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Abstract Submission

THE PLAINS CO_2 REDUCTION (PCOR) PARTNERSHIP GEOLOGIC CO_2 SEQUESTRATION APPROACH – DEMONSTRATING THE TECHNICAL AND COMMERCIAL VIABILITY OF THIS EMERGING TECHNOLOGY

TOPIC: Global Climate Change: Science, Sequestration, and Utilization

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Abstract
The Plains CO_2 Reduction (PCOR) Partnership is one of seven regional partnerships established by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) to assess carbon sequestration opportunities that exist nationwide. The PCOR Partnership covers an area of over 1.4 million square miles in the central interior of North America and includes all or part of nine states and four Canadian provinces. The central interior of North America contains several seismically stable intracratonic geologic basins that are ideal sinks for geologic CO_2 sequestration. These basins have been well characterized because of commercial oil and gas activities. The geologic characteristics of the oil and gas reservoirs offer significant opportunities for developing the expertise and infrastructure required to make geologic CO_2 sequestration a commercial reality while maintaining and even enhancing the regional economy.

The coal-fired electrical utilities in the region produce over 60% of the CO_2 emissions from stationary sources. With the distinct possibility of carbon management becoming more important in the future, industries that rely on fossil fuels are looking towards CO_2 sequestration as a strategy for carbon management. Further, many of the region's oil fields could develop CO_2-based enhanced oil recovery (EOR) projects with increased availability of CO_2. These situations make the PCOR Partnership region a prime area for CO_2 sequestration demonstrations and projects. PCOR Partnership activities include four CO_2 sequestration field tests. Three of the tests combine sequestration and enhanced resource recovery, while an additional test is based on terrestrial sequestration. All of the tests are aimed at monetizing carbon credits and developing long-term industrial projects.

The PCOR Partnership has developed a regional vision for the widespread commercial development of CO_2 sequestration. The vision includes several key elements: 1) targeting tertiary EOR opportunities, 2) employing the existing oil and gas regulatory structure and agencies for oversight, 3) developing a protocol for the establishment of geologic sequestration units (GSUs) that is based on the standard oil-field practice of unitization, 4) developing rigorous site selection criteria that will allow for the adoption of commercially viable measuring, monitoring, and verification (MMV) procedures, and 5) coordination of MMV procedures with oil and gas sampling requirements already in place, wherever possible. This strategy will first allow for the development of EOR-based opportunities, to be followed by nonresource recovery-based sequestration when the EOR opportunities have been exhausted.

PCOR Partnership Regional Vision

The PCOR Partnership is one of seven regional partnerships established by the DOE NETL to assess carbon sequestration opportunities that exist nationwide. The PCOR Partnership covers an area of over 1.4 million square miles in the central interior of North America and includes all or part of nine states and four Canadian provinces. The central interior of North America contains several seismically stable intracratonic geologic basins that are ideal sinks for geologic CO_2 sequestration. These basins have been well characterized because of commercial oil and gas activities. The geologic characteristics of the oil and gas reservoirs offer significant opportunities for developing the expertise and infrastructure required to make geologic CO_2 sequestration a commercial reality while maintaining and even enhancing the regional economy.

The PCOR Partnership region is rich in relatively deep, aerially-extensive, and seismically-stable sedimentary basins (see Figure 1) that lend themselves to geologic sequestration. These basins are home to extensive deep saline formations, commercial deposits of coal, oil and natural gas that serve as ideal CO_2 sequestration targets. The rich agricultural lands, forests and wetlands provide an ideal setting for the development of terrestrial sequestration opportunities. Further, the sparse population and socioeconomic conditions mean that in many cases CO_2 sequestration activities can develop over the short term with widespread public support. The PCOR Partnership has developed a regional vision for carbon management that includes significant commercial-scale CO_2 sequestration and the potential for the region to become a world-leader in this emerging technology.

