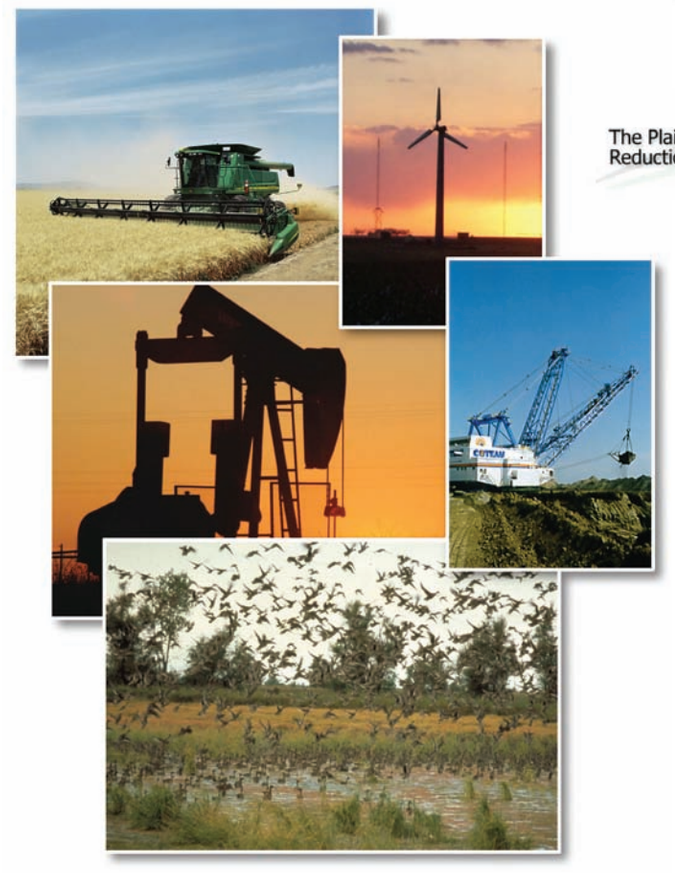


The Plains CO_2 Reduction Partnership

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

The regional characterization activities conducted by the PCOR Partnership confirmed that while numerous large stationary CO_2 sources are available, the Region also has tremendous capacity 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 U.S. 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 that stretches from northwestern Iowa, across the Dakotas, and into Saskatchewan and Alberta holds promise as an area that can be transformed into a significant terrestrial CO_2 sequestration site.

