PLAINS CO_2 REDUCTION PARTNERSHIP: BELL CREEK FIELD PROJECT

DE-FC26-05NT42592

Mastering the Subsurface Through Technology Innovation & Collaboration:
Carbon Storage & Oil & Natural Gas Technologies Review Meeting

August 18, 2016

Charles Gorecki, Director of Subsurface R&D
Energy & Environmental Research Center

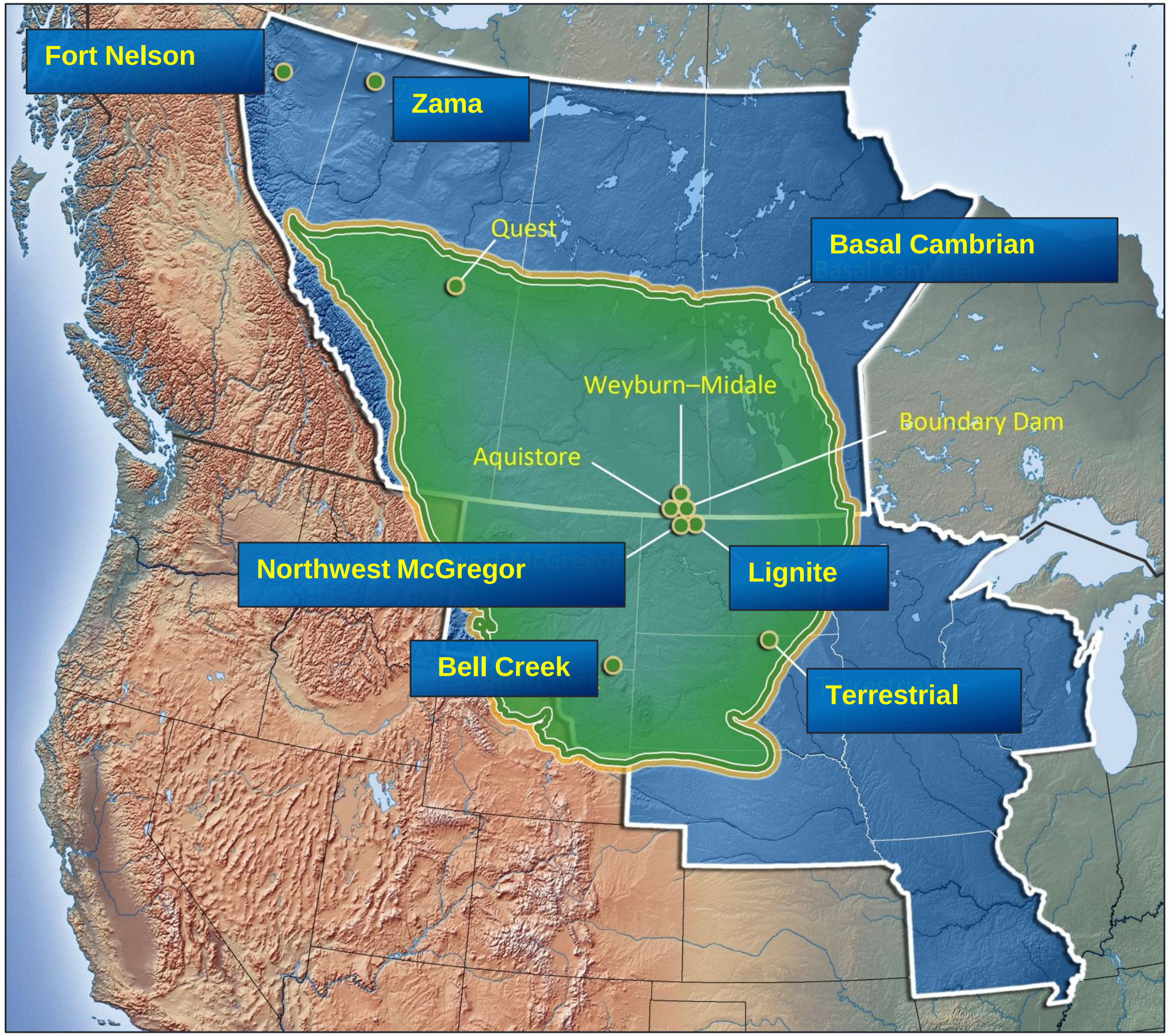
Critical Challenges. Practical Solutions.

