Plains CO_2 Reduction (PCOR) Partnership Monthly Update
September 1–30, 2017

PHASE III ACTIVITIES

Task 1 – Regional Characterization (Wesley D. Peck)

Highlights

- Submitted Deliverable (D) 1 entitled "Review of Source Attributes," and received approval on September 27, 2017.
- Received approval for D81 entitled "PCOR Partnership Atlas Update" on September 28, 2017. The PCOR Partnership Atlas, 5th Edition Revised, will be available on the public Web site and the partners-only Decision Support System (DSS) Web site. At this time, there is no plan to print hard copies.
- Continued preparing files from the 2015 PCOR Partnership Annual Membership Meeting for the page on the PCOR Partnership partners-only DSS Web site.
- Continued activities to update the content of the **PCOR Partnership general database**, including the following:
  - Updated North Dakota, South Dakota, Montana, Wyoming, Manitoba, and Saskatchewan well information.
  - Continued database preventive maintenance of Petra projects.
- Continued work on regional models, including collecting input data for the Gooseneck Field and extracting the field history production data for history matching.
- With regard to **Williston Basin** CO_2 Storage Sink Relative Permeability Laboratory Characterization:
  - Modified the value-added report based on internal review.
- With regard to the **Aquistore** project's static modeling and dynamic predictive simulations effort:
  - Attended Petroleum Technology Research Centre's (PTRC's) Aquistore Project 2017 Annual General Meeting held September 12–13, 2017, in Ottawa, Ontario, Canada. Presented a poster entitled "Updated Numerical Modeling and Simulation Study of the Aquistore CO_2 Storage Project." Presented as part of the Modeling Panel Discussion and Question and Answer Session.
  - Received comments from PTRC on draft D93 – Geological Modeling and Simulation Report for the Aquistore Project, on September 15, 2017. D93 will be revised based on PTRC's comments and submitted to the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) by the October 31, 2017, due date.
  - Downloaded and processed injection and pressure data through September 5, 2017.
  - Reprocessed field data to create clean data set for simulation purposes.

Task 2 – Public Outreach and Education (Daniel J. Daly)

Highlights

- Presented a screening of the draft Documentary D22 (Coal Powered) to approximately 60 Energy & Environmental Research Center (EERC) staff members on September 12, 2017, over the lunch hour. Solicited comments from staff members.
- Reviewed draft video clips from Documentary D21 entitled "The Bell Creek Story – CO_2 in Action" for use on the PCOR Partnership Web site.
- Prepared text for an update to the Phase III PCOR Partnership General Fact Sheet (D14).
- Worked on updates to the Bell Creek Test Site Fact Sheet (D15).
- Prepared text for a value-added documentary flyer.
- Participated in the monthly Outreach Working Group (OWG) conference call on September 21, 2017.
- Continued work on the PCOR Partnership public Web site, including content updates and preparation for Web site format on the following pages:
  - Home page
  - CO_2 Sequestration Projects
  - Carbon and CO_2 on Earth – Things Have Changed!

Task 3 – Permitting and NEPA (National Environmental Policy Act) Compliance (Charles D. Gorecki)

Highlights

- Attended the Wyoming Petroleum Section of the Society of Petroleum Engineers (SPE) meeting and met with Denbury Onshore (Denbury) staff in attendance to discuss CO_2 delivery operations and pipeline right-of-way permitting.

Task 4 – Site Characterization and Modeling (Charles D. Gorecki)

This task ended in Quarter 1 – Budget Period (BP) 5, Year 10 (March 2017).

Task 5 – Well Drilling and Completion (John A. Hamling)

This task ended in Quarter 3 – BP4, Year 7 (June 2014).

Task 6 – Infrastructure Development (Melanie D. Jensen)

Highlights

- Nothing to note at this time.

Task 7 – CO_2 Procurement (John A. Harju)

This task ended in Quarter 4 – BP4, Year 6 (September 2013).

