• Region includes:
  – Nine states.
  – Four Canadian provinces.
  – Over 3.6 million km².
• Several completed field projects.
• Over 3 million tons of CO₂ stored and monitored in association with CO₂ enhanced oil recovery (EOR).
• More than 120 partners.
PCOR PARTNERSHIP

PCOR Partnership 2003 – Present

[Logos of various companies and organizations]
PCOR PARTNERSHIP OBJECTIVES

• Safely and permanently achieve CO$_2$ storage on a commercial scale.
• Establish a relationship between the CO$_2$ EOR process and long-term storage of CO$_2$.
• Establish monitoring, verification, and accounting (MVA) methods to effectively monitor CO$_2$ storage.
• Use commercial oil/gas practices as the backbone of MVA strategies, and augment with additional cost-effective techniques.
• Share lessons learned for the benefit of similar projects across the region.
CO₂ EOR

• **A great near-term storage option:**
  • Over 40 years of handling and injecting large volumes of CO₂.
  • 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 CO₂.
• Nearly every tonne of CO₂ purchased is eventually stored.
COMPARING CO$_2$ EOR TO “REGULAR” OIL

Adapted from:
The spreadsheet CO$_2$ EOR life cycle analysis model is available on the PCOR Partnership public Web site!"
The Bell Creek oil field is operated by Denbury Onshore LLC.

CO₂ is sourced from ConocoPhillips’ Lost Cabin and ExxonMobil’s Shute Creek gas-processing plants.

The Energy & Environmental Research Center is studying CO₂ storage associated with commercial CO₂ EOR.
FIELD DEVELOPMENT

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

- Estimated 40–50 million incremental bbl of oil.

- Estimated 12.7 million tonnes of CO₂ stored.
**CO₂ INJECTION**

**As of March 2017**

- Oil Produced: ~3.7 million barrels  
  *(source: Montana Board of Oil & Gas [MBOG] database)*

- CO₂ Stored: ~3.7 million tonnes  
  *(source: Denbury)*

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*CO₂ volumes corrected for gas composition.*
ADAPTIVE MANAGEMENT APPROACH
MVA

• 16 techniques
• 1.5 years of preinjection monitoring
• 3+ years of operational monitoring

Demonstrate and validate monitoring techniques and their associated economics to inform viable MVA strategies for commercial-scale carbon capture and storage (CCS).

Building off of the backbone of commercial operations data.
PULSED-NEUTRON LOG (PNL) CAMPAIGN

• Seven PNL campaigns:
  – 45 wells (92 total logs) logged to date:
    ♦ 45 baseline
    ♦ 47 repeat
MVA FOR MODEL VALIDATION – PULSED-NEUTRON LOGGING
BASELINE 3-D SEISMIC SURVEY

• 104-km Baseline Survey (August 2012)

High-Amplitude Shale-Filled Channel Identified as Permeability Barrier

Low-Amplitude Eroded Surface Filled with Low-Permeability Material
SIMULATION-GUIDED MVA

- Simulation was used to predict location and saturation of CO₂.
- 2-D seismic line used to confirm ability of seismic to detect CO₂ in the reservoir.
- Results supported decision to conduct large 3-D survey.
FIRST REPEAT 3-D SURVEY

- 26-km² repeat (October 2014).
- ~1.2 Mt CO₂ stored in monitored area at the time of survey.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Start of CO₂ Injection</th>
<th>Estimated Associated CO₂ Storage (Oct 2014), Mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May 2013</td>
<td>1.04</td>
</tr>
<tr>
<td>2</td>
<td>Dec 2013</td>
<td>.166</td>
</tr>
</tbody>
</table>

Calculated using MBOG data.
FIRST REPEAT 4-D DIFFERENCE INTERPRETATION (2012–2014)

CO₂ Banking Against Permeability Barrier

CO₂ and Pressure Moving Updip Away from the Injector Toward Producer

Pressure Buildup from Water Injection

Higher Amplitude in Phase 2 Relative to Phase 1 Because of Higher Pressure Buildup

Fluid and Pressure Communication Between Phases 1 and 2

Values near zero (cooler colors) indicate little change from baseline survey.

Larger values (warmer colors) indicate changes in pressure and/or CO₂ saturation since baseline seismic acquisition.
ADDITIONAL OBSERVATIONS

An additional 4-D seismic analysis (survey acquired in 2015) shows suspected fluid communication between the Phase 1 and 3 areas…
WHAT DOES IT MEAN?

What does the change in amplitude response in 4-D investigations mean?

- The difference is due to comingled effects of changes in pressure and CO₂ saturation, which are difficult to distinguish from one another.
- However, initial investigation of pulsed-neutron logs acquired contemporaneously with the 2015 seismic survey indicate an average $S_{CO₂}$ of 3%–4% over an interval of 20 feet is detectable (at a minimum) in Bell Creek 4-D seismic.
IMPORTANT LEARNINGS FROM THE 4-D SEISMIC INVESTIGATION

• Permeability barriers (preventing fluid communication and pressure dissipation) have been illuminated where they were masked previously in the baseline seismic.
• Cross-phase fluid communication has been identified.
• CO₂ accumulating updip along the western edge of the N–S permeability barrier is visible.
• CO₂ and pressure plumes associated with injection wells are clearly shown.
• Improved insight into the reservoir’s interwell heterogeneity.
  – Yielded important details necessary to adapt static models, enable better history matching, and increase accuracy in predictive simulations.
• Provided actionable information for the engineers operating the field while demonstrating associated CO₂ storage incidental to EOR.
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THANK YOU!