PLAINS CO\textsubscript{2} REDUCTION PARTNERSHIP:
BELL CREEK FIELD PROJECT
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Mastering the Subsurface Through Technology Innovation & Collaboration:
Carbon Storage & Oil & Natural Gas Technologies Review Meeting
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PRESENTATION OUTLINE

• PCOR Partnership
• Enhanced oil recovery and associated CO$_2$ storage
• Bell Creek project
• Aquistore project
• Outreach activities
• Best practices manuals
• Summary
PCOR PARTNERSHIP

• Region includes:
  – Nine states
  – Four Canadian provinces
  – 1,382,089 mi²
• Two active demonstration projects:
  – Bell Creek project
  – Aquistore project
• More than 100 partners
PCOR PARTNERSHIP

PCOR Partnership
2003 – Present

Aquistore
Baker Hughes
Ballantine
Billyjack Consultants Inc.
Biocrecro
Blue Source
BNI
COAL
CER
global
C3 Energy
The CENTER Group, Inc.
CGI
Continental
Cortec

CNOOC
Denbury
Carbon
Enduro
Encore
Endeavour
EACBP
Environment Canada
Excellence
Fischer Oil and Gas, Inc.

Halliburton
Hess
Huntsman
Husky Energy
National Energy Board

Hillsboro
Hillhead Energy
Hillhead
House

Hycarbon
Humedica
Hydro
Indus

Kiewit
Manitoba
Manitoba Hydro

Minnesota Power
MISO
Missouri Power
Missouri River Energy Services

Missouri Public Service
Montana-Dakota

Nexen

New Century Coal
North Dakota Economic Development Authority
North Dakota Rural Development

North Dakota State University
Nordex

Ottewill Energy

Peabody

Pinnacle
Pioneer

Prot & Whitney

PetroHarvester

PSN

SaskPower

Saskatchewan Energy Authority

Saskatchewan Resources

Suncor

TESORO

TGS

Trident

USGS

Weatherford

Western Environmental Association

Western Energy Association

Westmoreland Coal Company

XcelEnergy

Xand
PCOR PARTNERSHIP’S INTEGRATED ADAPTIVE MANAGEMENT APPROACH

- Focused on site characterization, modeling and simulation, and risk assessment to guide monitoring, verification, and accounting (MVA) strategy.
PCOR PARTNERSHIP OBJECTIVES

• Safely and permanently achieve CO₂ storage on a commercial scale in conjunction with enhanced oil recovery (EOR).

• Demonstrate that oil-bearing formations are viable sinks with significant storage capacity to help meet near-term CO₂ storage objectives.

• Establish MVA methods to safely and effectively monitor CO₂ storage.

• Use commercial oil/gas practices as the backbone of the MVA strategy, and augment with additional cost-effective techniques.

• Estimate the CO₂ storage resource potential in saline formations and hydrocarbon reservoirs in the PCOR Partnership Region.

• Serve as a knowledge hub to support in the future deployment of CCUS projects in the region. “Regional Vision”
CO$_2$ EOR

- A great near-term storage option:
  - Over 40 years of handling and injecting large volumes of CO$_2$.
  - Much of the infrastructure already in place.
  - Storage cost can be offset by income from EOR.

“Greener” than conventionally produced oil:

- Existing EOR operations are already storing CO$_2$.
- Nearly every tonne of CO$_2$ purchased is eventually stored.
SYSTEM MODEL CAPTURES UPSTREAM, GATE-TO-GATE, AND DOWNSTREAM

Upstream
- Coal Mining, Processing, and Transport
  - Coal
  - Coal-Fired Power Plant (with CO₂ Capture)
  - CO₂
  - Electricity Transmission and Distribution

Gate-to-Gate
- Pipeline CO₂ Transport
  - CO₂
- CO₂ EOR Operations (gate-to-gate)
  - CO₂

