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The Plains CO_2 Reduction (PCOR) Partnership: Developing Carbon Management Options for the Central Interior of North America

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Abstract

The Plains CO_2 Reduction (PCOR) Partnership has developed a regional vision for the widespread commercial development of carbon capture and storage (CCS). This regional vision includes several key elements: 1) targeting relatively low-cost anthropogenic CO_2 sources such as gas-processing facilities; 2) employing CO_2-based enhanced oil recovery (EOR) opportunities as initial sink targets whenever the economics and geology are favorable; 3) using the existing oil and gas regulatory structure and agencies for oversight; 4) developing a protocol for the establishment of geologic sequestration units that is based on the standard oil field practice of unitization; 5) developing rigorous site selection criteria that will allow for the adoption of commercially viable monitoring, verification, and accounting (MVA) procedures; 6) developing integrated risk management, MVA, and simulation project plans that continue to evolve as the project progresses and more data become available; and 7) developing the technical information needed for our commercial partners to ultimately monetize carbon credits to reduce the costs of CCS projects. The realization of this vision will result in the development of commercial CCS projects, both saline formation injection and EOR-based opportunities in the PCOR Partnership region, which has very favorable geology and socioeconomic conditions for the widespread adoption of CCS.

Keywords: CO_2, sequestration; PCOR Partnership; carbon capture and storage (CCS); DOE regional partnerships

Introduction

The Plains CO_2 Reduction (PCOR) Partnership is one of seven regional partnerships operating under the U.S. Department of Energy (DOE) National Energy Technology Laboratory Regional Carbon Sequestration Partnership (RCSP) Program. The PCOR Partnership is led by the Energy & Environmental Research Center (EERC) at the University of North Dakota in Grand Forks, North Dakota, and includes stakeholders from both the public and private sectors. The PCOR Partnership region includes all or part of nine states (Iowa, Minnesota, Missouri, Montana, Nebraska, North

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Dakota, South Dakota, Wisconsin, and Wyoming) and four Canadian provinces (Alberta, British Columbia, Manitoba, and Saskatchewan).

The PCOR Partnership was established in the fall of 2003. Phase I focused on characterizing sequestration opportunities in the region. In the fall of 2005, the PCOR Partnership launched its 4-year Phase II program, which focused on carbon storage field validation projects that were designed to develop the regional technical expertise and experience needed to facilitate future large-scale carbon capture and storage (CCS) efforts in the region's subsurface and terrestrial settings. In the fall of 2007, the PCOR Partnership initiated its 10-year Phase III program, which is focused on implementing two commercial-scale geologic carbon sequestration demonstration projects in the region.

The PCOR Partnership is focused on assisting DOE in achieving its goal of "developing, by 2012, fossil fuel conversion systems that offer 90% CO_2 capture with 99% storage permanence at less than 10% increase in the cost of energy service" [1]. To that end, the PCOR Partnership is working with a diverse group of public and private sector stakeholders to establish effective outreach, expand the understanding of CO_2 storage options, facilitate more accurate estimates of CO_2 storage capacity, and establish a regional infrastructure capable of supporting the future deployment of CCS strategies.

Based on assessments of sources, sinks, and deployment issues, i.e, capture and separation technologies and transportation issues, the PCOR Partnership identified four source–sink combinations for further investigation of the geological and terrestrial sequestration potential [2]. Three geologic sequestration projects were identified at the following locations: 1) Zama Keg River F Pool, Alberta, Canada, for the injection of acid gas (70% CO_2 and 30% hydrogen sulfide [H_2S]) from sour gas plants into oil fields for simultaneous sequestration and enhanced oil recovery (EOR); 2) Burke County, Williston Basin, North Dakota, for injection of CO_2 into an economically unminable lignite seam to determine suitability for sequestration and enhanced coalbed methane production; and 3) McGregor oil field in the Williston Basin, North Dakota, for the injection of CO_2 into an oil field in the proximity of an existing CO_2 pipeline for simultaneous sequestration and EOR. A terrestrial sequestration project was identified for the grasslands and wetland catchments within the Prairie Pothole Region (PPR) covering parts of Montana, North and South Dakota, Minnesota, and Iowa [3].