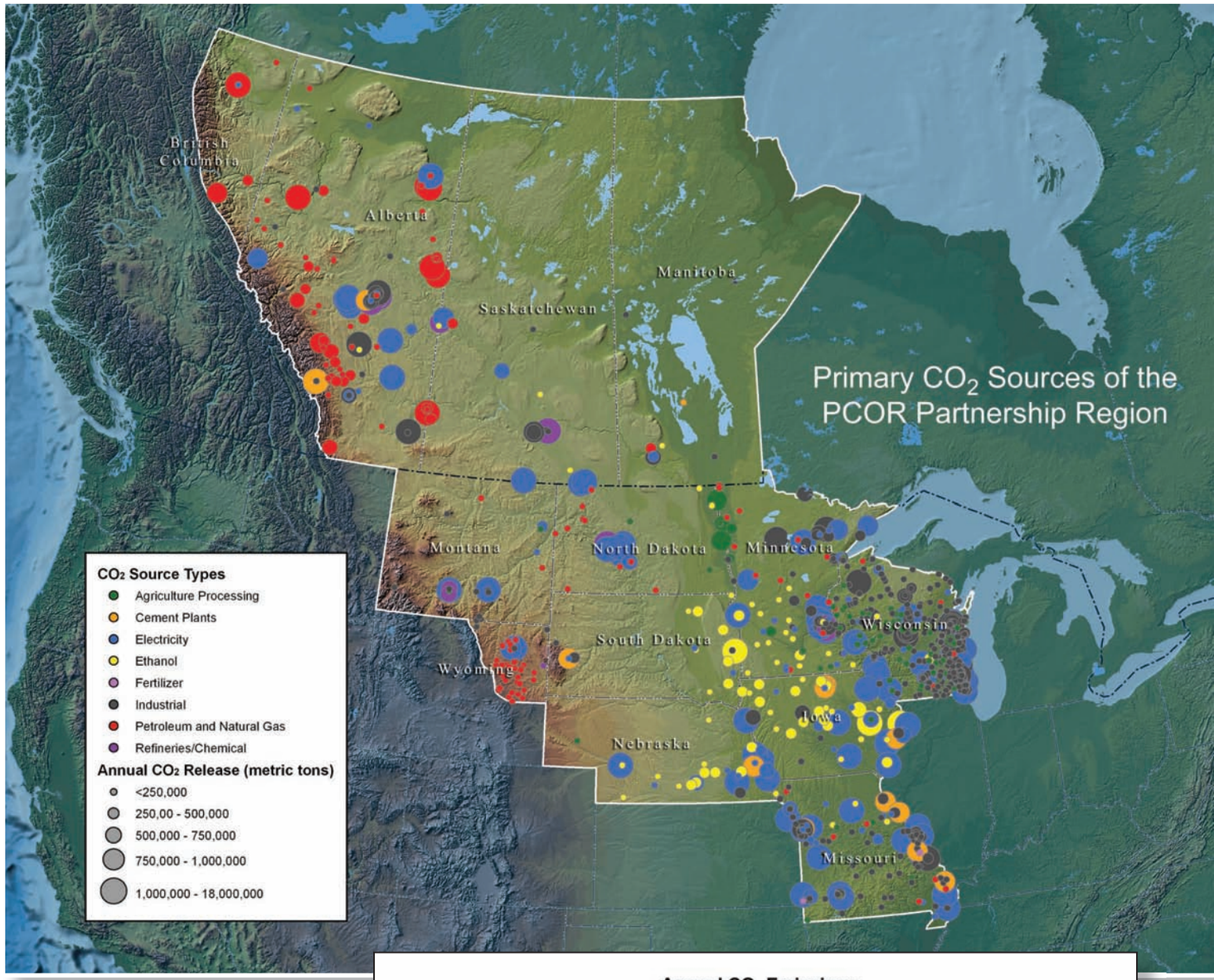
Deep beneath the surface of the Region lay geologic formations that hold tremendous potential to store CO_2. Oil fields, already considered to be capable of sequestering CO_2, can be found in roughly half the Region, while formations of limestone, sandstone, and coal suitable for CO_2 storage exist in basins that, in some cases, extend over thousands of square miles. In many cases, large sources in the Region are proximally located to large-capacity sequestration sites and, in some cases, key infrastructure is already in place.

The PCOR Partnership is a collaboration of more than 60 public- and private-sector stakeholders from the central interior of North America and adjacent areas that have expertise in power generation, energy exploration and production, geology, engineering, the environment, agriculture, forestry, and economics. Our partners are the backbone of the PCOR Partnership and provide data, guidance, and practical experience with direct and indirect sequestration, including value-added projects.

