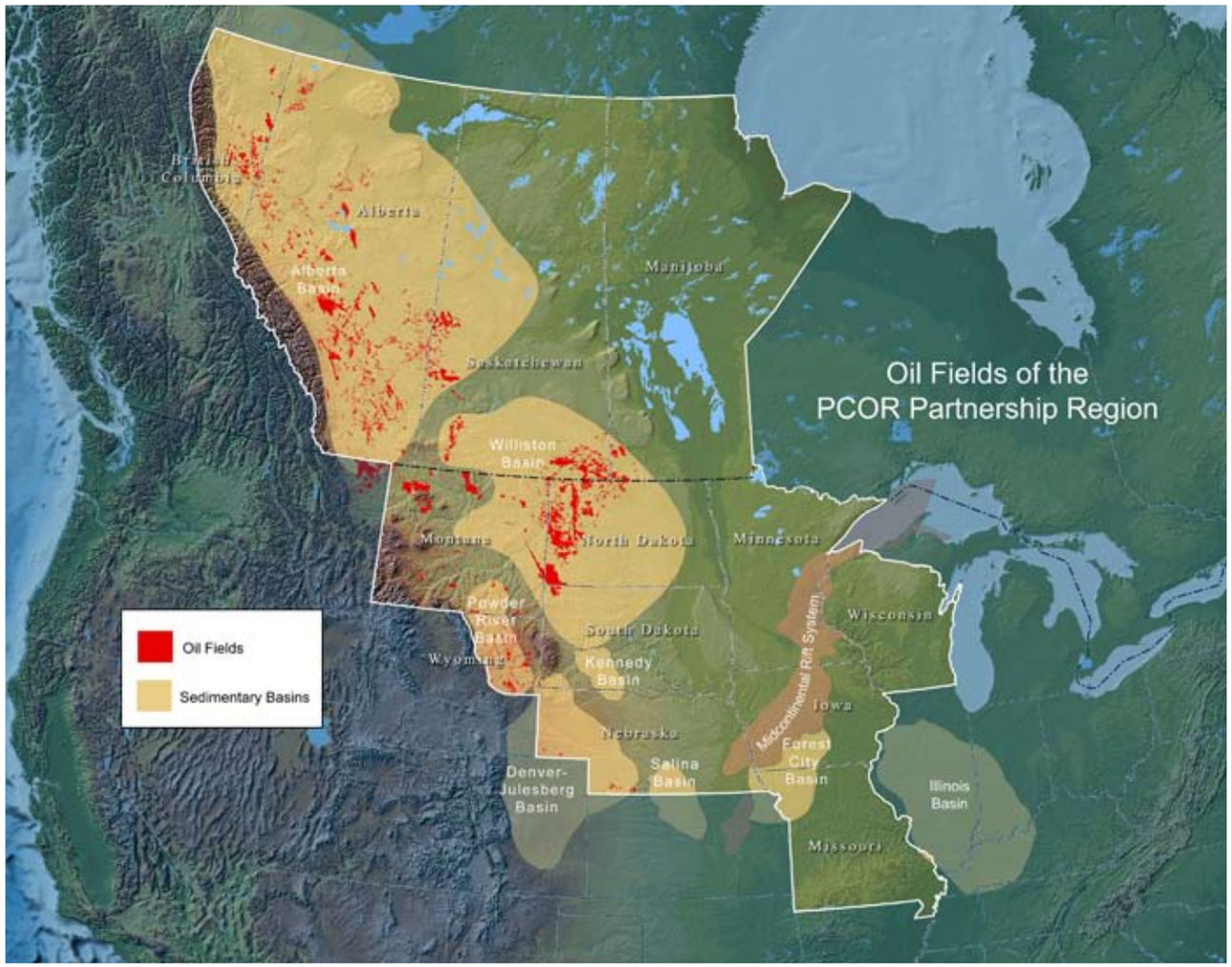


Refinery

Gas Processing Plant

Cement Plant

Electric Generation Plant



Geologic Sequestration: Oil and Gas

The geology of CO_2 sequestration is analogous to the geology of petroleum exploration; the search for oil is the search for sequestered hydrocarbons. Oil fields have many characteristics that make them excellent target locations for geologic storage of CO_2. Therefore, the geologic conditions that are conducive to hydrocarbon storage are also the conditions that are conducive to CO_2 sequestration. The three requirements for storing hydrocarbons are a hydrocarbon source, a suitable reservoir, and an impermeable trap. These requirements are the same as for sequestering CO_2.

A single oil field can have multiple zones of accumulation which are commonly referred to as pools, although specific legal definitions of fields, pools, and reservoirs can vary in a particular state or province. Once injected into an oil field, CO_2 may be sequestered in a pool through dissolution into the formation fluids (oil and/or water), located as a buoyant supercritical-phase CO_2 plume at the top of the reservoir (depending on the location of the injection zone within the reservoir), and/or mineralized through geochemical reactions between the CO_2, formation waters, and the formation rock matrix.

Oil is drawn from the many oil fields in the PCOR Partnership Region from depths ranging from 760 to 1,200 m (2,500 to 4,000 ft) for the shallower pools to 3,700 to 4,900 m (12,000 to 16,000 ft) for the deepest pools.