Based on the results of the above-mentioned regional characterization and field validation tests, it was concluded that the PCOR Partnership region has tremendous carbon storage potential [3].

Zama Acid Gas Injection Site, Alberta, Canada

The primary objective of the Zama Field Validation Test was to demonstrate the safe and cost-effective injection of acid gas into a partially depleted oil field for the simultaneous purposes of a) acid gas disposal, b) CO_2 sequestration, and c) EOR. The reservoirs in the Zama oil field exist in the form of isolated, porous, and permeable pinnacle reefs (carbonate rocks) sealed by a thick layer of essentially impermeable anhydrite. The depth from surface to the pinnacles is typically about 1500 m [4].

The injection process and subsequent hydrocarbon recovery were carried out by Apache Canada, Ltd., while the EERC conducted monitoring, verification, and accounting (MVA) activities at the site with as little disruption to the ongoing oil production as possible. The MVA activities were designed in such a way as to be cost-effective while still providing critical data on the behavior and fate of the acid gas mixture. In March 2007, the Zama project was nominated by the United States and Canada for recognition by the Carbon Sequestration Leadership Forum (CSLF) as an official geological CO_2 sequestration project [5]. Established in 2003, the CSLF is an international climate change initiative that is focused on development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage.

Through August 30, 2009, a cumulative total of over 22.65 million m^3 of acid gas was injected into the F Pool, equating to approximately 18,000 net metric tons of CO_2 stored. Oil was being produced at an average rate of 100 barrels a day, with a total of 25,000 barrels of oil produced from this pinnacle [3]. The transportation of high concentrations of acid gas through pipelines has been safely and cost-effectively conducted for decades, especially in western Canada where a network of thousands of wells and gathering lines has produced and moved trillions of cubic feet of methane and acid gas throughout Alberta and British Columbia for several decades [6]. Key conclusions from the Zama Field Validation Test included that the injection of acid gas into the pinnacle reefs of the Zama Keg River Formation is a safe operation and an effective EOR technique [4]. It was determined that the acid gas will be confined to the injection horizon by the reef structures that originally trapped the oil and gas. There is minimal potential for acid gas leakage through faults and fractures in the Zama area or for acid gas migration to shallower strata, potable groundwater, or the surface as a result of flow through naturally occurring permeability streaks or flow paths. The MVA activities at Zama suggest that the Zama Field and other pinnacle reef complexes are worthy of consideration as commercial CO_2 storage locations [3].

Currently, over 800 pinnacle reefs are known to be in the Zama subbasin of the Western Canadian Sedimentary Basin. Hundreds of similar pinnacle reefs are also known to occur in the Williston Basin, Michigan Basin, and Illinois Basin, as well as other basins throughout the world [7]. The geological and hydrogeological studies conducted at Zama provide supporting documentation that pinnacle reefs can be suitable and even excellent sites for CCS [8].

Lignite CO_2 Sequestration Enhanced Coalbed Methane Site, Burke County, North Dakota, Williston Basin.

The overall objective of this validation test was to demonstrate the ability to sequester CO_2 in economically unminable lignite seams while simultaneously investigating the potential for CO_2-enhanced coalbed methane production. The test consisted of laboratory- and field-based investigations [3]. The selection of the demonstration test site was driven by a number of technical factors, i.e., review of geophysical logs from the North Dakota Industrial Commission Oil and Gas Division database, and nontechnical factors, i.e., the availability of mineral rights. Initial reservoir characterization at the study site was conducted using data available from the literature. The reservoir characteristics estimated from these data served as the basis for the planning of the CO_2 injection and the subsequent MVA activities at the study site [9].