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 mi^2
- Two active demonstration projects:
  - Bell Creek project
  - Aquistore project
- More than 100 partners



PCOR PARTNERSHIP

PCOR Partnership 2003 – Present

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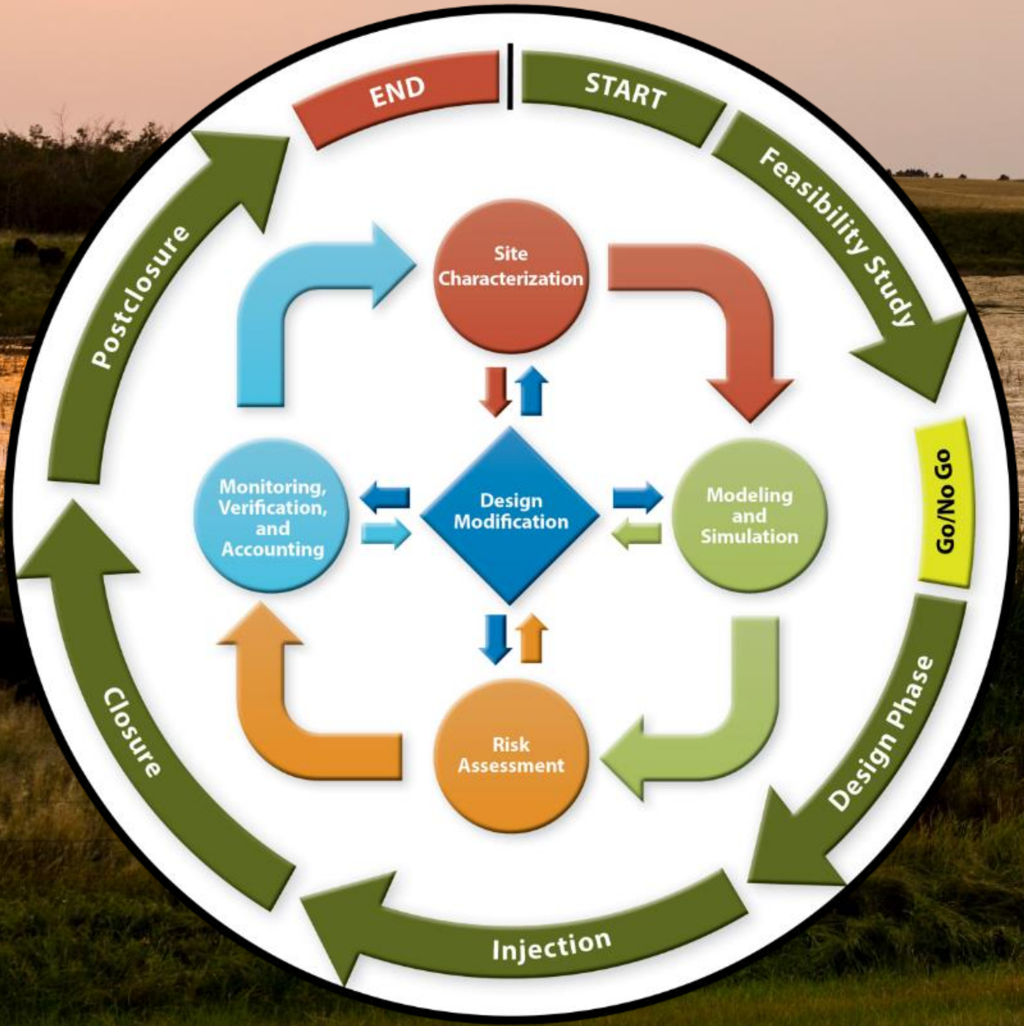
PCOR PARTNERSHIP'S INTEGRATED ADAPTIVE MANAGEMENT APPROACH

- 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 CO_2 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 CO_2 storage objectives.
- Establish MVA methods to safely and effectively monitor CO_2 storage.
- Use commercial oil/gas practices as the backbone of the MVA strategy, and augment with additional cost-effective techniques.
- Estimate the CO_2 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”