CO_2 Sources in the PCOR Partnership Region

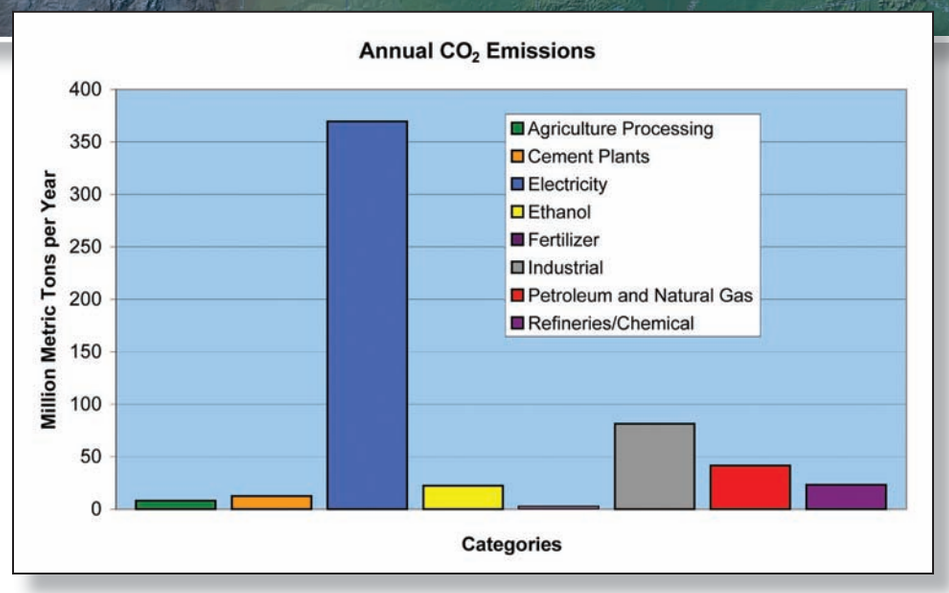
The PCOR Partnership project has identified, quantified, and categorized 1,106 stationary CO_2 sources in the Region. These stationary sources have a combined annual CO_2 output of nearly 505 million metric tons (556 million tons). Although not a target source of CO_2 for direct sequestration, the transportation sector contributes nearly 202 million additional metric tons of CO_2 to the atmosphere every year.

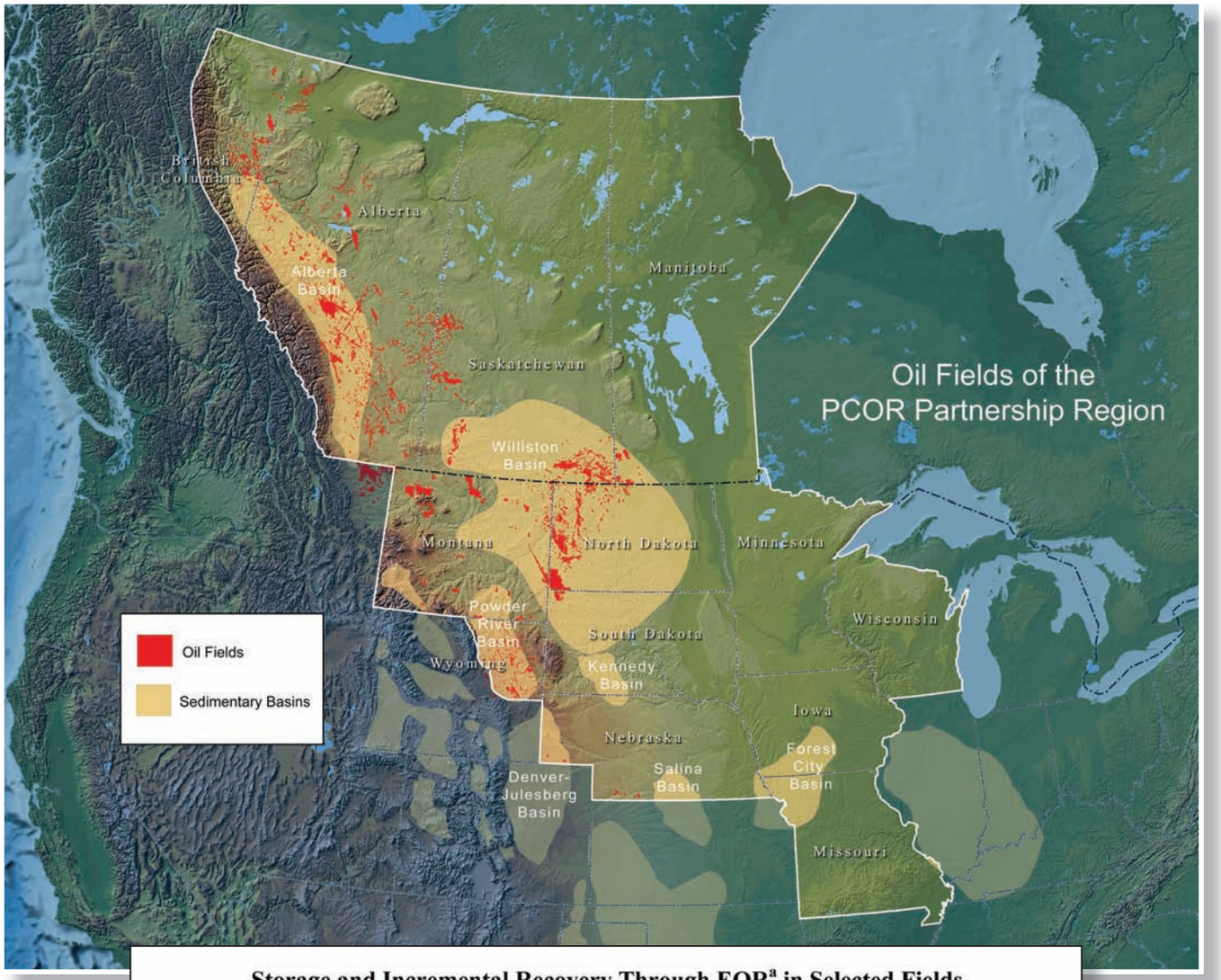
The annual output from the various stationary sources ranges from 9 million to 16 million metric tons (10 million to 18 million tons) for the larger coal-fired electric generation facilities to under 4,500 metric tons (4,960 tons) for industrial and agricultural processing facilities. For the most part, the distribution of the sources with the largest CO_2 output is coincident with the availability of fossil fuel resources, namely, coal 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 and southeastern Wisconsin.