In August 2007, five wells were drilled in a modified five-spot configuration within a 64.75-hectare spacing unit. Approximately 80 metric tons of CO_2 was injected over a roughly 2-week period into a 3- to 3.5-m-thick coal seam at a depth of approximately 335 m. A total of nine distinct phases of CO_2 injection were employed in an attempt to maximize the rate of CO_2 injection into the formation. Although the short durations of these individual injection phases made it difficult to reach any firm conclusions, the data did suggest that some improvements in injection rates could be achieved by heating the CO_2 and injecting it in a purely gaseous state at fairly high pressures [3]. Of the MVA techniques utilized, reservoir saturation tool (RST) logs and time-lapse crosswell seismic tomography provided the most valuable information, demonstrating that the CO_2 did not significantly move away from the wellbore and was contained within the coal seam for the duration of the approximately 3-month monitoring period [10].

The demonstration test determined that the coal formation was significantly underpressurized, with an actual reservoir pressure of about 2.4 MPa absolute versus an expected formation pressure of approximately 3.2 MPa absolute. Uplift and erosion are the likely mechanisms of underpressure in the targeted coal seam, particularly given that Williston Basin studies have indicated that evidence exists for uplift and erosion in many formations [11]. The underpressurized nature of the reservoir may be a reason for the low methane content observed in this coal seam. The validation test affirmed that CO_2 can be safely injected and stored in an unminable lignite seam; however, the feasibility of recovering methane was not demonstrated because of the very low methane content measured [3].

Williston Basin CO_2 Huff 'n' Puff Field Validation Test

Regional characterization conducted by the PCOR Partnership indicated that Williston Basin oil fields may have the capacity to store over 453.6 million metric tons of CO_2 as part of CO_2 flood EOR operations [12] and that Williston Basin oil fields may have over 1.2 billion barrels of incremental oil that could be produced from these operations [13]. Oil is produced in the Williston Basin from at least a dozen rock formations at depths ranging from about 900 m on the northeast margin to greater than 4200 m near the basin center. The CO_2-based EOR operations at the Weyburn and Midale Fields in Saskatchewan are good examples of economically and technically successful injection of CO_2 for simultaneous EOR and sequestration. However, the depths of injection and, therefore, reservoir conditions in those fields are relatively shallow (ca. 1400 m) and not necessarily representative of many large Williston Basin oil fields. The primary goals of the PCOR Partnership Williston Basin Field Validation Test were to evaluate the CO_2 sequestration potential of deep carbonate reservoirs and to investigate the effectiveness of CO_2 for EOR and sequestration in oil fields at depths greater than 2400 m. To achieve that goal, a CO_2 huff 'n' puff (HnP) test was conducted in a producing oil well from an interval of the Mississippian age Madison Group at a depth of approximately 2450 m in the Northwest McGregor oil field in Williams County, North Dakota [3]. A CO_2-based HnP operation is a well stimulation or EOR technique that is typically conducted on a single well that is not part of a secondary or tertiary oil recovery operation. CO_2-based HnP operations have been conducted globally at hundreds of individual well locations, and there is a wealth of published information on the effectiveness of this technique for the stimulation of mature wells in a variety of reservoir settings [14]. Over the course of a typical HnP operation, the producing oil well will be put through three phases: injection, soak, and production [15].