Storage and Incremental Recovery Through EOR in Selected Fields

Basin	Cumulative Recovery, million bbl	CO_2 Sequestration Potential, Bcf	CO_2 Sequestration Potential, million metric tons
Williston	1,023	8,186	455
Powder River	381	3,049	170
Denver-Julesberg	25	199	11
Alberta	6,000	4,856	2,282

Although oil was discovered in this Region in the late 1800s, significant development and exploration did not begin until the late 1940s and early 1950s. The body of knowledge gained in the past 60 years of exploration and production of hydrocarbons in this Region is a significant step toward understanding the mechanisms for secure sequestration of significant amounts of CO_2.

Geologic Sequestration: Unmineable Coal

Many coal seams throughout central North America are too deep or too thin to be mined economically. However, many of these coals have varying amounts of methane adsorbed onto pore surfaces, and wells can be drilled into the coal beds to recover this "coalbed methane" (CBM). In fact, CBM is the fastest growing source of natural gas in the United States and accounted for 7.2 percent of domestic production in 2003.

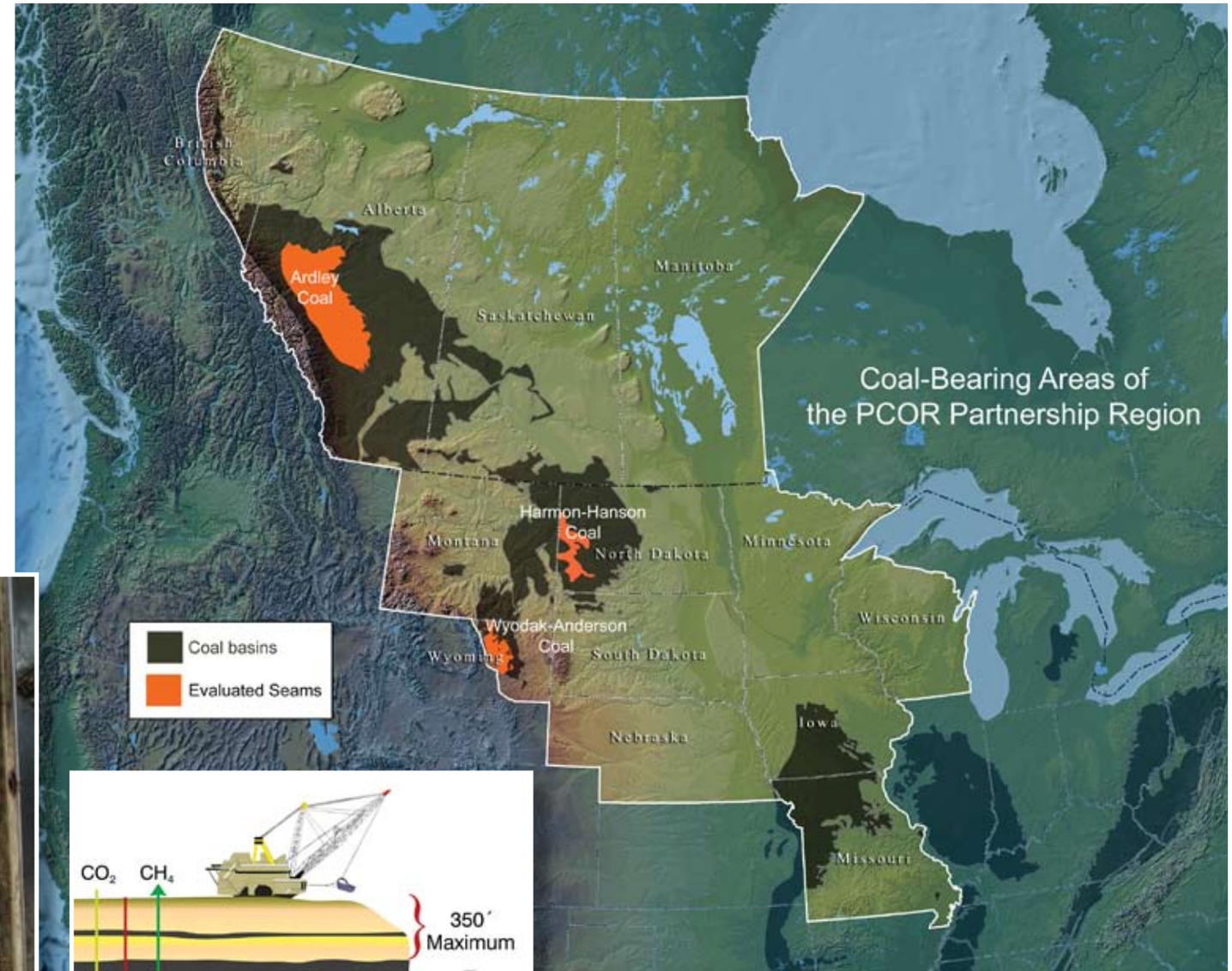
As with oil reservoirs, the initial CBM recovery methods, dewatering and depressurization, can leave methane in the coal seam. Additional CBM recovery can be achieved by sweeping the coal bed with CO_2, which preferentially adsorbs onto the surface of the coal, displacing the methane. For the coals in the PCOR Partnership Region, up to 13 molecules of CO_2 can be adsorbed for each molecule of methane released, thereby providing an excellent storage possibility for CO_2. Just as with depleting oil reservoirs, unmineable coal beds are a good opportunity for CO_2 storage.