American Crystal Sugar Company plant.

Coal-fired generation plant in North Dakota.





Storage and Incremental Recovery Through EOR[a] in Selected Fields

Basin	Cummulative Incremental Recovery, million stb	CO_2 Required,[b] Bcf	CO_2 Sequestration Potential, Bcf	CO_2 Sequestration Potential, tonnes
Williston	1023	8186	8186	455,223,886
Powder River	381	3049	3049	169,563,509
Denver–Julesberg	25	199	199	11,076,137
Alberta	NA	8888[c]	8888[c]	494,315,000[c]

[a] Enhanced oil recovery.
[b] CO_2 quantity required is the total purchase amount and does not consider recycling of CO_2 from the tertiary recovery operation.
[c] Values for the Alberta Basin were determined using a different methodology than the other basins and, therefore, may not be directly comparable to the other estimates. They are included in the table to provide insight regarding the general magnitude of CO_2 flood-related sequestration capacity and potential incremental oil production in Alberta.

PCOR Partnership Oil Fields

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 sequestration are also the conditions that are conducive to CO_2 sequestration. The three requirements for sequestering hydrocarbons are a hydrocarbon source, a suitable reservoir, and an impermeable trap. These requirements are the same as for sequestering CO_2, except that the source is artificial and the reservoir is referred to as a sequestration site.

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 vary for each 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), 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 760–1,200 m (2,500–4,000 ft) for the shallower pools to 3,700–4,900 m (12,000–16,000 ft) for the deepest pools.

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.