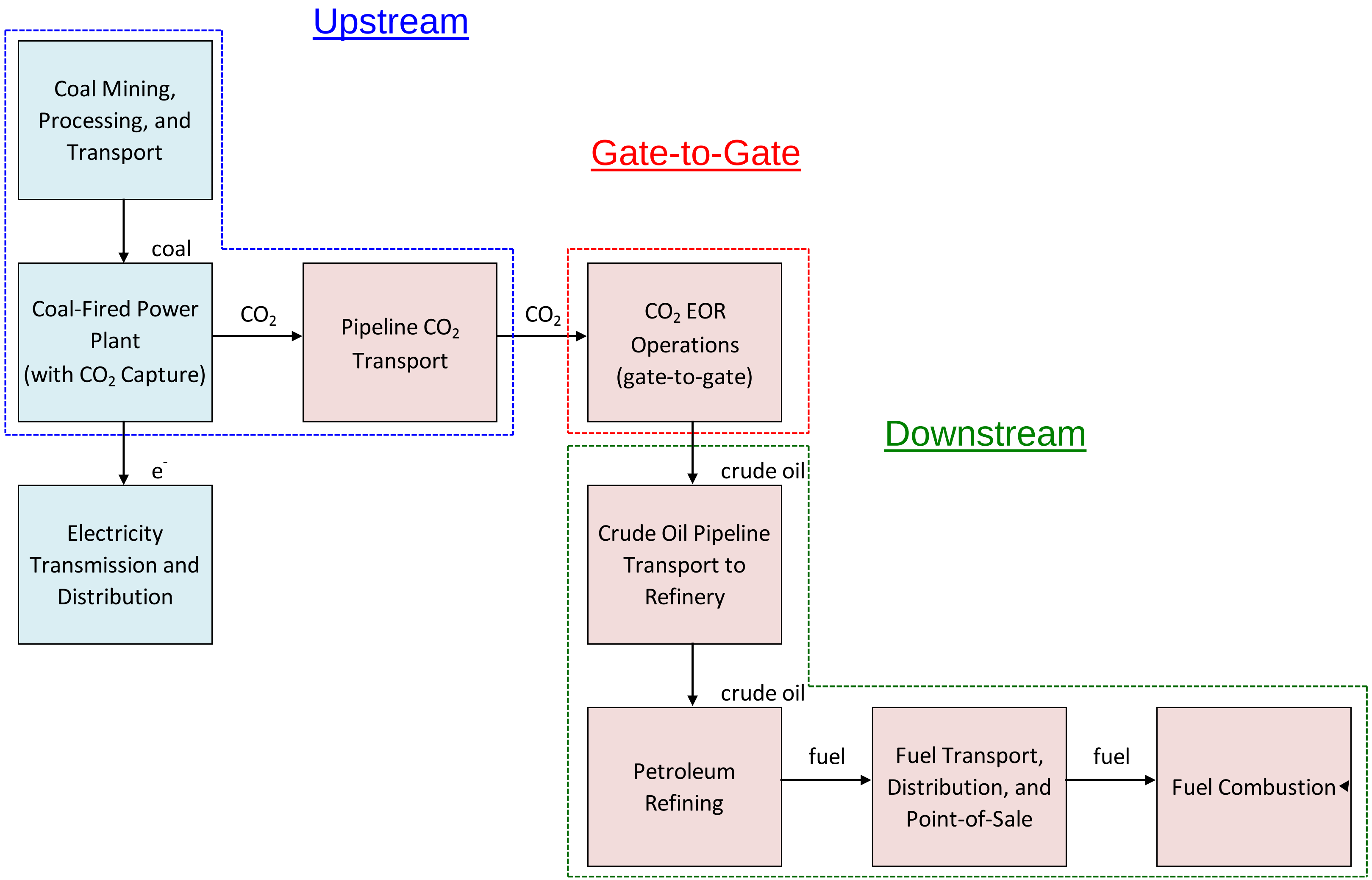
CO_2 EOR

- **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.