The PCOR Partnership vision of widespread commercial application of CO_2 sequestration relies on the development of more cost-effective CO_2 capture technologies form anthropogenic sources and a network of pipelines with multiple gathering and distribution legs to transport the CO_2 from major stationary sources to the enhanced resource recovery and sequestration sites (see Figure 2). Coal-fired electrical utilities dominate the CO_2 emissions from stationary sources (see Figure 3). And as such are the primary capture and sequestration targets. In many cases the coal-fired power plants are located proximal to the coal deposits and sequestration opportunities.

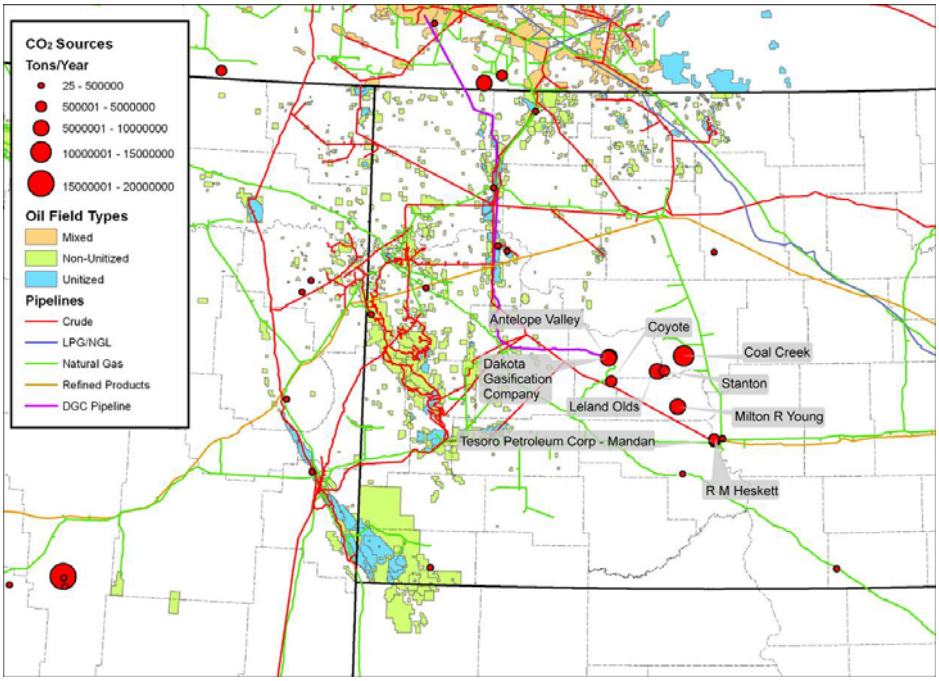

Figure 1. Need caption.

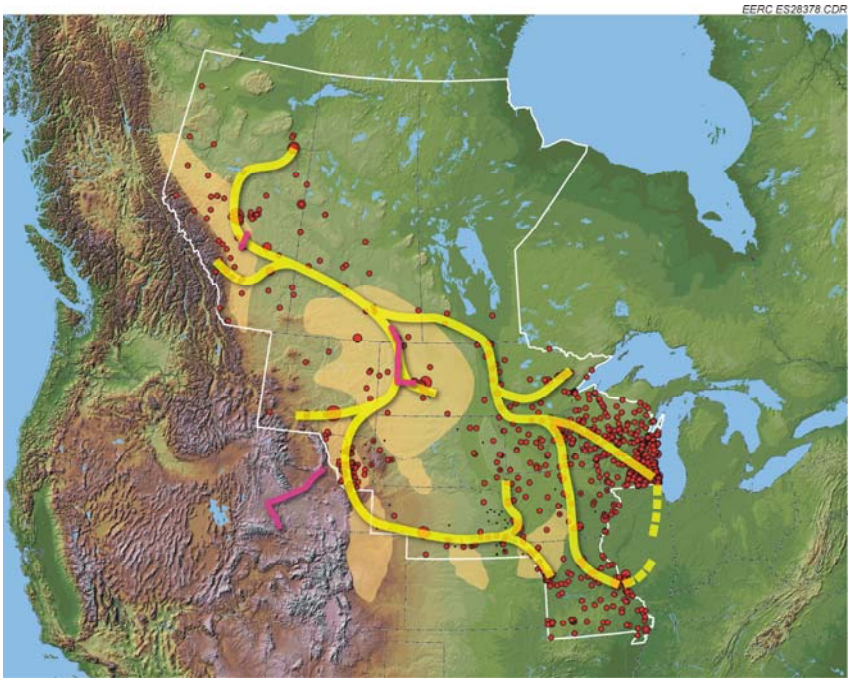

Figure 2. PCOR Partnership general vision of CO_2 pipeline infrastructure that may develop in a carbon-managed future.