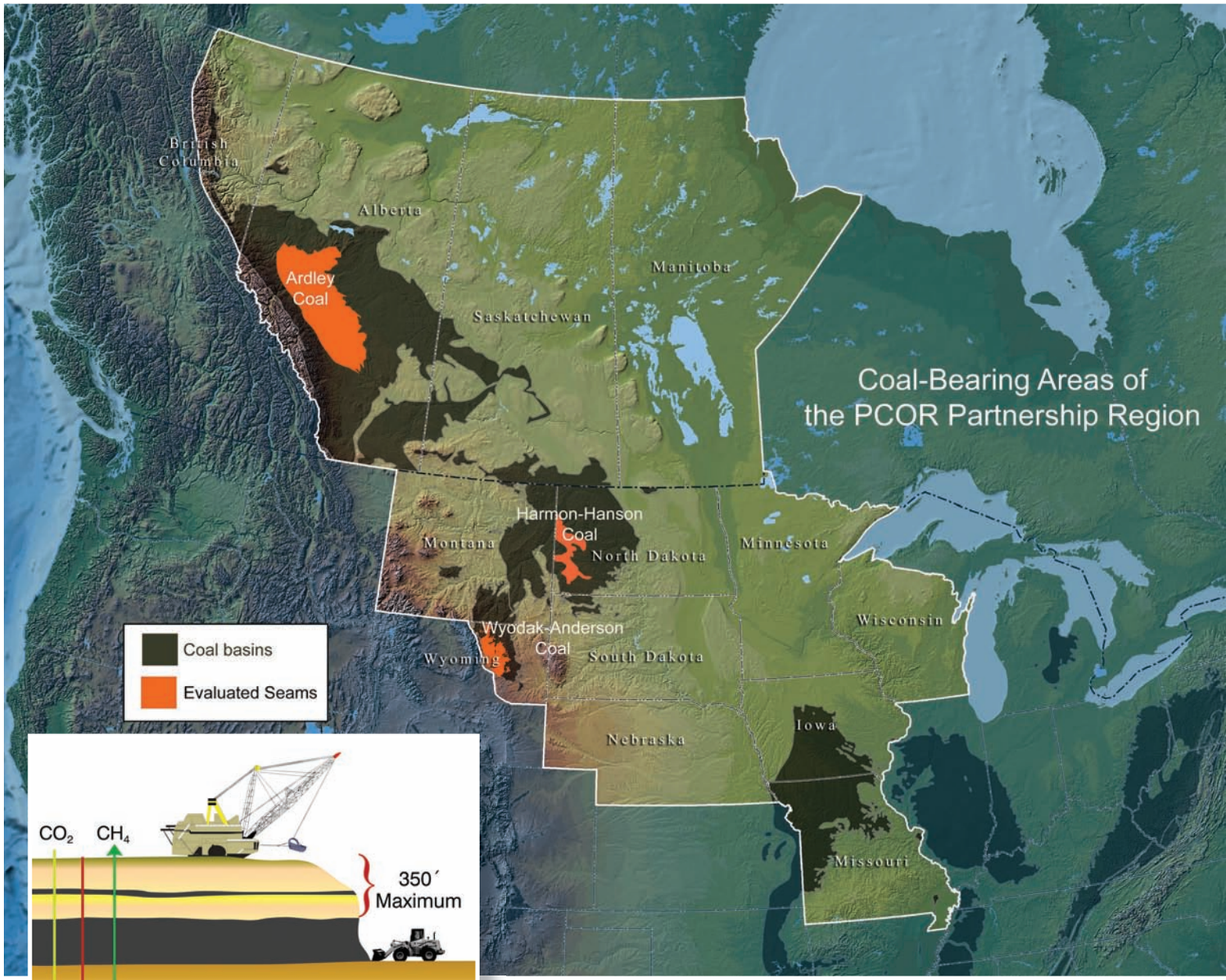
PCOR Partnership Unmineable Coal Seams

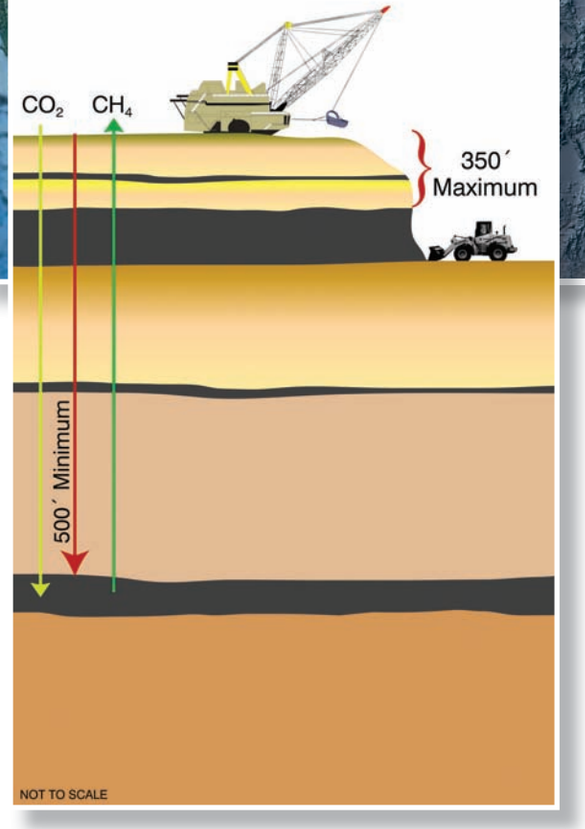
Many coal seams throughout central North America are too deep or too thin to be mined economically. However, many of these coals have varying amounts of methane adsorbed onto pore surfaces, and wells can be drilled into the coal beds to recover this CBM. In fact, CBM is the fastest growing source of natural gas in the U.S. 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, releasing 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 