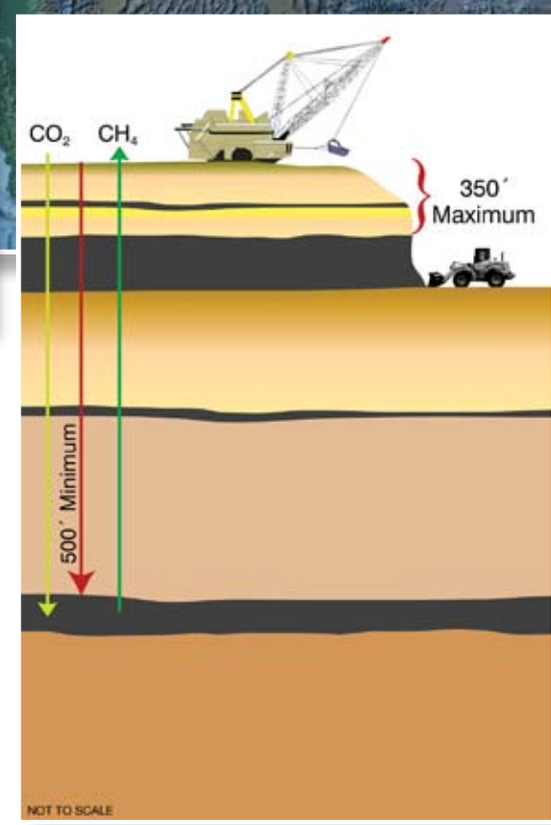
Preparing to take a core sample from a lignite bed in the Williston Basin.

Three major coal horizons in the PCOR Partnership Region have been identified for further study: the Wyodak–Anderson bed in the Powder River Basin, the Harmon–Hanson interval in the Williston Basin, and the Ardley coal zone in the Alberta Basin. The CO_2 sequestration potential estimated for these three coal horizons is approximately 7.3 billion metric tons (8.0 billion tons).

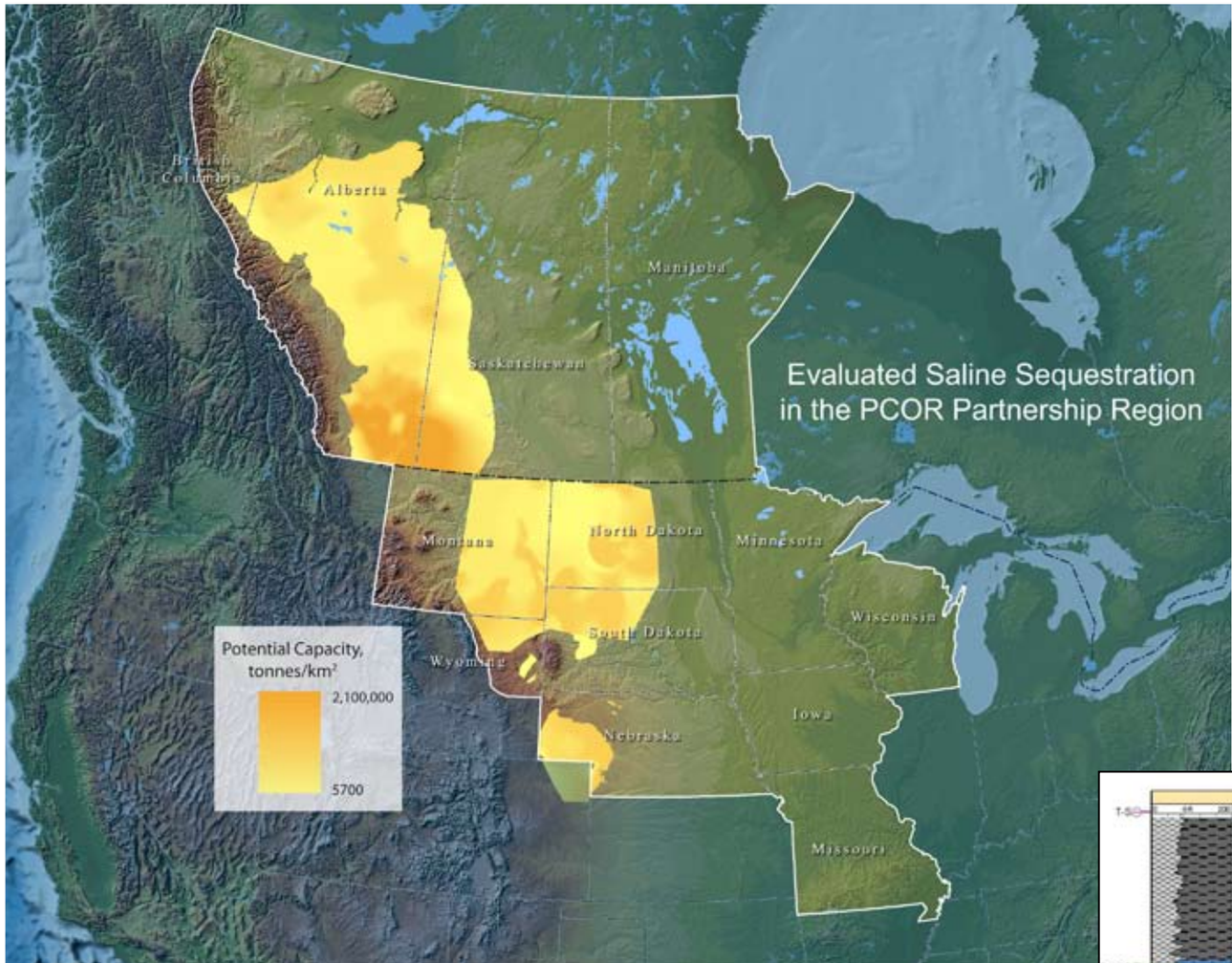
In northeastern Wyoming, the estimated CO_2 sequestration potential for the areas where the coal overburden thickness is > 305 m (1,000 ft) is 6.2 billion metric tons (6.8 billion tons). The coal resources that underlie these deep areas could potentially sequester all of the current annual CO_2 emissions from nearby power plants for the next 156 years.