Task 8 – Transportation and Injection Operations (Melanie D. Jensen)

This task ended in Quarter 4 – BP4, Year 8 (September 2015).

Task 9 – Operational Monitoring and Modeling (John A. Hamling and Larry J. Pekot)

Highlights

- Submitted Milestone (M) 55 entitled "Investigation of Crude Oil Composition Changes During CO_2 EOR (Enhanced Oil Recovery)," and received approval on September 25, 2017.
- Continued planning of a project meeting with Denbury in conjunction with the PCOR Partnership Annual Membership Meeting and Workshop.
- Continued work on the best practices manual – Monitoring for CO_2 Storage and CO_2 EOR (D51), including revised and added content to several portions of the deliverable and revised content based on an initial internal review.
- Based on mutual agreement with the DOE project manager, the PCOR Partnership plans to submit an update to D69 (Best Practices for Modeling and Simulation of CO_2 Storage), which was submitted May 31, 2017, that incorporates additional reviewer perspectives and findings. Continued work on revisions to lessons learned, recommended best practices, case studies, and text.
- Continued compilation of data for a PCOR Partnership data set to be submitted to NETL's Energy Data eXchange (EDX) in 2018.
- Began preparing materials for a meeting planned with Denbury on October 23, 2017, in advance of the PCOR Partnership Annual Membership Meeting and Workshop.
- **Bell Creek** injection-phase site activities included the following:
  - Continued reservoir pressure and distributed temperature monitoring of 05-06 OW (observation well) from the permanent downhole monitoring system using the casing-conveyed pressure–temperature gauges and fiber-optic distributed temperature system:
    - Near-continuous operation since April 2012.
  - Continued dynamic reservoir pressure and multiphase fluid flow simulation efforts. The modeling and simulation focus remains on Bell Creek Field Phase Areas 1–4. Accomplishments and activities include the following:
    - History matching of the simulation model is complete for Phase Areas 1–3. Predictive simulation is complete for Phase Areas 1 and 2. Long-term simulations of CO_2 migration are complete for Phase Areas 3–7.
    - History matching of the simulation model is complete for the waterflooding and CO_2-flooding stages for Phase Area 4 using the simulation model based on the Version 3 geologic model.
    - Continued conducting simulation for associated CO_2 storage in the Bell Creek oil field using models with different scales—the most important storage mechanisms are considered in these models.
  - Continued work with seismic attributes. Extracted seismic attributes from the difference seismic data (2012–2015). Extracted seismic attributes from the difference seismic data (2014–2015). Worked on tying seismic attributes from the three sets of seismic difference data to the pulsed-neutron log (PNL) well data.
  - Used the most recent publicly available data to determine that cumulative CO_2 gas injection is 7,967,974 tonnes through July 31, 2017. This value represents the total gas injected, which includes purchase and recycle streams and is NOT corrected for a gas composition of approximately 98% CO_2 (Table 1).

Table 1. Bell Creek CO_2 Gas Injection Totals for July 2017 (cumulative totals May 2013 to July 2017)[1]

	July 2017 Injection
Total, Mscf	4,645,863
Total, tons[2]	265,736
Total, tonnes[3]	241,306
Cumulative Total, Mscf[4]	153,407,410
Cumulative Total, tons[2,4]	8,774,662
Cumulative Total, tonnes[3,4]	7,967,974

Source: Montana Board of Oil and Gas database.

[1] Total gas injection quantities are ***NOT CORRECTED*** for gas composition and include the combined purchased and recycled gas streams.

[2] Calculated utilizing a conversion of 17.483 Mscf/ton.

[3] Calculated utilizing a conversion of 19.253 Mscf/tonne.

[4] Cumulative totals are for the period from May 2013 to the month listed.