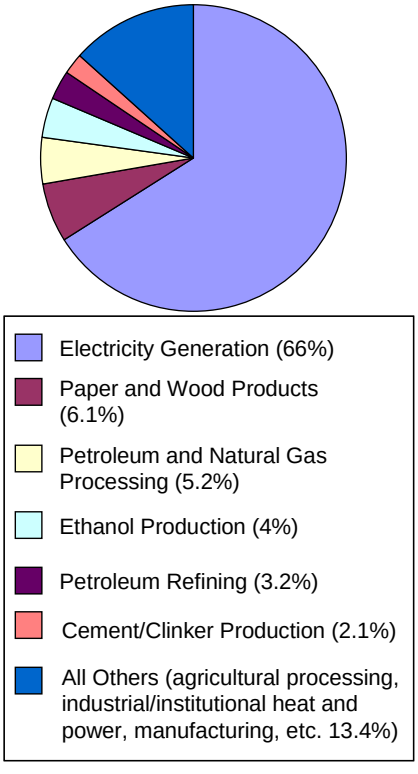

Figure 3. Need caption

CO_2-Based EOR Opportunities in the Williston Basin

The Williston Basin is a deep, seismically-stable sedimentary basin with multiple stacked CO_2 sequestration targets including lignite deposits, oil reservoirs, and saline formations. The oil fields of the Williston Basin are mature with many of the fields having already undergone primary recovery and decades of secondary recovery. Many of the fields exhibit the characteristics that point towards the opportunity for commercial success utilizing CO_2-based tertiary recovery methods. Unlike the Permian Basin in Texas, which has seen the successful application of CO_2-based EOR for over three decades, there is no ready natural source of CO_2 within economically feasible distances and in sufficient quantities. This situation has led the oil producers in the region to look towards anthropogenic sources of CO_2 for EOR applications.

The major factor holding back the further development of EOR Opportunities in the region is the lack of readily available CO_2. Most industrial sources of CO_2 can not afford to capture their CO_2 emissions under current economic conditions and the lack of infrastructure and regulatory uncertainties have meant that the Weyburn and Midale operations stand alone as EOR opportunities in the Williston Basin. This situation is likely to change as the global focus on global warming and the potential role of anthropogenic emissions has pointed towards the need to reduce CO_2 emissions. The Kyoto protocol and more recently, local, state, and pending federal legislation with regards to reducing green house gas (GHG) emissions, especially CO_2, have resulted in a focus on developing economical means of capturing and sequestering CO_2 from major stationary sources. In the PCOR Partnership vision, the revenues and expertise gained by the development of commercial CO_2-based EOR opportunities will facilitate a regional system of CO_2 capture, compression, piping, and injection that will eventually serve to sequester the CO_2 long after EOR opportunities have been depleted.

The PCOR Partnership has completed a basin-wide assessment of the EOR and sequestration potential in the Williston Basin. Table 1 shows the calculated EOR potential and sequestration capacities for selected unitized oil fields in the Williston Basin while Figure 4 illustrates the locations of these select fields and the potential sources of CO_2 from coal-fired power plants.

Where data was available, Williston Basin oil fields were evaluated with respect to the potential incremental oil recovery and subsequent CO_2 storage capacity resulting from EOR..

The oil fields were also evaluated for their potential capacities for non-EOR-related CO_2 sequestration. The maximum storage potential for each field was calculated based largely on the pore volume of the reservoir that can be filled with CO_2. The twenty North Dakota pools that were evaluated have the potential to hold approximately 2.1 billion tons of CO_2, based on the non-EOR CO_2 sequestration method. This volume represents over 40 years of the current cumulative CO_2 emissions from 25 source facilities.