Current efforts include the Validation Phase site in northwestern North Dakota and collaboration with the Iowa and Missouri Geological Surveys to evaluate the potential for sequestration in the coal seams in the southeastern portion of the PCOR Partnership Region.

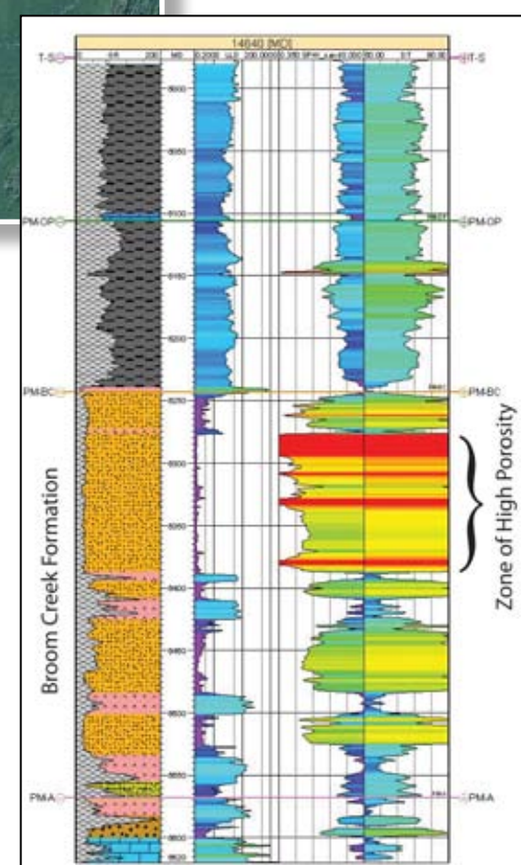




Schematic of enhanced CBM recovery.



Formation	Basin	Estimated CO_2 Capacity, billion tonnes
Lower Cretaceous System		
Newcastle Formation	Williston and Powder River	1
Viking Formation	Alberta	60
Maha Formation	Denver–Julesberg	3
Permian System		
Broom Creek Formation	Williston	5
Mississippian System		
Madison Formation	Williston and Powder River	37



State-of-the-art petrophysical modeling is used to derive resource estimates for multiple saline formations in the Williston Basin. This geophysical well log identifies zones of high porosity in the sands of the Broom Creek Formation at depths between 6,250 and 6,550 feet. These sands are excellent target zones for the injection of CO_2 in west-central North Dakota.

Geologic Sequestration: Deep Saline Formations

Saline formations within the PCOR Partnership Region have the potential to store vast quantities of anthropogenic CO_2. In the earliest phase of the project, two saline formations, the Mississippian Madison and the Lower Cretaceous, were evaluated on a broad regional basis using published data.

More recent efforts have focused on creating higher resolution petrophysical models for a series of four stacked saline formations in west-central North Dakota.

The lateral extent of these formations, the current understanding of their storage potential gained through injection well performance, and the geographic proximity to major CO_2 sources suggest the formations may be suitable storage for future CO_2 sequestration.

Efforts are also under way in cooperation with the Geological Surveys of Minnesota, Missouri, and Iowa to assess saline formation sequestration potential in their respective states.

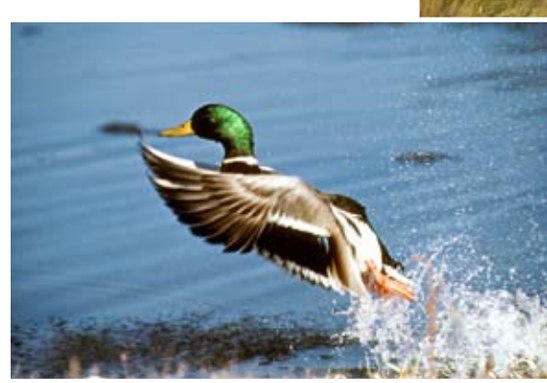
Terrestrial Sequestration

In contrast to geologic sequestration deep within the earth, the concept of terrestrial sequestration focuses on a more natural mechanism of CO_2 storage in vegetation and soils within a few feet of the surface. From the Central Lowlands' forests and cropland in the southeastern portion of the region, through the expansive grasslands and croplands of the northern Great Plains, to the northern boreal forests of Canada, much of the PCOR Partnership Region has a rich agrarian history founded on fertile soils. However, as central North America developed into the pattern of land use seen today, much of the original soil carbon has been lost to the atmosphere. In this setting, the most promising potential to sequester carbon would be to convert marginal agricultural lands and degraded lands back to grasslands, wetlands, and forests when favorable conditions exist.