site for CO_2. Just as with depleting oil reservoirs, unmineable coal beds are a good opportunity for CO_2 storage.

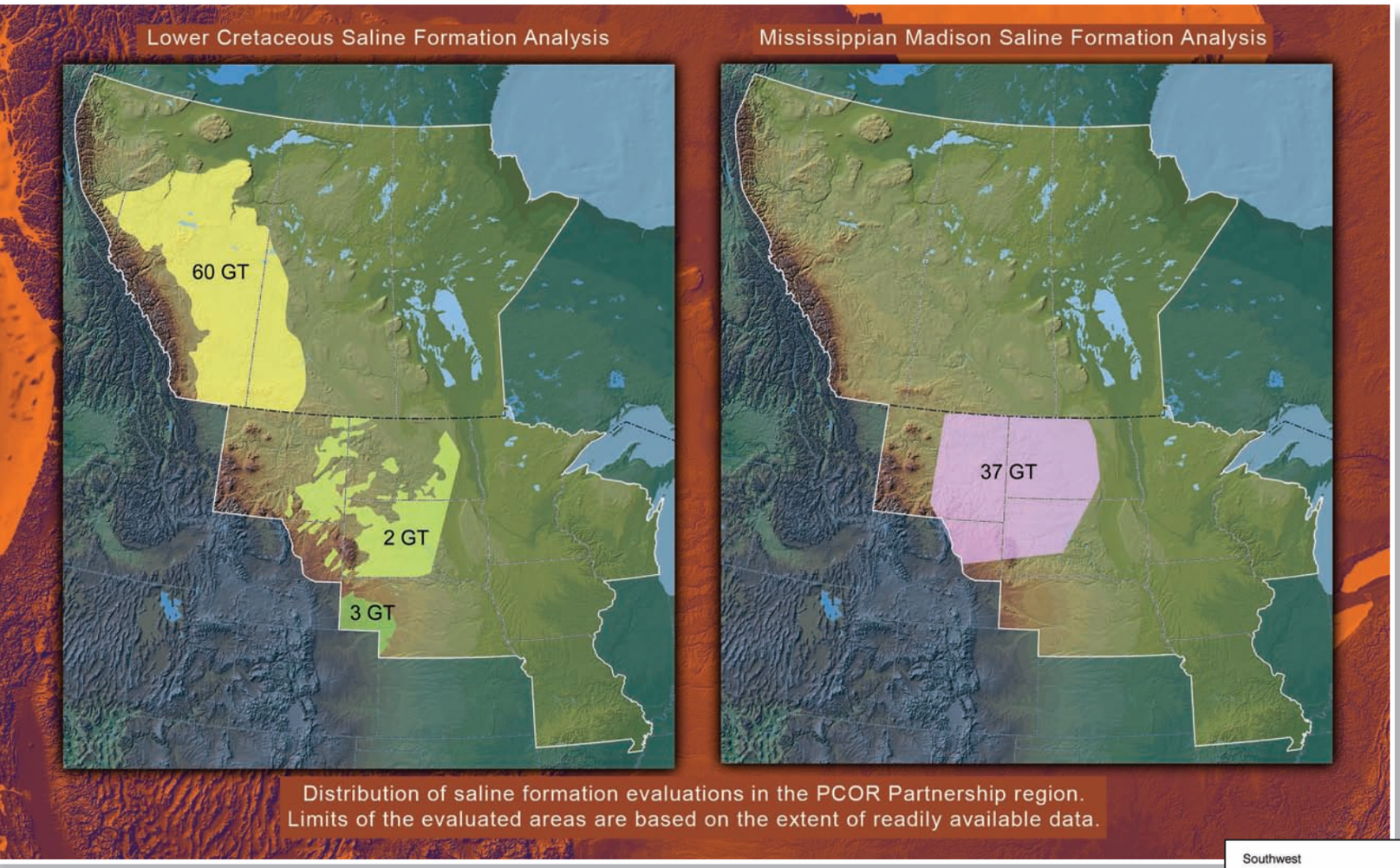
Three major coal horizons in the PCOR Partnership Region have been identified for further study: the Wyodak–Anderson bed in the Powder River Basin, the Harmon–Hanson interval in the Williston Basin, and the Ardley coal zone in the Alberta Basin. The total maximum CO_2 sequestration potential for all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