The PCOR Partnership region is home to a commercial EOR operation that is using anthropogenic CO_2. The Weyburn commercial EOR operation is using CO_2 captured at the Dakota Gasification facility in Beulah, North Dakota for an EOR operation over 200 miles to the northwest in Weyburn Saskatchewan. While the Weyburn EOR Operation is primarily focused on profiting from the EOR, there is a significant amount of CO_2 sequestration occurring incidental to the commercial operations. Approximately 5000 tonnes of CO_2 per year are being transported to Weyburn and it is estimated that at the close of commercial operations a total of approximately 20 million tonnes of CO_2 will be injected into the reservoir at Weyburn (Petroleum Technology Research Centre, 2004). The success of the Weyburn project is such that it is being expanded to include the near-by Midale oil field.

The Weyburn project has also been host to a major international research project that is investigating the technical and economic feasibility of CO_2 sequestration. The Weyburn project is a working model of how the PCOR Partnership envisions Carbon Capture and Storage (CCS) proceeding in our region. The abundant EOR opportunities allow for the development of significant CCS expertise and infrastructure with the commercial proceeds helping to defray the costs. Further when CO_2 is treated as a commodity and used in commercial operations many of the regulatory and liability risks are reduced or eliminated.

Regulatory Oversight of CO_2 Sequestration and Geologic Sequestration Units

The search for ideal CO_2 sequestration targets is akin to the search for oil and gas deposits (Fischer et al., 2005). In both cases one is looking for strata with the capacity and geometry that will trap fluids in the subsurface over long periods of time. Thus the stratagraphic and hydrodynamic trapping mechanisms that result in commercial deposits of

Table 1. North Dakota Unitized Pools and Their Potential for CO_2 EOR and CO_2 Storage Capacity (based on the amounts of OOIP)

NDIC Unit Name	NDIC Pool Unitized	NDIC Estimated OOIP, million stb	CO_2 Oil Recovery at 12% NDIC OOIP, million stb	CO_2 Needed Using 8 Mcf/bbl Oil Recovered, Bcf	Potential CO_2 Storage, Bcf	Potential CO_2 Storage, million tons
Cedar Hills South	Red River 'B'	360	43	346	346	21
Tioga	Madison	216	26	207	207	13
Beaver Lodge	Madison	172	21	165	165	10
Big Stick	Madison	166	20	159	159	10
Fryburg	Heath–Madison	155	19	149	149	9
Beaver Lodge	Devonian	139	17	133	133	8
Antelope	Madison	100	12	96	96	6
Newburg	Spearfish–Charles	96	12	92	92	6
Wiley	Glenburn	96	12	92	92	5
Blue Buttes	Madison	93	11	89	89	5
Charlson North	Madison	80	10	77	77	5
Rival	Madison	79	9	76	76	5
Dickinson	Heath	62	7	59	59	4
Medora	Heath–Madison	58	7	56	56	3
North Elkhorn Ranch	Madison	56	7	53	53	3
Beaver Lodge	Silurian	34	4	33	33	2
Lignite	Madison	33	4	31	31	2
Rough Rider East	Madison	31	4	30	30	2
Clear Creek	Madison	27	3	26	26	2
Fryburg South	Tyler	22	3	21	21	1
Knutson	Madison	19	2	18	18	1
Beaver Lodge	Ordovician	18	2	18	18	1
Antelope	Devonian	16	2	16	16	1
Mohall	Madison	15	2	15	15	1
Bear Creek	Duperow	14	2	13	13	1
Charlson South	Madison	10	1	9	9	1
Tracy Mountain	Tyler	9	1	9	9	0.5
Landa	Madison	8	1	8	8	0.5
Total Potential Storage in Selected Units					**2095**	**128**

** Figure 4 – Wes has this-the latest basin map with mid-continent rift. NEED TO GET FROM HIM**

oil and gas are also those that will successfully trap CO_2. Further, the existing regulations and regulatory bodies that oversee oil and gas operations at the state level have the knowledge, databases and regulations that can be readily modified to accommodate CO_2 sequestration. The PCOR Partnership is working with the Interstate Oil and Gas Compact Commission Task force to develop practical regulatory guidelines that will facilitate the commercial application of CO_2 sequestration while ensuring that the public and environment are safeguarded.