The PCOR Partnership Region includes the Prairie Pothole Region, a major biogeographical region that encompasses approximately 347,000 mi^2 (899,000 km^2) and includes portions of Iowa, Minnesota, Montana, North Dakota, and South Dakota in the United States and Alberta, Saskatchewan, and Manitoba in Canada. Formed by glacial events, this Region historically was dominated by grasslands interspersed with shallow palustrine wetlands. Prior to European settlement, this Region may have supported more than 48 million acres of wetlands, making it the largest wetland complex in North America. However, fertile soils in this Region resulted in the extensive loss of native wetlands as cultivated agriculture became the dominant land use. Because of oxidation of organic matter by cultivation, agriculture has resulted in the depletion of soil organic carbon (SOC) in wetlands.

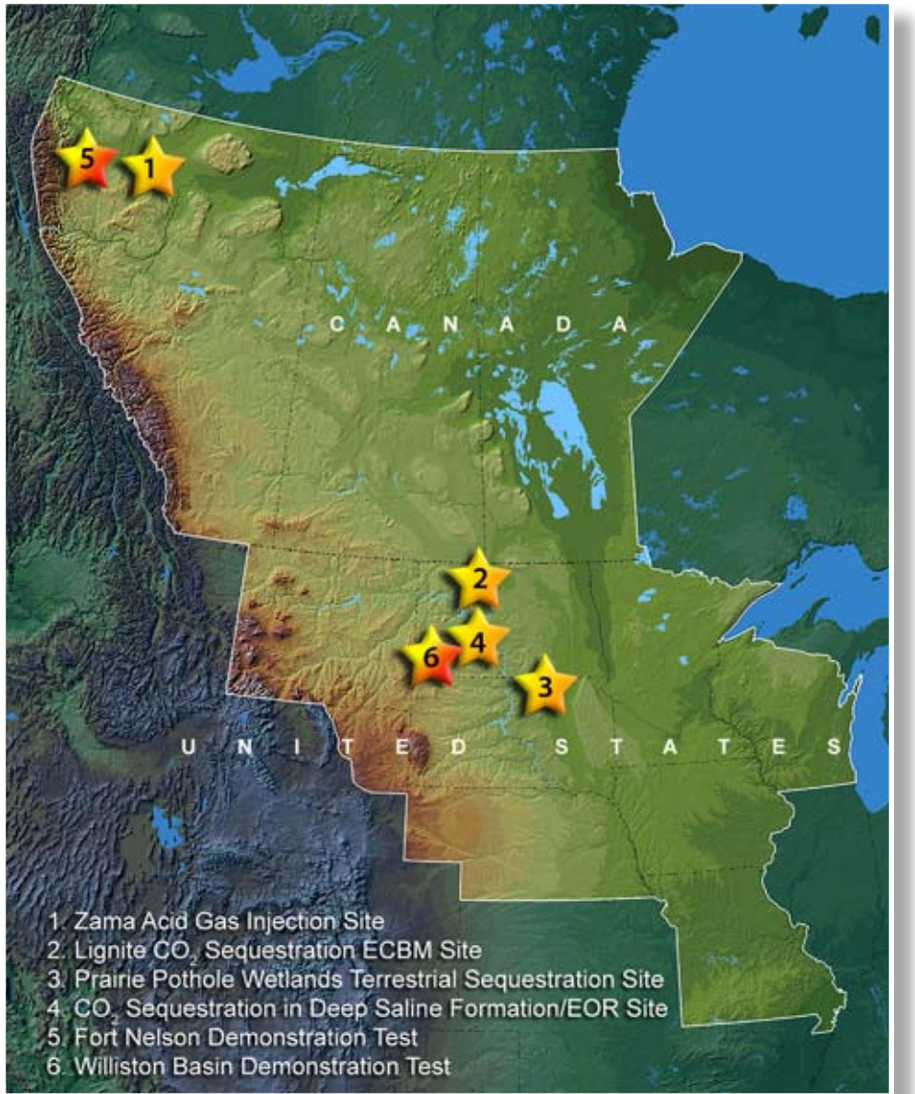
Recently, in PCOR Partnership efforts conducted at wetlands study sites by U.S. Geological Survey and Ducks Unlimited, Inc., scientists demonstrated that restoration of previously farmed wetlands results in the rapid replenishment of SOC lost to cultivation at an average rate of 1 metric ton per acre per year. Restored prairie wetlands and grasslands provide a unique and previously overlooked opportunity to store atmospheric carbon in the PCOR Partnership Region.

Grasslands of Alberta.



Survey of soil organic carbon.

Pothole region of central North Dakota.



Field Validation and Development Sites

Validation Phase

In the fall of 2005, the PCOR Partnership embarked on a 4-year field verification program designed to enhance the local expertise, experience, and working relationships needed to develop and demonstrate practical and environmentally sound sequestration opportunities in the Region. An overall goal of the Validation Phase is to validate the most promising sequestration technologies and infrastructure concepts identified in Characterization Phase activities and to refine the regional characterization efforts started in this Phase. Four field validation tests were developed to test the efficacy of CO_2 sequestration. Results of the activities will include: (1) technical data and reports; (2) television documentaries; (3) enhanced working relationships between government, regulatory, industrial, and citizen groups with respect to CO_2 sequestration; (4) an enhanced assessment of terrestrial and geologic sequestration potential in the region; and (5) an improved assessment of regional economic opportunities with respect to enhanced production of oil and gas resources.