In northeastern Wyoming, the 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 sequester all of the current annual CO_2 emissions from nearby power plants for approximately the next 150 years.





Schematic of enhanced CBM recovery.



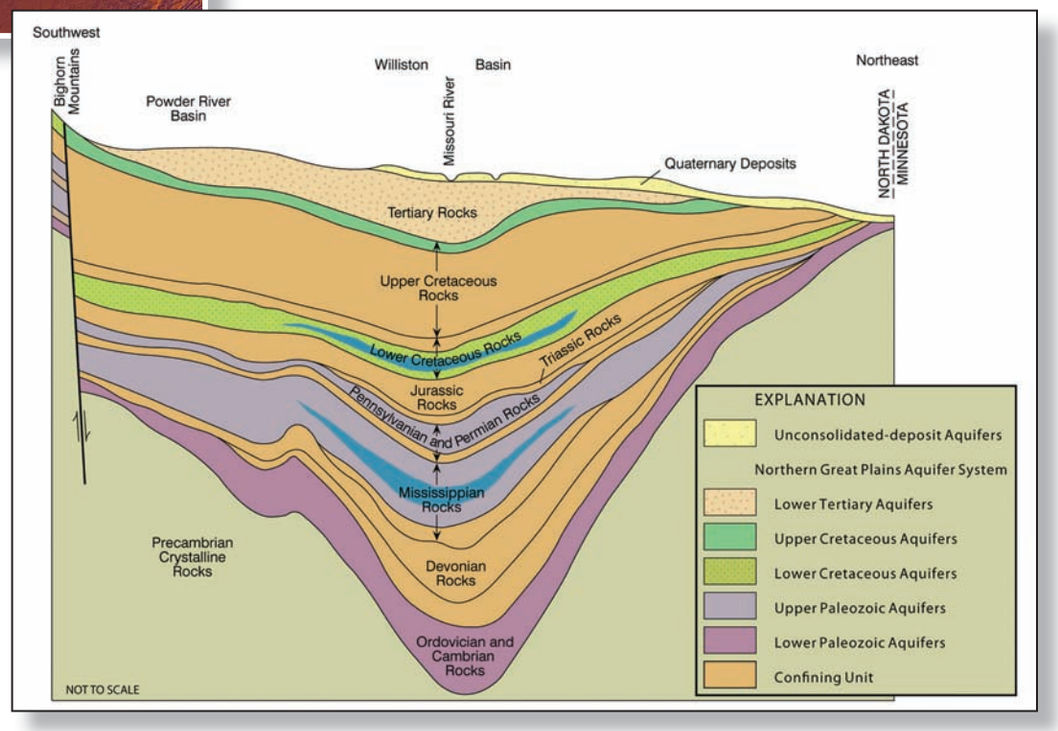
Distribution of saline formation evaluations in the PCOR Partnership region.
Limits of the evaluated areas are based on the extent of readily available data.