The widespread commercial application of CO_2 sequestration will require a formal process to coordinate injection activities and to address the regulatory, legal, and technical issues (Sorensen et al., in publication). The issues associated with sequestration parallel those associated with the production of oil and gas in oil pools. This process that has been established to address these issues in oil and gas production areas is commonly referred to as "unitization". The PCOR Partnership has been promoting the idea of establishing a standardized process that will formalize the legal and regulatory procedures required to inject large volumes of CO_2 into the subsurface. The term GSU has been suggested as a means of referring to this formalized injection target areas. While there are still a number of legal, technical and regulatory issues to sort out, the GSU terminology and approach should prove useful to those looking to establish guidelines for sequestration. As carbon management becomes more important the unitization approach to CO_2 sequestration and the use of GSUs may prove a valuable tool especially when one considers the monetization of carbon credits (Sorensen et al., in publication).

CO_2 Sequestration Site Selection Criteria and Commercially Focused MMV

CCS is an emerging technology and although there are several examples of commercial EOR operations most CCS projects currently operating are demonstration activities with research objectives taking precedent over commercial operations. Since the research community is operating most of these tests the MMV associated with them has been designed to meet research, not commercial objectives. Typically the research approach to MMV is to incorporate every methodology that the research budget allows. While this may be appropriate for research, commercial operations take quite the opposite approach and seek to develop MMV strategies that provide adequate data for safety and to document permanence for monetization purposes. While the research MMV approach typically assumes that leakage is likely to occur, the commercial approach is to very judiciously pick sites for which the chances of leakage is extremely unlikely and provide minimal MMV that will confirm predictions made during the site selection process. Unnecessarily elaborate MMV schemes are likely to be too expensive to implement, especially when one considers that periodic verification of the permanence may have to take place over decades or more.

Successful implementation of the PCOR Partnership's commercially-focused MMV approach relies on very careful sequestration site selection. Site selection must include a detailed characterization of the sequestration target strata, caprock, and other surrounding strata. Table 1 provides a summary of the characterization data needed to determine the suitability of a sequestration targets.

An example of the PCOR Partnership's commercially focused MMV strategy has been developed in cooperation with Apache Canada Ltd. for the Zama Acid Gas injection field validation test. Both CO_2 and hydrogen sulfide (H_2S) are co produced with solution gas and non-associated natural gas from pinnacle reef structures of the Zama Field. Treatment for downstream marketing results in the production of an acid gas by-product stream largely composed of CO_2 and H_2S. In the past, a portion of this acid gas, not disposed of in underground formations, was processed to convert the H_2S to elemental sulfur. The CO_2 from this portion of the acid gas was then vented to the atmosphere.

Apache Canada Ltd. is providing the acid gas and the injection wells for the demonstration and will be responsible for initial injection, continual recovery and re-injection of acid gas during the demonstration, separation and recovery of the produced hydrocarbons, and monitoring after the demonstration phase. The Energy & Environmental Research Center will plan and implement the MMV procedures that will provide a road map for the development of further CO_2 and acid gas injection projects. The geology of the pinnacle reef (Figure 2) is well understood and offers an excellent opportunity to test and refine geologic CO_2 sequestration MMV protocols that can be applied to CO_2 and acid gas sequestration opportunities in the future.

Since Apache Canada Ltd. is required to do periodic testing and analysis by the Alberta Energy and Utilities Board the PCOR Partnership team established an MMV strategy that took advantage of this required testing during operations. The samples provided by the required testing (see Figure 5) were found to be adequate for MMV purposes if a few modifications to the analysis were added. For example a tracer is being introduced into the injectate as a means of monitoring any potential leakage that may occur. The tracer strategy was adopted since the injected CO_2/H_2S mixture is produced from the very formations into which it is being injected. This means that isotope ratios and other more standard methodologies for leak detection will not work since the origin of any CO_2 detected at depth would be impossible to discern with out the addition of the tracer.