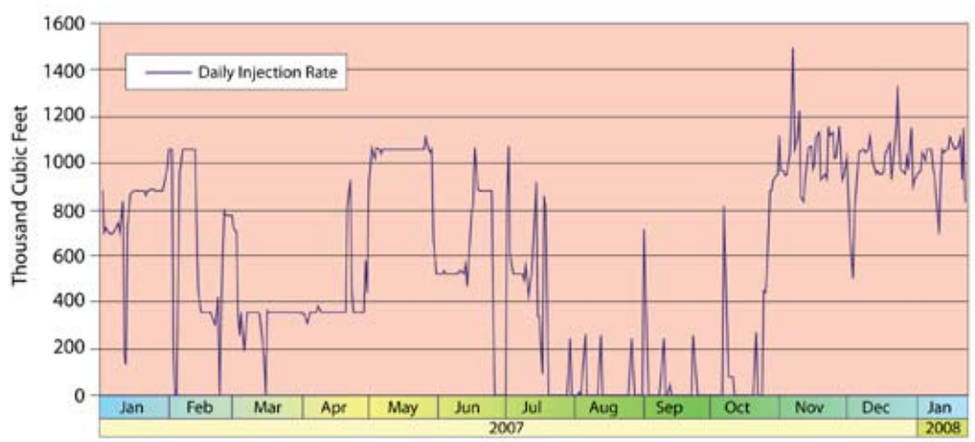
Development Phase

The Development Phase for PCOR Partnership features two commercial-scale demonstrations of geologic sequestration of anthropogenic CO_2. These two demonstrations, the Western Canadian Basin Demonstration in northeastern British Columbia and the Williston Basin Demonstration in western North Dakota, are designed to sequester a total of over 10 million metric tons (11 million tons) of CO_2 by 2017 in deep, well-characterized, underground storage reservoirs. The primary objectives of the Development Phase are (1) to gather characterization data to verify the ability of the target formations to store CO_2, (2) to develop the infrastructure required to transport CO_2 from the source to the injection site, (3) to facilitate development of the rapidly evolving North American regulatory and permitting framework, and (4) to develop a mechanism by which carbon credits can be monetized for CO_2 sequestered in geologic formations.

Validation Phase Field Sites

CO_2-rich Gas in a Pinnacle Reef Structure – The field validation test being conducted in the Zama Field of northern Alberta, Canada, is evaluating the potential for geologic sequestration of CO_2 as part of a gas stream that also includes high concentrations of hydrogen sulfide (H_2S). Acid gas (70% CO_2, 30% H_2S) from the Zama natural-gas-processing plant is being injected at a depth of 1,500 m (4,900 ft) into an oil-producing pinnacle reef structure for the dual purposes of CO_2 sequestration and tertiary EOR. Through January of 2008, the project injected over 10,880 metric tons (12,000 tons) of acid gas and is expected to exceed 54,420 metric tons (60,000 tons) through the project end in 2009.

Results of the Zama activities are providing insight regarding the impact of impurities on formation integrity (i.e., potential seal degradation), MVA techniques, and EOR success within a carbonate reservoir and will be used to create best management practice scenarios for geologic storage applications of this type. In March 2007, the project was recognized by the Carbon Sequestration Leadership Forum (CSLF) as a niche area that will further develop the knowledge base required for large-scale deployment of carbon sequestration.



CO_2 in a Deep Oil Reservoir – CO_2 will be injected into an oil-bearing zone at great depth in an oil field in western North Dakota. The activity will be used to determine the efficacy of CO_2 sequestration and the use of CO_2 to produce additional oil from deep carbonate source rocks. Efforts conducted in this field validation test will facilitate the implementation of the Development Phase Williston Basin demonstration test.

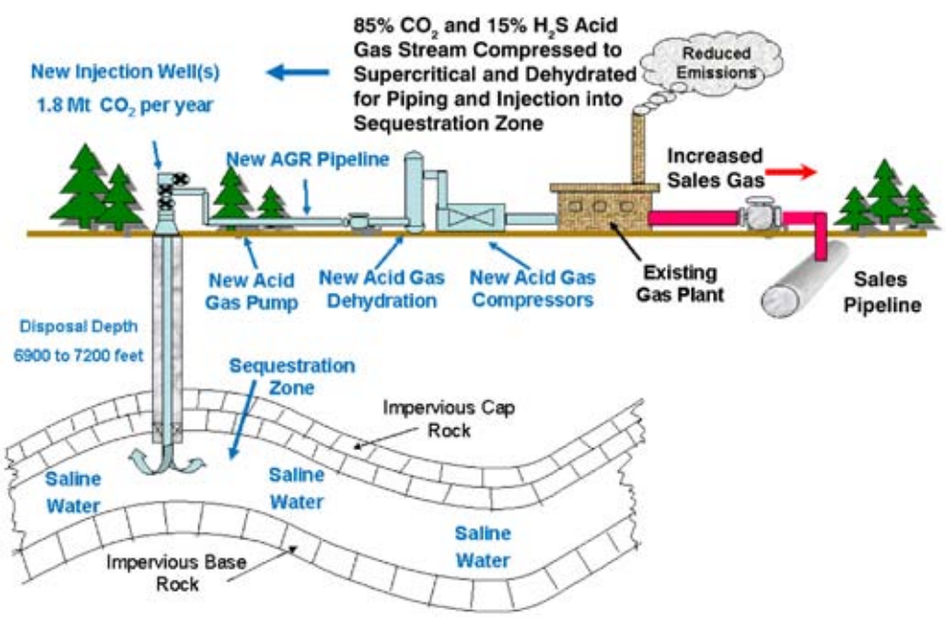
Out of the Air—Into the Soil – As part of the PCOR Partnership Validation Phase Program, Ducks Unlimited, Inc.; the U.S. Geological Survey's Northern Prairie Wildlife Research Center; and North Dakota State University are demonstrating optimal practices for sequestering CO_2 in native, restored, and cropland wetlands and surrounding grasslands at multiple sites located in the PPR. Grasslands and wetlands are being sampled throughout Montana, North and South Dakota, Minnesota, and Iowa. The project results are intended to serve as a model to promote and implement terrestrial sequestration across the PPR. PCOR Partnership is currently providing payments to landowners interested in conveying carbon rights on native grassland and expiring Conservation Reserve Program acres. The accumulated credits from numerous landowners are being transferred to a firm that specializes in marketing carbon credits, which are then sold on the open market.