- As of June 30, 2017, the most recent month of record, 4.017 million tonnes of total gas (composition of approximately 98% CO_2) has been purchased for injection into the Bell Creek Field, equating to an estimated 3.956 million tonnes of CO_2 stored (Table 2), with the difference comprising other trace gases in the purchase gas stream. A separate method from that used to calculate estimated total gas injected was used to calculate a cumulative associated CO_2 storage by correcting the gas purchase volume (approximately 98% CO_2) obtained from Denbury's custody transfer meter with gas compositional data.
- Worked with Denbury on the collection of the eighth round of oil samples from a select group of wells in the Bell Creek Field.
- A summary of all oil and CO_2 gas stream samples collected for analyses to date is provided in Table 3.

Table 2. Cumulative Total Gas Purchased and Estimated Associated CO_2 Storage for the Bell Creek Field[1]

	June 2017 Gas Totals
Monthly Total Gas Purchased, MMscf[2]	1499
Monthly Total Gas Purchased, million tons[2]	0.086
Monthly Total Gas Purchased, million tonnes[2]	0.078
Cumulative Total Gas Purchased, MMscf[2,3]	77,331
Cumulative Total Gas Purchased, million tons[2,3]	4.423
Cumulative Total Gas Purchased, million tonnes[2,3]	4.017
Cumulative Total CO_2 Stored, MMscf[3,4]	76,168
Cumulative Total CO_2 Stored, million tons[3,4]	4.357
Cumulative Total CO_2 Stored, million tonnes[3,4]	3.956

[1] Conversion factors of 17.483 Mscf/ton and 19.253 Mscf/tonne were used to calculate equivalent purchase and storage quantities.

[2] Total gas purchased *NOT CORRECTED* for gas composition.

[3] Cumulative totals are for the period from May 2013 to the month listed.

[4] Total CO_2 stored *CORRECTED* for gas composition.

Table 3. Oil and CO_2 Gas Stream Sampling and Analyses

		Production Stream by Development Phase, Well[1]									
	Purchase/	Phase 1				Phase 3			Phase 4		
Date Sampled	Recycle[1]	56-14R	32-02	05-06	04-04	28-02	21-10	21-14	34-09	34-07	34-03
Jan 2014		O	O	O							
Mar 2014		O	O								
May 2014	P	O	O	O							
Jun 2014	PR	O	O	O							
Jul 2014	PR	O	O	O							
Sep 2014	PR	OG	OG	O							
Oct 2014	PR	O	O								
Nov/Dec 2014		OG	OG	G							
Jan 2015			O	OG							
Mar 2015		G	G	G							
Apr 2015	PR										
Jun 2015		O	O	O							
Jul 2015	PR	G	G	G							
Sep 2015	PR										
Nov 2015		O		O							
Jan 2016	PR										
Apr/May 2016		O	O	O	O	O	O	O			
Jun/Jul 2016	PR	O		O	O	O	O	O			
Aug/Sep 2016		O	O		O	O	O	O	O		
Oct 2016				O							
Nov/Dec 2016[2]	PR	O	O	O	O	O	O	O	O	O	O
Feb 2017[2]		O	O		O	O	O	O	O	O	O
May 2017[2]	PR	O	O	O	O	O	O	O	O	O	O
July 2017[2]		O			O	O	O	O	O	O	O

[1] P = purchase CO_2 gas stream, R = recycle CO_2 gas stream, O = produced oil stream, and G = produced CO_2 gas stream.
[2] Oil samples collected but not yet analyzed.

Task 10 – Site Closure (John A. Hamling)

Highlights

- Worked on the abstract, outline, and text for D54 (Site Closure Procedures).

Task 11 – Postinjection Monitoring and Modeling (John A. Hamling and Larry J. Pekot)

Highlights

- Completed the draft outline for D73 (Monitoring and Modeling Fate of Stored CO_2).

Task 12 – Project Assessment (Loreal V. Heebink)

Highlights

- Continued updating sections in the BP5 Program Year 10 annual report based on deliverables and milestones.