Downstream
- Crude Oil Pipeline Transport to Refinery
  - Crude oil
- Petroleum Refining
  - Fuel
- Fuel Transport, Distribution, and Point-of-Sale
  - Fuel
- Fuel Combustion

coal → CO₂ → electricity

FIGURE 1: SYSTEM MODEL CAPTURES UPSTREAM, GATE-TO-GATE, AND DOWNSTREAM
SYSTEM MODEL CAPTURES UPSTREAM, GATE-TO-GATE, AND DOWNSTREAM

**Upstream**
- 30 kg CO\(_2\)e/bbl
- 80 kg CO\(_2\)e/bbl
- 5 kg CO\(_2\)e/bbl
- 115 kg CO\(_2\)e/bbl

**Gate-to-Gate**
- 100 kg CO\(_2\)e/bbl

**Downstream**
- 4 kg CO\(_2\)e/bbl
- 46 kg CO\(_2\)e/bbl
- 5 kg CO\(_2\)e/bbl
- 415 kg CO\(_2\)e/bbl
- 470 kg CO\(_2\)e/bbl

**Total Emissions**
- 115 kg CO\(_2\)e/bbl
- 100 kg CO\(_2\)e/bbl
- 470 kg CO\(_2\)e/bbl
- 685 kg CO\(_2\)e/bbl

**Displacement of Electricity (e-)**
- 425 kg CO\(_2\)e/bbl

**Net Life Cycle GHG Balance**
- 260 kg CO\(_2\)e/bbl

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Coal Mining, Processing, and Transport

Coal-Fired Power Plant (with CO\(_2\) Capture)

Electricity Transmission and Distribution

Crude Oil Pipeline Transport to Refinery

Petroleum Refining

Fuel Transport, Distribution, and Point-of-Sale

Fuel Combustion

CO\(_2\) EOR Operations (gate-to-gate)

**e- Displacement**
- 260 kg CO\(_2\)e/bbl
COMPARING CO₂ EOR TO “REGULAR” OIL

Adapted from:
The spreadsheet CO$_2$ EOR life cycle analysis model is available on the PCOR Partnership public Web site!
BELL CREEK PROJECT OVERVIEW

- Operated by Denbury Onshore LLC.
- CO₂ is sourced from ConocoPhillips’ Lost Cabin natural gas-processing plant and Exxon’s Shute Creek gas-processing plant.
- The EERC, through the PCOR Partnership, is studying CO₂ storage associated with the commercial CO₂ EOR project.
BELL CREEK FIELD

- Phased development.

- Primary production and waterflooding produced ~37.5% original oil in place (OOIP)

- CO₂ EOR is under way in Phases 1–5.

- An estimated 40–50 million incremental bbl of oil will be recovered.
- An estimated 12.7 million tonnes of CO₂ will be stored.
**CO₂ INJECTION**

**As of June 2016**

- Oil Produced: ~2.5 million barrels  
  *(source: Montana Board of Oil and Gas Database)*
- CO₂ stored: ~3.2 million tonnes  
  *(source: Denbury)*

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**Monthly Oil Production, bbl**

- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5

**Source:** Montana Board of Oil & Gas Conservation (May, 2016)

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**Cumulative Associated CO₂ Storage, million tonnes**

- Total Gas Purchased
- Net CO₂ Stored*

*CO₂ volumes corrected for gas composition.

**Source:** Denbury (July 2016)

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**Monthly Oil Production, bbl**

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**Source:** Montana Board of Oil & Gas Conservation (May, 2016)

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**Cumulative Associated CO₂ Storage, million tonnes**

- Total Gas Purchased
- Net CO₂ Stored*

*CO₂ volumes corrected for gas composition.