During the Williston Basin test, nearly 400 metric tons of CO_2 were injected into a single well and allowed to "soak" for 2 weeks, after which the well was put back onto production. Unique elements of the Northwest McGregor Mission Canyon reservoir, as compared to other HnP operations in the literature, include the following: 1) at a depth of 2450 m, it would be among the deepest; 2) pressure (20 MPa gauge) and temperature (82°C) would be among the highest; and 3) most HnPs in the literature are in clastic reservoirs, while the Northwest McGregor Mission Canyon reservoir is a carbonate reservoir. Monitoring activities focused on the near-reservoir environment, including monitoring for leakage through cap rock, migration away from the intended zone of influence within the reservoir, and wellbore leakage. In addition, shallow groundwater wells in the vicinity of the Northwest McGregor HnP test were tested before injection, during the operational phase of the project, and at the end of the project performance period to ensure that the CO_2 injection program did not impact local groundwater resources [3]. The results of the RST and VSP (vertical seismic profiling) indicated that the CO_2 penetrated approximately 90 m horizontally and as much as 30 m vertically into the reservoir. Productivity of the oil well was observed to more than double over the course of a 3-month production period. The results of the field demonstration indicate that CO_2-based HnP operations may be a viable option for EOR in deep carbonate oil reservoirs [16].

Creation of Geologic Sequestration Units

The development of carbon credit markets for geologic sequestration will require a framework for accounting for injected CO_2 that is based on detailed characterization data, sound engineering design, and an equitable legal and regulatory process. Such a system has already been established in the oil field unitization process under which the U.S. petroleum industry currently operates. Over the course of evaluating more than 1900 oil pools, three coal beds, and two saline aquifer systems throughout the region, it became apparent that although each one of the three types of geologic targets generally uses different mechanisms for CO_2 sequestration (for example, dissolution into oil versus dissolution into saline water versus adsorption onto coal), they have several properties in common that may dictate the conditions under which large-scale injection of CO_2 can be conducted. For instance, all three types of targets must have competent seals and other trapping mechanisms. Application of an existing unitization process that has been modified to address issues unique to geologic sequestration can facilitate the implementation of geologic sequestration projects and, ultimately, the monetization of credits derived from such projects [17]. Although many challenges must be addressed before geologic sequestration unitization processes can be established, the fact that hundreds of millions of tons of CO_2 have been safely injected into unitized oil fields as part of tertiary oil recovery operations in Texas, New Mexico, and Canada [18, 19] provides support to the validity of applying the oil field unitization model to establishing geologic sequestration units. We believe that developing geologic sequestration units would prove a valuable construct for establishing a legal and regulatory framework for CCS.

Prairie Pothole Region Wetlands Sequestration Site

The objective of the PCOR Partnership Terrestrial Field Validation Test was to develop the technical capacity to systematically identify, develop, and apply alternate land-use management practices for greenhouse gas (GHG) reductions in the PPR at both local and regional scales. Terrestrial sequestration is the process of removing carbon dioxide from the atmosphere by plants via photosynthesis and storing the carbon in biomass and soils. Terrestrial carbon sequestration projects offer an immediate and potentially cost-effective strategy to reduce atmospheric emissions while other methods, i.e., geologic sequestration, are advanced [20].

The diversity of landscapes and land uses in the PCOR Partnership region offers many opportunities for terrestrial carbon sequestration. Geographic information system and empirical data were compiled to determine sample location, distribution, and strata within the region. Seven monitoring sites, located in Montana, Minnesota, Iowa, North Dakota, and South Dakota, were identified for characterization. A total of 2850 grassland samples were collected, covering approximately 58 km^2 [3]. Three restored, three native, and three cropland wetlands located in north-central South Dakota were also monitored. These wetland sites were instrumented to monitor fluxes of GHG emissions (i.e., CO_2, CH_4, N_2O) from the wetlands themselves and surrounding uplands following standard protocols developed by the U.S. Geological Survey Northern Prairie Wildlife Research Center [21].

Initial research conducted by the PCOR Partnership has found wetlands to be significant terrestrial sinks and a large potential source of emissions if exposed to cultivation [22]. In much of the PCOR Partnership area, grass-based economies dominate the landscape with activities such as haying and grazing to support livestock production. Research has shown that haying and grazing activities can continue without detrimentally impacting soil carbon sequestration rates or storage [23].