PCOR Partnership Deep Saline Formations

Saline formations within the PCOR Partnership Region have the potential to store vast quantities of anthropogenic CO_2. Two saline formations, the Mississippian Madison and the Lower Cretaceous, have been evaluated for their regional continuity, hydrodynamic characteristics, fluid properties, and ultimate storage capacities using published data.

The lateral extent of these reservoirs, the current understanding of their storage potential gained through injection well performance, and the geographic proximity to major CO_2 sources suggest they may be suitable sequestration sites for future storage needs. For example, reconnaissance-level calculations on the Mississippian System in the Williston Basin and Powder River Basin suggest the potential to store upwards of 37 billion metric tons (41 billion tons) of CO_2 over the evaluated Region, while the Cretaceous system has the potential to store over 65 billion metric tons (72 billion tons.)

Formation	Basin	Estimated CO_2 Capacity (billion tonnes)
Lower Cretaceous System		
Newcastle Formation	Williston and Powder River	2
Viking Formation	Alberta	60
Maha Formation	Denver-Julesberg	3
Mississippian System		
Madison Formation	Williston and Powder River	37



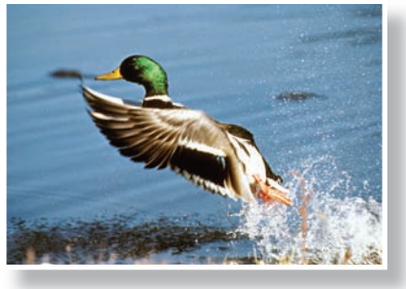
Geologic cross section showing the position of deep saline formations.

PCOR Partnership Terrestrial Sequestration

In contrast to direct sequestration deep within the earth, the concept of terrestrial sequestration focuses on a more passive 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, 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 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 899,000 km^2 (347,000 mi^2) and includes portions of Iowa, Minnesota, Montana, North Dakota, and South Dakota in the U.S. 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 190,000 m2 (73,000 mi^2) of wetlands, making it the largest wetland complex in North America. However, the abundance of fertile soils in this Region heralded 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.

Recent work by U.S. Geological Survey and Ducks Unlimited, Inc., scientists for the PCOR Partnership conducted at wetlands study sites demonstrated that restoration of previously farmed wetlands results in the rapid replenishment of SOC lost to cultivation at an average rate of 250 metric tons/km^2/yr (710 tons/mi^2/yr). Restored prairie wetlands provide a unique and previously overlooked opportunity to store atmospheric carbon in the PCOR Partnership Region.



Prarie pothole region, North Dakota.

Zama Region of Northern Alberta

PCOR Partnership Field Test Sites

CO_2-Rich Gas in a Pinnacle Reef Structure—Acid gas (67 percent CO_2, 33 percent hydrogen sulfide [H_2S]) from natural gas-processing plants in northern Alberta, Canada, is being injected into an oil-producing zone in an underground pinnacle reef structure. Results will help to determine the best practices to support sequestration in these unique geologic structures as well as further our understanding of the effects of H_2S on tertiary oil recovery and CO_2 sequestration.

CO_2 in a Deep Oil Reservoir—CO_2 will be injected into an oil-bearing zone at great depth in the Beaver Lodge oil field in northwestern 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.

CO_2 in an Unminable Lignite Seam—CO_2 will be injected into unminable lignite seams in northwestern North Dakota. The injected CO_2 is trapped by naturally bonding to the surfaces of the fractured lignite. The injected CO_2 also has the potential to displace methane occupying the coal fractures. This validation test will give valuable information regarding lignites for both CO_2 sequestration and enhanced coalbed methane production.

Out of the Air – Into the Soil—A managed wetland will be implemented in north-central South Dakota to demonstrate practices that will improve CO_2 uptake. The results will help to optimize CO_2 storage, MM&V methods and facilitate the monetization of terrestrial carbon offsets in the Region and elsewhere.