Task 13 – Project Management (Charles D. Gorecki)

Highlights

- Attended the European Association of Geoscientists and Engineers (EAGE) Technical Programme of the Fourth Sustainable Earth Sciences Conference held September 3–7, 2017, in Malmö, Sweden, and presented "The Plains CO_2 Reduction (PCOR) Partnership: Successes Leading to New Innovation."
- Attended the 2017 Midwest Carbon Sequestration Science Conference held September 19–20, 2017, in Champaign, Illinois, and presented "The Plains CO_2 Reduction (PCOR) Partnership."
- Attended the Mission Innovation Carbon Capture Utilization and Storage Experts' Workshop held September 25–29, 2017, in Houston, Texas.
- Attended the North Dakota Petroleum Council Annual Meeting held September 26–28, 2017, in Bismarck, North Dakota.
- Submitted an abstract for consideration to the 2018 Carbon Capture, Utilization, and Storage (CCUS) Conference entitled "Regional Update of CCUS Field Projects Within the PCOR Partnership Region: Improving the Commercial Viability of CO_2 Storage Through Improved Performance Monitoring and Operational Management" to be held March 20–22, 2018, in Nashville, Tennessee. The proposed presentation will include updates from the PCOR Partnership project and other EERC projects.
- Submitted the quarterly international activity update on September 21, 2017.
- Continued work on a planned special issue of *International Journal of Greenhouse Gas Control*. Team members began drafting outlines and writing text for potential papers. Revised the list of potential papers (see Appendix A).
- Continued planning for the PCOR Partnership Annual Membership Meeting and Workshop, including:
  - Sent an e-mail blast on September 1, 2017, to announce the preliminary agenda and serve as a sponsorship agenda. The e-mail blast also contained links to registration and the hotel.
  - Continued development of the workshop agenda and interactive activity.
  - Worked on development of meeting materials, including booths that will be displayed during the meeting.
  - Held a planning meeting on September 18, 2017, to discuss audiovisual needs, firming up the agenda, workshop updates, upcoming e-mail blasts, side meetings, materials for meeting distribution, and booths and posters.
  - Sent e-mail blasts on September 20 and 27, 2017, to remind participants of the hotel registration deadline.
  - Held a planning meeting on September 29, 2017, to discuss firming up the agenda, potential sponsors, event menus, meeting room setup, workshop update, side meetings, evening event update, participation promotional item status, and booths and posters.
  - Continued work on securing speakers and updated the meeting Web site with recent speaker confirmations.
- Completed deliverables and milestones in September:
  - August monthly update
  - Task 1: D1 – Review of Source Attributes
  - Task 9: M55 – Investigation of Crude Oil Composition Changes During CO_2 EOR
  - Task 14: M62 – Research Related to Water and Carbon Capture and Storage (CCS) Nexus Completed

Task 14 – RCSP Water Working Group (WWG) Coordination (Ryan J. Klapperich)

Highlights

- Submitted M62 entitled "Research Related to Water and CCS Nexus Completed," and received approval on September 25, 2017.
- Continued development of the draft D107 (Journal Article or Topical Report – Major Research Focuses for Water and CCS). It is anticipated an abstract will be submitted to Greenhouse Gas Control Technologies (GHGT)-14 and a final product will be created that conforms to typical GHGT paper requirements. Progress was made on the text and appendix materials.

Task 15 – Further Characterization of the Zama Acid Gas EOR, CO_2 Storage, and Monitoring Project (Charles D. Gorecki)

This task ended in Quarter 2 – BP4, Year 7 (February 2014).

Task 16 – Characterization of the Basal Cambrian System (Wesley D. Peck)

This task ended in Quarter 2 – BP4, Year 7 (March 2014).

Travel/Meetings

- September 2–7, 2017: traveled to Malmö, Sweden, to present at the EAGE 4th Sustainable Earth Sciences Conference.
- September 19–20, 2017: traveled to Champaign, Illinois, to present at the 2017 Midwest Carbon Sequestration Science Conference.
- September 25–28, 2017: traveled to Houston, Texas, to be a panelist for the CCUS Experts Workshop.