The region has many opportunities to benefit from carbon market finance. Based on information developed in this test, approximately 178,000 metric tons of native grassland carbon offsets were generated in the PCOR Partnership region and sold in September 2008 [3].

Development Phase – Large-Scale Commercial Projects

The PCOR Partnership is building on the information generated in its Characterization and Validation Phases toward an overall RCSP primary objective of the development of large-scale (approximately 900,000 million metric tons of CO_2) CCS projects, which will demonstrate that large volumes of CO_2 can be injected safely, permanently, and economically into geologic formations representative of large storage capacity [24]. The PCOR Partnership is working toward the establishment of two demonstration sites: 1) in the Bell Creek oil field in Powder River County in southeastern Montana and 2) situated near Spectra Energy's Fort Nelson gas-processing facility, Fort Nelson, British Columbia, Canada. The PCOR Partnership's objectives for the demonstration projects are as follows: 1) conduct a successful field demonstration to verify that the region's large number of oil fields have the potential to store significant quantities of CO_2 in a safe, economical, and environmentally responsible manner and 2) conduct a successful demonstration to verify the economic feasibility of using the region's carbonate saline formations for safe, long-term CO_2 storage. During this phase, the PCOR Partnership will continue to refine storage resource estimates and evaluate other factors relevant to regional storage goals.

The Fort Nelson Plant is one of the largest sour gas-processing plants in North America and processes gas from an extensive network of approximately 1000 km of gathering pipelines servicing the Horn River producing basin. The sour CO_2 (approximately 90% CO_2 and 10% H_2S) developed by this process will be pipelined a short distance to a storage site. If determined feasible, the Fort Nelson project plans to inject up to 1.8 million metric tons of sour CO_2 (mixture of CO_2 and H_2S) a year into a saline formation deep underground. The sour CO_2 will be compressed and transported approximately 15 km in a supercritical state via pipeline to the target injection location. The target zone is the Devonian age Elk Point carbonate rock (limestone and dolomite) formation located in relatively close proximity to the gas plant at a depth of >2200 m. In October 2009, the Fort Nelson project was recognized by CSLF at its London ministerial meeting [25].

In a second large-scale project, the PCOR Partnership is developing a robust and practical MVA, risk management, and simulation project associated with commercial-scale injection of CO_2 for the purpose of simultaneous EOR and storage of CO_2. The project, which will be conducted in the Bell Creek oil field in Powder River County, southeastern Montana, will provide insight regarding the impact of miscible CO_2-flood tertiary recovery on oil production and successful CO_2 storage within a sandstone reservoir in the Cretaceous Muddy Formation. The Bell Creek project will be a significant opportunity to develop a set of cost-effective MVA protocols for large-scale CO_2 storage associated with an EOR operation.

Conclusion

The PCOR Partnership region has tremendous carbon storage potential. Tertiary-phase EOR, where CO_2 storage and EOR are simultaneously achieved, represents the primary near-term opportunity for storing CO_2 in the region, so much so that the regional EOR demand for CO_2 exceeds the near-term supply. The PCOR Partnership region includes hundreds of large stationary sources of CO_2, many of which are located in close proximity (within 160 km) to oil fields that are suitable for CO_2-based EOR operations. The size of the potential oil resource in the PCOR Partnership region that may be associated with CO_2-based EOR is over 3.4 billion barrels of oil [26]. At a price of US$70/barrel, this resource could have a value over US$238 billion. These economics provide a substantial incentive to develop large-scale CCS/EOR projects for some of those close-proximity sources [3]. Once the EOR opportunities are exhausted, substantial saline formation capacities that are both stratigraphically and geographically proximal can be utilized. This staged approach has the added advantage of being accompanied by significant economic incentives, which have the potential to drive large-scale deployment of this carbon sequestration strategy. Work conducted by the PCOR Partnership has demonstrated that the central interior region of North America has significant potential for commercial-scale CCS.

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Disclaimer

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