**Source:** Denbury (July 2016)
Properties:
- Cretaceous Muddy Sandstone Formation
- Nearshore marine/strand plain (barrier bars)
- Approximately 1311–1371-m (4300–4500-ft) depth
- Overlain by more than 914 m (3000 ft) of siltstones and shales
- Average thickness 9–14 m (30–45 ft)
- Average porosity range
  - 25%–35%
- Average permeability range
  - 150–1175 mD

*USDW = Underground Source of Drinking Water
MODEL REFINEMENT

- Phase 1 geomodel
- Simulation model
  - Phase 1 history-matched (pre-CO$_2$) and performance forecasts

- Full-field geomodel
  - Electrofacies
- Phases 1 and 2 history-matched and performance forecasts

**Version 3 (under development)**
- Geobody interpretations and facies model
  - Trained with seismic data, logs, and core
  - Multiple-point statistics to populate facies with realistic heterogeneity
- Phases 1–4 history-matched and performance forecasts (pending)
SIMULATION MODELS – COMBINED

Challenge

• Phase 1 and 2 models assumed no flow between phases.
• Material balance in Phase 2 showed injection water flowing from Phase 2 to Phase 1.
• Time-lapse seismic data showed possible fluid connection between them.

Response

A combined model including Phases 1 and 2 was created.
102 wells in the combined model:

**Phase 1 Area:**
- 26 producers,
- 27 injectors

**Phase 2 Area:**
- 17 producers,
- 18 injectors

**Surrounding Area:**
- Ten producers,
- Four injectors

Five-Spot Flooding Pattern
HISTORY MATCH RESULTS

CO$_2$ Injection Begins
**CO₂ UTILIZATION FACTOR**

- CO₂ utilization factor (amount of CO₂ needed to produce 1 bbl of oil):
  - Water alternating gas (WAG): 10 mscf/bbl after 1 HCPVI, 7 mscf/bbl after 3 HCPVI
  - Continuous CO₂ injection (CCI): >10 mscf/bbl even after 4 HCPVI

**Conclusion**: WAG requires less CO₂ than CCI to produce the same amount of oil. In agreement with other CO₂ EOR projects.*

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WHAT ARE THE EFFECTS OF SMALL AMOUNT OF CH\textsubscript{4} (1%~4%) IN THE PRODUCED CO\textsubscript{2}? 

Vanishing interfacial tension (VIT) methods were used to measure minimum miscibility pressure (MMP) as CH\textsubscript{4} mole percentage increases from 0 to 100% in the solvent phase (T = 42°C).

Miscible flooding is still reachable when CH\textsubscript{4} is less than 36% and reservoir pressure is above 2500 psi.

Monitoring data are interpreted both independently and as part of an integrated geologic modeling and simulation workflow.
MVA FOR MODEL VALIDATION – PULSED-NEUTRON LOGGING

05-01 Saturations

04-04 Saturations

04-03 Saturations

Water
Oil
Gas

Gas saturation

0.8
0.6
0.4
0.2
0

Well Type
- Injector
- Producer

Phase
1
2
3
4
5

Critical Challenges.

Practical Solutions.
MVA FOR MODEL VALIDATION – SEISMIC

4-D Seismic Amplitude Difference

Simulation Results

CCI, 1 HCPVI

WAG, 1 HCPVI
AQUISTORE PROJECT

• Injection of CO$_2$ from the Boundary Dam Power Station in southeastern Saskatchewan began in April 2015.

• Most CO$_2$ captured at Boundary Dam is used for EOR; Aquistore serves as buffer storage for excess CO$_2$.

• PCOR Partnership activities include:
  − Core analysis.
  − Static and dynamic modeling.
  − Public outreach.
  − Participation in Aquistore Science and Engineering Research Council (SERC).
• Target saline formations:
  - Deadwood and Black Island Formations ~3200 m (10,500 ft) deep, >50 m (>150 ft) thick.
• ~75,000 tonnes of CO$_2$ injected (August 4, 2016)
• Injection rate of 350–550 tonnes/day
HISTORY MATCH

• Injection data are being used to history-match in near-real time.
• MVA field activities are being used to validate the models.
May 2016:
• CO₂ plume prediction: Plume reached the observation well (~68,000 tonnes cumulative injection).

February 2016:
• CO₂ breakthrough was observed in second perforation interval at observation well.