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APPENDIX A

POTENTIAL *INTERNATIONAL JOURNAL OF GREENHOUSE GAS CONTROL* PAPERS (REVISED)

PROPOSED PAPERS FOR PCOR PARTNERSHIP INTERNATIONAL JOURNAL OF GREENHOUSE GAS CONTROL (IJGGC) SPECIAL ISSUE[1]

1. **Introduction: The Plains CO_2 Reduction (PCOR) Partnership Program and large-scale demonstration of associated CO_2 geological storage**
   Neil Wildgust, David Nakles, and Ryan Klapperlich (editors)

This concise introduction to the PCOR Partnership large-scale CO_2 storage project will describe the context and scope of work undertaken with specific reference to the associated storage that is incidental to CO_2 enhanced oil recovery (CO_2 EOR) operations.

2. **CO_2 storage associated with CO_2 enhanced oil recovery: a statistical analysis of historical operations. International Journal of Greenhouse Gas Control (IJGGC) 37 (2015) 384–397.[2]**

3. **Characterization of a case study CO_2 EOR project to support the assessment of associated CO_2 storage**
   Lead author: Nick Bosshart

The approaches taken to characterize a CO_2 EOR project for the assessment of associated CO_2 geologic storage are described in this paper. Novel approaches to characterization are presented with reference to the critical parameters and factors needed to assess associated storage. The paper describes how use of multiple-point statistics has allowed a more realistic representation of the connectivity and compartmentalization of reservoir sands and, allied to other technical disciplines used in an adaptive management approach, allowed new interpretations of reservoir properties and structure to revise and refine predictive simulations of CO_2 behavior in the reservoir.

4. **Quantifying CO_2 storage efficiency factors in hydrocarbon reservoirs: a detailed look at CO_2 enhanced oil recovery**
   Wesley Peck et al., currently submitted to IJGGC and under peer review

5. **Using pulsed-neutron logs (PNL) to monitor wellbore integrity at a CO_2 storage site: lessons learned from field deployment by the PCOR Partnership**
   Lead author: Nicholas Azzolina

Pulsed-neutron logs (PNL) have been used at the PCOR Partnership large-scale demonstration project as a key subsurface monitoring technique. This paper will illustrate two methods for processing PNL logs, specifically the "sigma" measurement—a measure of the die-away time of a short-lived neutron pulse. Multiple (repeat) PNL measurements from the same well locations allowed assessment of PNL sensitivity to changes from baseline (preinjection)

[1] Highlighted papers were developed under separate funding and are either under journal review or have already been published. These papers are planned to be included in the special issue because of the relevant subject matter.

[2] This paper has already been published by the journal.

conditions. These methods provide a simple means for developing an automated process for using PNL to make real-time decisions about any potential CO_2 leakage along a wellbore.

6. Laboratory measurements of CO_2 draining oil relative permeability and hysteresis effects for a conventional clastic reservoir
Lead author: John Hurley

Determination of hysteresis in relative permeability data is useful in obtaining more reliable predictions of associated CO_2 storage of CO_2 in WAG (water alternating gas) injection scenarios. A laboratory-based evaluation of CO_2 draining oil has been conducted on reservoir rocks from the Bell Creek oil field located in southeastern Montana, United States. Experimentation was conducted at reservoir conditions of 2300 psi and 110°F. Results of testing will be incorporated into dynamic reservoir simulation scenarios being conducted to demonstrate the storage potential associated with commercial-scale CO_2 injection in conjunction with an EOR operation.

7. Evaluation of recycle gas injection and associated impurities on performance of associated storage
Lead author: Lu Jin

Assessment of associated storage, incidental to CO_2 EOR operations, requires an understanding of various technical factors which govern the recovery of incremental oil from the reservoir. Recycling systems are an important facet of CO_2 EOR operations and have the potential to alter the composition of the injected CO_2 stream through variation in impurities. In a case study based on a large-scale injection project, a history-matched reservoir simulation employs a calibrated equation of state to predict the effects of reservoir heterogeneity and phase behavior on incremental oil recovery and associated storage.