CO_2 in an Unmineable Lignite Seam – CO_2 will be injected into unmineable lignite seams in northwestern North Dakota. The injected CO_2 is trapped by naturally bonding to the surfaces of the fractured lignite and also has the potential to displace methane occupying the coal fractures. In August 2007, five wells were drilled, and a series of tests were conducted on the wells. Geophysical information on the properties of the subsurface system was collected, and approximately 9 m (30 ft) of rock and coal core samples, ten of which were the primary coal seam of interest, were retrieved from one of the wells. Well development will continue through the summer of 2008, with CO_2 injection slated for early that fall. This validation test will provide valuable information regarding lignite for both CO_2 sequestration and enhanced coalbed methane production.

Development Phase Commercial-Scale Demonstrations

Williston Basin Demonstration

The cost-effective separation of CO_2 from flue gases is a major barrier to the widespread implementation of geologic sequestration at conventional power plants and other large-scale stationary sources of CO_2. The Williston Basin Demonstration will be one of the first large-scale CCS projects utilizing CO_2 from a retrofitted conventional coal-fired power plant. A portion of the flue gas output of Basin Electric Power Cooperative's Antelope Valley Station will be processed to capture its CO_2. This CO_2 will then be dehydrated, compressed to supercritical conditions, and transported about 150 miles (220 km) via pipeline to the sequestration site. The project will benefit economically by utilizing some of the existing compression and pipeline assets at the adjacent Great Plains Synfuels Plant. Once at the sequestration site, the CO_2 will be injected at a depth of nearly 2 miles (approximately 10,000 ft or 3,000 m) into the pore space of an oil reservoir. In the pore space, the CO_2 will dissolve into the oil and allow the oil to flow more easily to the production wells. At the end of economical oil production, most of the purchased CO_2 will remain permanently trapped in the underground reservoir. The demonstration will emplace nearly 1 million metric tons (1.1 million tons) of CO_2 a year. The characterization of the Williston Basin in western North Dakota indicates there are several billion metric tons of additional storage capacity in these types of geologic settings. The primary objective of the PCOR Partnership Development Phase Williston Basin Demonstration is to verify and validate the concept of utilizing the Region's large number of oil fields for large-scale injection of anthropogenic CO_2 for the purposes of EOR leading to permanent CO_2 storage.