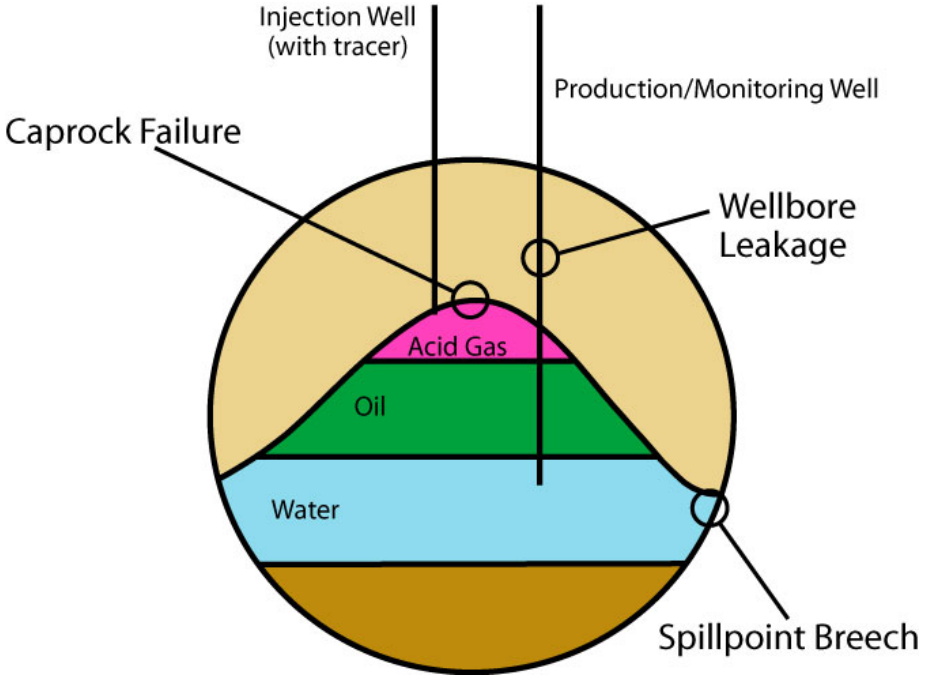

Figure 5. Needs caption.

MMV Operations

The following techniques will be employed over the course of the 4-year project to monitor the effects of acid gas injection at the Zama field demonstration site. The preinjection state of each of these parameters will be determined either by currently available data or field activities to acquire new data:

1. To monitor the CO_2/H_2S plume:
   - Reservoir pressure monitoring
   - Wellhead and formation fluid sampling (oil, water, gas)
   - Geochemical changes identified in observation or production wells

2. To provide early warning of storage reservoir failure:
   - Injection well and reservoir pressure monitoring
   - Pressure and geochemical monitoring of overlying formations

3. To monitor CO_2 concentrations and fluxes at the ground surface:
   - Monitoring for natural and/or introduced tracers (likely H_2S)

4. To monitor injection well condition, flow rates, and pressures:
   - Wellhead pressure gauges
   - Well integrity tests
   - Wellbore annulus pressure measurements

- Surface H_2S measured near injector points and high-risk areas

5. To monitor solubility and mineral trapping:
   - Formation fluid sampling using wellhead or deep well concentrations of CO_2
   - Major ion chemistry and isotopes
   - Monitoring for natural and/or introduced tracers

6. To monitor for leakage up faults or fractures:
   - Reservoir and aquifer pressure monitoring

Conclusions

The PCOR Partnership is working to achieve a regional approach to CO_2 sequestration that draws on the existing regulatory framework, expertise, and economic drivers of the oil and gas companies. Judicious site selection, the establishment of geologic sequestration units, and the implementation of practical cost-effective MMV strategies are all key elements to making this regional vision a reality. In this vision, the EOR opportunities would be exploited fist followed by non-resource recover sequestration in the future. The region has a large demand for CO_2 for EOR applications. The sedimentary basins have huge sequestration capacities often with stacked sequestration targets. The PCOR Partnership region is likely to play a major role in the establishment of CCS as a commercial technology because of a combination of favorable geology and socioeconomic conditions.

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