8. Lessons learned and best practices derived from environmental monitoring at a large-scale CO_2 injection project
Lead author: Kerryanne Leroux

The PCOR Partnership has monitored environmental media including groundwater, surface water, and soils at a large-scale CO_2 injection project for EOR. Five years of data obtained included extensive baseline characterization of these shallow environmental systems. This paper describes the lessons learned from the monitoring campaign. Emphasis is placed on the natural variability of shallow environmental data and the resulting challenges in formulating future monitoring strategies for the greater number of future CO_2 geologic storage projects required to support carbon capture and storage deployment.

9. Effects of gas relative permeability hysteresis and solubility on associated CO_2 storage performance
Lead author: Lu Jin

In a CO_2 EOR process, a proportion of the injected CO_2 remains behind through residual and solubility trapping mechanisms when it flows through the reservoir. This paper presents the

hysteresis of gas relative permeability in an oil field and assesses the effect of residual trapping on associated CO_2 storage. Also investigated is CO_2 solubility in different reservoir fluids, i.e., oil and water, which shows that CO_2 solubility in oil is much greater (≥5 times) than that in water. Results indicate that depleted oil reservoirs have great potential to store a huge quantity of CO_2 as residual oil saturation is 0.3 or greater in most conventional oil reservoirs after water flooding.

10. Detection of subsurface CO_2 migration using 4-D seismic monitoring to update history matching and improve reservoir simulation
Lead author: Olarinre Salako

The PCOR Partnership has adopted an adaptive management approach to the assessment of associated storage at a large-scale CO_2 EOR project. This paper describes the interplay between predictive simulation and 4-D seismic monitoring of the injection, enabling history matching and providing new insights into the structure and characteristics of the reservoir.

11. Comparison of saturation values from PNLs and seismic
Lead author: Shaughn Burnison

PNLs and multiple time-lapse 3-D surface seismic surveys (4-D seismic) have been acquired to better understand migration and accumulation of injected CO_2 in an active CO_2 EOR operation. PNLs have provided point measurements of CO_2 saturation at well locations. Interpretations of 4-D seismic amplitude changes have highlighted the combined effects of changes in pressure and CO_2 saturation within the reservoir. PNL saturation data in four wells acquired concurrently with time-lapse surface seismic data have allowed the determination of a numerical relationship between the point measurements of CO_2 saturation and observed changes in seismic amplitude. Application of this relationship may provide a greater understanding of fluid migration within the reservoir, CO_2 storage and sweep efficiency, and containment within the zone of interest.

12. Application of 4-D seismic inversion to improve seismic amplitude interpretation of a reservoir undergoing CO_2 injection
Lead author: Olarinre Salako

Inversion of 3-D seismic reflection data is a commonly used technique to determine CO_2 storage reservoir properties. Inversion of 4-D seismic reflectivity against changes in acoustic properties, such as P-wave velocities and impedances, can offer improved understanding of the dynamic changes in reservoirs resulting from CO_2 injection. Inverting time-lapse prestack data against changes in S-wave velocities can help distinguish fluid saturation effects from pressure effects. The resulting interpretation can improve geologic modeling and fluid flow simulation of storage.

13. How green is my oil? A detailed look at greenhouse gas accounting for CO_2 enhanced oil recovery (CO_2 EOR) sites. International Journal of Greenhouse Gas Control 51 (2016) 369–379.[2]

14. Life cycle analysis: case study of associated storage with enhanced oil recovery
Lead author: Melanie Jensen

This paper will illustrate the life cycle emission factors for a case study CO_2 EOR project, including CO_2 sourced from a natural gas-processing plant. Previous work has shown that scenarios with CO_2 capture and CO_2 EOR produce both natural gas and oil with lower life cycle emissions than from conventional oil and gas fields. Sensitivity analysis showed that the model results were sensitive to net CO_2 utilization, which directly impacts the purchased CO_2 requirement and, therefore, dictates upstream emissions associated with the capture source.