RST interpretation, Schlumberger
PCOR PARTNERSHIP OUTREACH ACTIVITIES

In development:
- Atlas: 5th Edition
- Documentaries
  - Coal and the Modern Age
  - Bell Creek Story
BEST PRACTICES MANUALS

• Participated in updating several DOE best practices manuals (BPMs)
  – Site characterization
  – Risk assessment/simulation
  – MVA
  – Operations
  – Outreach

• PCOR Partnership BPMs (in development)
  – Adaptive management approach
  – Site characterization
  – MVA
  – Risk assessment
  – Modeling and simulation
SUMMARY

• CO₂ EOR produces oil while also storing CO₂. Nearly all the CO₂ purchased for EOR is eventually stored.

• CO₂ storage associated with commercial CO₂ EOR is being investigated at the Bell Creek project. Over 3.2 million metric tons of associated CO₂ storage as of June 2016.

• CO₂ is being injected into a saline formation at Aquistore as buffer storage for CO₂ produced from a coal-fired electricity-generating facility.

• Characterization activities indicate the PCOR Partnership region has incredible potential for CO₂ storage in saline formations and through CO₂ EOR.

• Outreach activities and complementary projects continue to support the PCOR Partnership Program.
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THANK YOU!
BENEFIT TO THE PROGRAM

• Develop technologies that will support the industry’s ability to predict carbon dioxide (CO₂) storage capacity in geologic formations to within ±30%:
  – Conducting pilot tests and demonstration projects in hydrocarbon reservoirs, saline formations, and coal seams to study sweep and storage efficiency in each project.
  – Evaluating multiple oil fields, saline formations, and coal seams in the Plains CO₂ Reduction (PCOR) Partnership region, and estimating volumetric and dynamic storage resource through characterization and simulation.
  – Sharing lessons learned from our projects, with the other partnerships and participating in all Regional Carbon Sequestration Partnership (RCSP) Storage Capacity working groups.
  – Conducting complementary projects that utilize the lessons learned from PCOR Partnership projects to improve the methodologies used to estimate CO₂ storage resource in saline formations and hydrocarbon reservoirs.
    - DOE project – Optimizing and Quantifying CO₂ Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs (active 2012–2015)
BENEFIT TO THE PROGRAM (con’t)

• Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness:
  – Testing new techniques or combining techniques to better account for injected CO$_2$ in the demonstration tests.
  – Evaluating different injection strategies through simulation and field activities to determine the optimal strategies for both improving storage efficiency and hydrocarbon recovery, with commercial partner Denbury Onshore LLC (Denbury) providing all resources for CO$_2$ injection.

• Develop and validate technologies to ensure 99% storage permanence:
  – Developing and implementing an adaptive management approach to project management that integrates site characterization, modeling, risk assessment, and monitoring, verification, and accounting (MVA) throughout a project’s life.
  – Evaluating the existing technologies used to monitor, verify, and account for the injected CO$_2$ to determine detection limits and the ability to meet the RCSP Program goals.
  – Testing new techniques or combining techniques to better account for injected CO$_2$ in the demonstration tests.
BENEFIT TO THE PROGRAM (con’t)

- Develop best practices manuals (BPMs) for MVA and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation:
  - Contributed technical expertise and lessons learned in the development of all the RCSP BPMs created to date.
The PCOR Partnership will develop several BPMs throughout the course of the program, including the following:

- Bell Creek Test Site – Site Characterization (9/30/2014)
- Bell Creek Test Site – Simulation (8/31/2016)
- Bell Creek Test Site – Monitoring for CO₂ Storage and CO₂ Enhanced Oil Recovery (EOR) (9/30/2017)
- Fort Nelson Test Site – Feasibility Study (6/30/2014)
- The Nexus of Water and Carbon Sequestration Activities (11/30/2016)
- Permitting (9/30/2017)

- Developed a videographic BPM entitled “Installing a Casing-Conveyed Permanent Downhole Monitoring (PDM) System” (draft under review).
SYNERGY OPPORTUNITIES

- Knowledge sharing, especially lessons learned, will help guide the creation of best practices for deploying commercial-scale CCS.