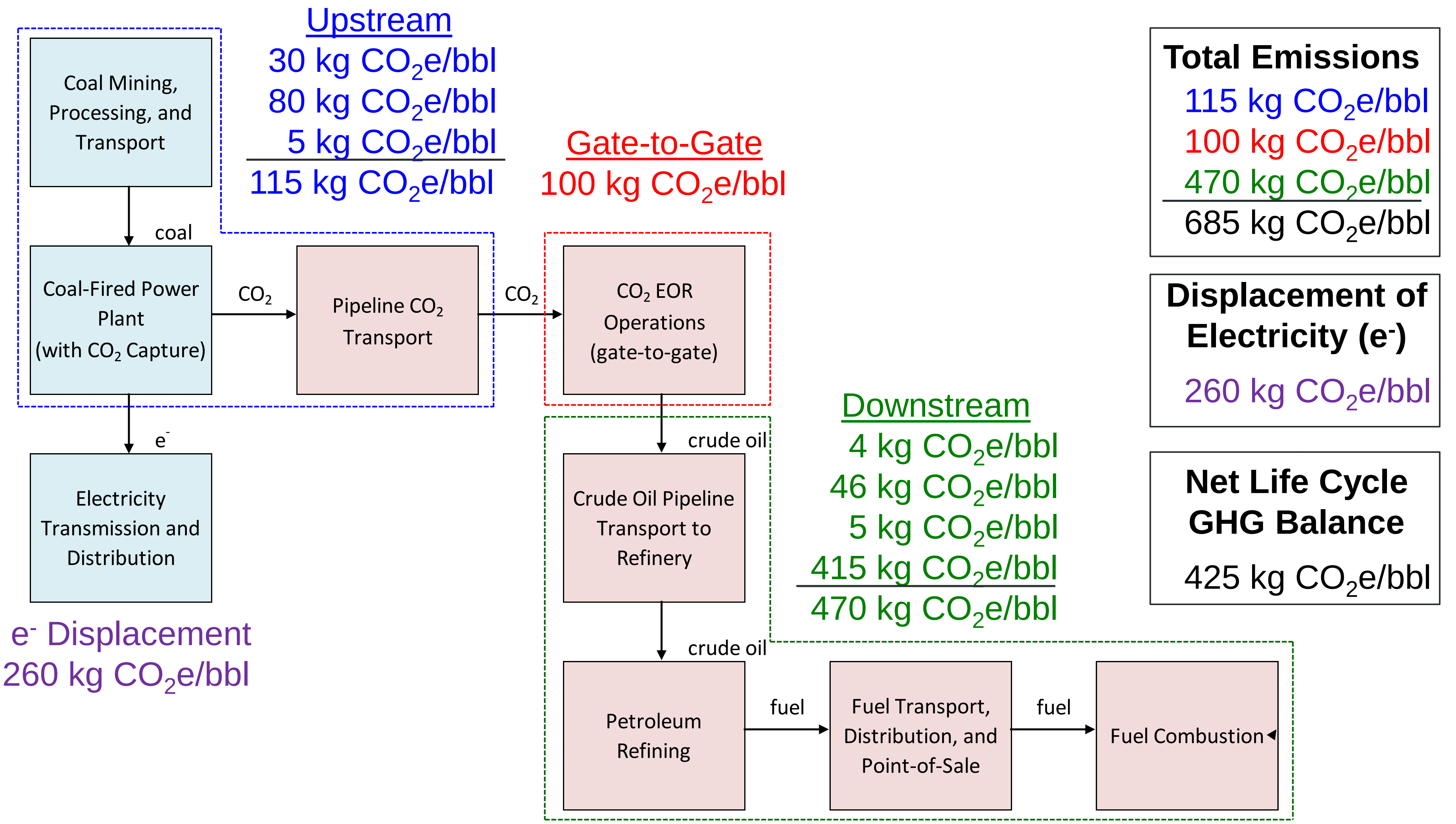
"Greener" than conventionally produced oil:

- Existing EOR operations are already storing CO_2.
- Nearly every tonne of CO_2 purchased is eventually stored.