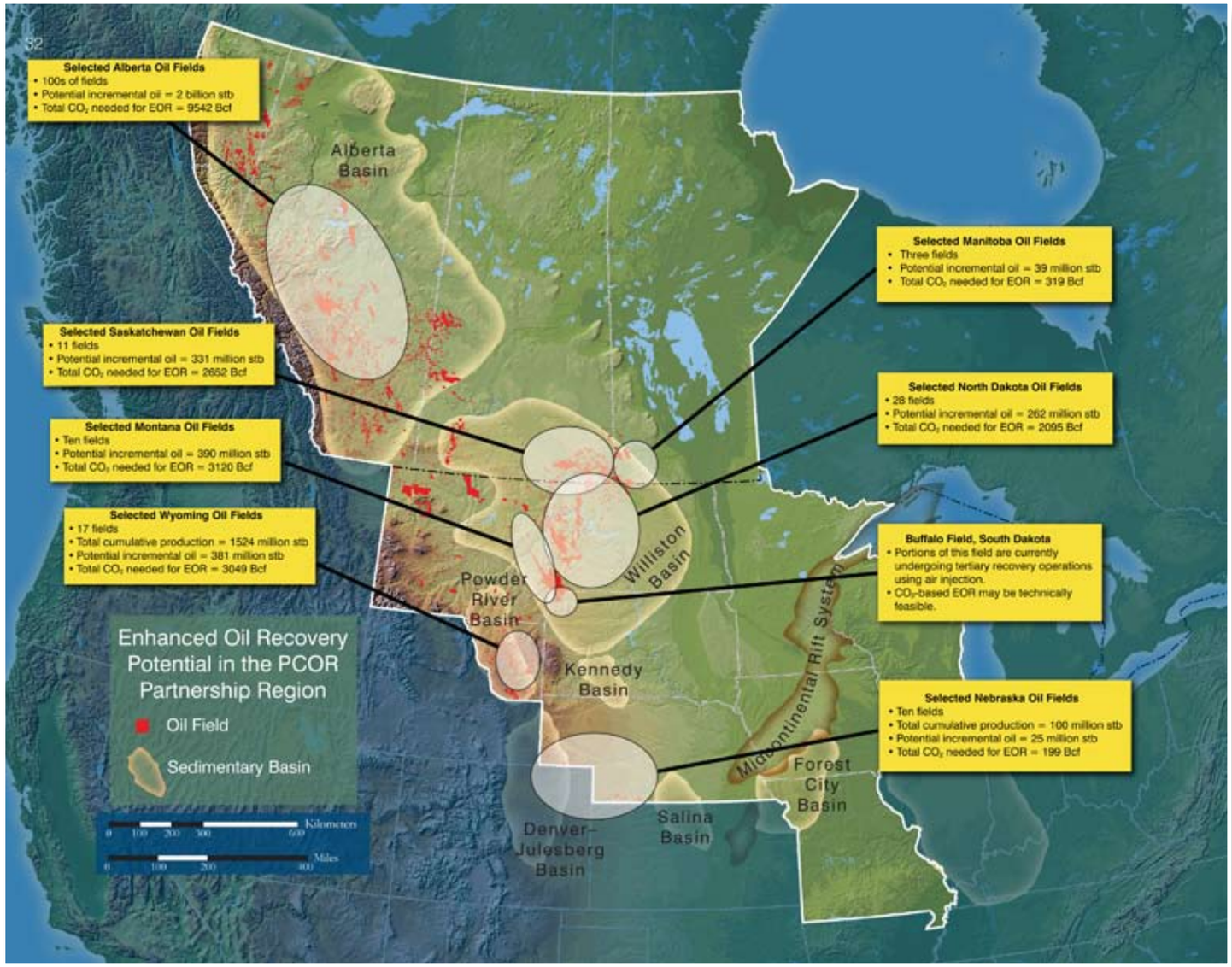
Western Canadian Basin Demonstration

Most geologic sequestration projects are designed to emplace CO_2 into an underground geologic structure, referred to as a trap, which may have previously contained oil or natural gas for millions of years. However, another type of geologic setting, known as a deep brine reservoir, is believed to offer even greater potential for CO_2 storage because of its regionally extensive nature. The Western Canadian Basin Demonstration will be one of the first commercial-scale geologic sequestration projects to emplace CO_2 into a North American brine reservoir. To accomplish this, over 1 million metric tons (1.1 million tons) of CO_2 (85% CO_2, 15% H_2S) produced at an existing gas-processing facility in northeastern British Columbia, Canada, will be compressed to a supercritical state—CO_2 gas will be put under high pressure so that it behaves like a fluid; the pressure is similar to the conditions in the underground geologic injection zone—before being transported via pipeline, approximately 3 miles (5 km) to an injection site. Once at the injection site, the CO_2 will be sent into the ground to a depth of approximately 6,500 ft (2,000 m). There the supercritical CO_2 will be injected into the carbonate rocks (limestone and dolomite) of the Elk Point Group rock formations and dissolve into the highly saline water that fills the pores of the Elk Point Group rocks. Once the CO_2 enters the pores of the carbonate rocks, the naturally high pressure and temperature conditions in the Elk Point Group will maintain the CO_2 in the supercritical state permanently. The injection zone in Elk Point is capped by a substantial shale layer that provides a very competent seal. Other geologic layers, including the thick shales of the Banff Formation, act as seals in the thousands of feet of rock between the top of the Elk Point Group and the base of the zone of drinkable groundwater. Characterization of the geology of the Region has shown many suitable sites for CO_2 storage and capacities exceeding several million metric tons of CO_2 per square mile.

The PCOR Partnership Region is rich in agricultural lands, forests, and wetlands that hold tremendous potential for terrestrial sequestration. The Prairie Pothole Region, which stretches from northwestern Iowa, across the Dakotas, and into Saskatchewan and Alberta, holds promise as an area for terrestrial CO_2 storage. The PCOR Partnership and Ducks Unlimited, Inc., recently announced the creation of a major carbon offset program. The goal of the program is to secure native and planted grasslands, reduce negative impacts on duck and other wildlife habitats, and ensure that existing soil carbon will not be exposed to the atmosphere, helping to mitigate the effects of climate change.

Many of the geologic formations deep beneath a wide area of the Region hold great potential to sequester CO_2. The western half of the Region contains numerous mature oil fields that are well suited for EOR through the injection of CO_2. Enhanced oil recovery has been identified as a means not only to store CO_2 emissions but also to manage CO_2 as a potential value-added product. In an example of a regional government initiative, the province of Alberta recently announced a $2 billion fund to advance projects that include CO_2 capture and EOR.

Aside from the EOR aspect, several areas of the PCOR Partnership Region overlie stacked sequences of prime geologic sequestration targets in saline formations. The arrangement of multiple target zones in close proximity to multiple CO_2 sources enables optimum sequestration potential with minimal transportation constraints. In some cases, key infrastructure is already in place. Examples include the well-known Weyburn sequestration project and the associated CO_2 capture and pipeline infrastructure operated by the Dakota Gasification Company.

Proactive industries in the Region have recently initiated additional capture and sequestration activities. These include Basin Electric's plan to capture over 1 million metric tons (1.1 million tons) of CO_2 annually from the Antelope Valley Station in North Dakota, as well as several others.

Early commercialization opportunities will be realized in meeting existing unmet CO_2 demand for EOR purposes. The potential to recover over 0.5 billion m^3 (3 billion barrels) of incremental oil through EOR will be a strong driver in the commercialization of capture and transportation efforts in the PCOR Partnership Region.