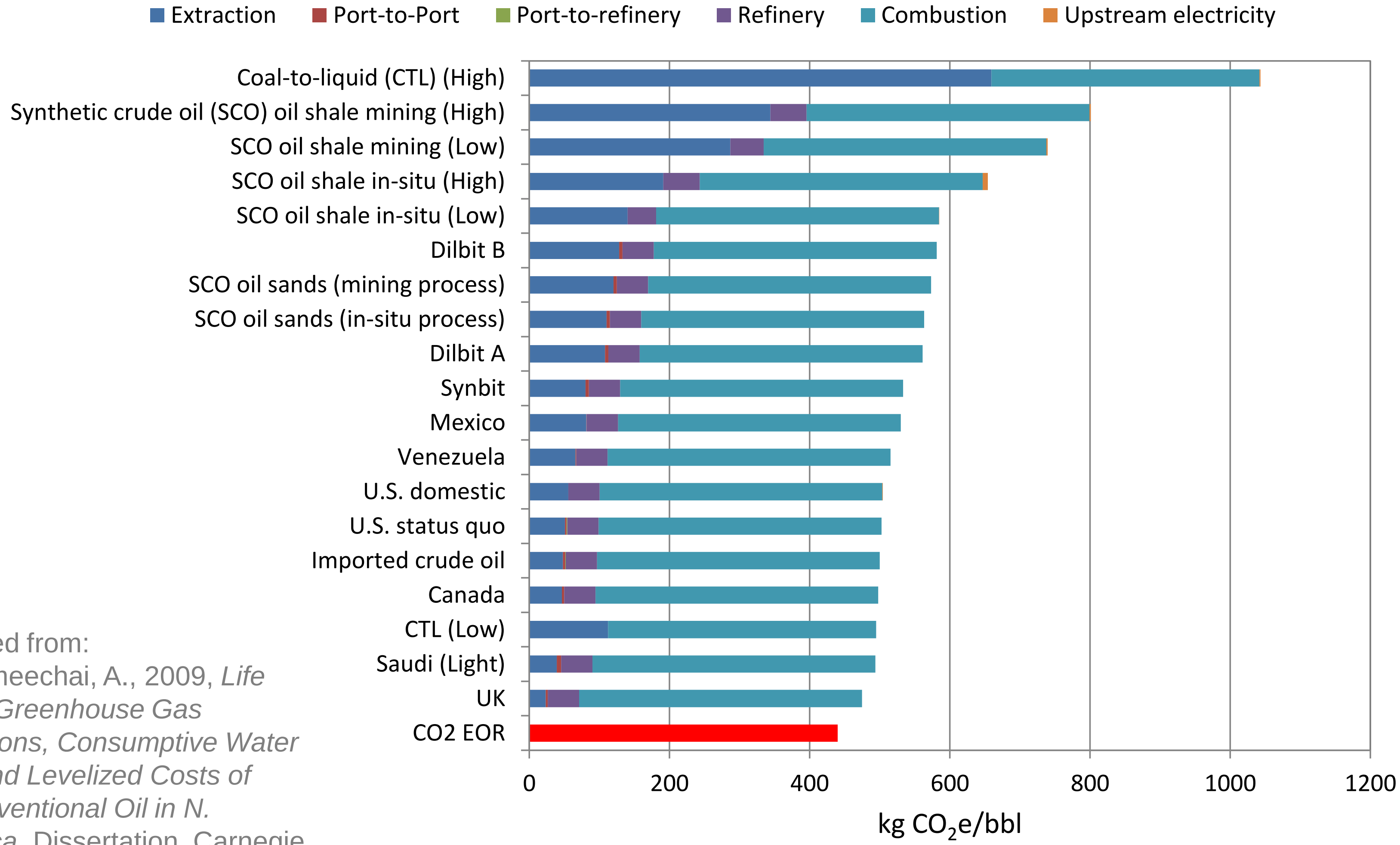
SYSTEM MODEL CAPTURES UPSTREAM, GATE-TO-GATE, AND DOWNSTREAM



SYSTEM MODEL CAPTURES UPSTREAM, GATE-TO-GATE, AND DOWNSTREAM



COMPARING CO_2 EOR TO "REGULAR" OIL



Adapted from:
Mangmeechai, A., 2009, *Life Cycle Greenhouse Gas Emissions, Consumptive Water Use and Levelized Costs of Unconventional Oil in N. America*. Dissertation, Carnegie Mellon University: Pittsburgh, PA.

JOURNAL ARTICLE

International Journal of Greenhouse Gas Control 51 (2016) 369–379

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

ELSEVIER

How green is my oil? A detailed look at greenhouse gas accounting for CO_2-enhanced oil recovery (CO_2-EOR) sites

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http://www.sciencedirect.com/science/article/pii/S1750583616302985

The spreadsheet CO_2 EOR life cycle analysis model is available on the PCOR Partnership public Web site!

Plains CO_2 Reduction (PCOR) Partnership
Practical, Environmentally Sound CO_2 Sequestration

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- About the Partnership
- Climate, CO_2, Sequestration
- Regional Storage Potential
- CO_2 Sequestration Projects
- Technical Publications
  - Technical Reports
  - Technical Posters
  - *CO_2 EOR LCA Model*
  - PDM Video
- Resources
- Documentaries
- Video Clip Library
- FAQs
- Links
- Household Energy

CO_2 EOR LCA Model

The PCOR Partnership performed a life cycle analysis (LCA) to estimate the greenhouse gas emissions associated with oil produced via CO_2 EOR, including comparing the results to conventional oil. The results were published in the *International Journal of Greenhouse Gas Control*.

A spreadsheet-based model developed through this work allows users to input their own site-specific values for conducting the analysis.

Download the model

Article Title: *How Green Is My Oil? A Detailed Look at Greenhouse Gas Accounting for CO_2 Enhanced Oil Recovery (CO_2 EOR) Sites*

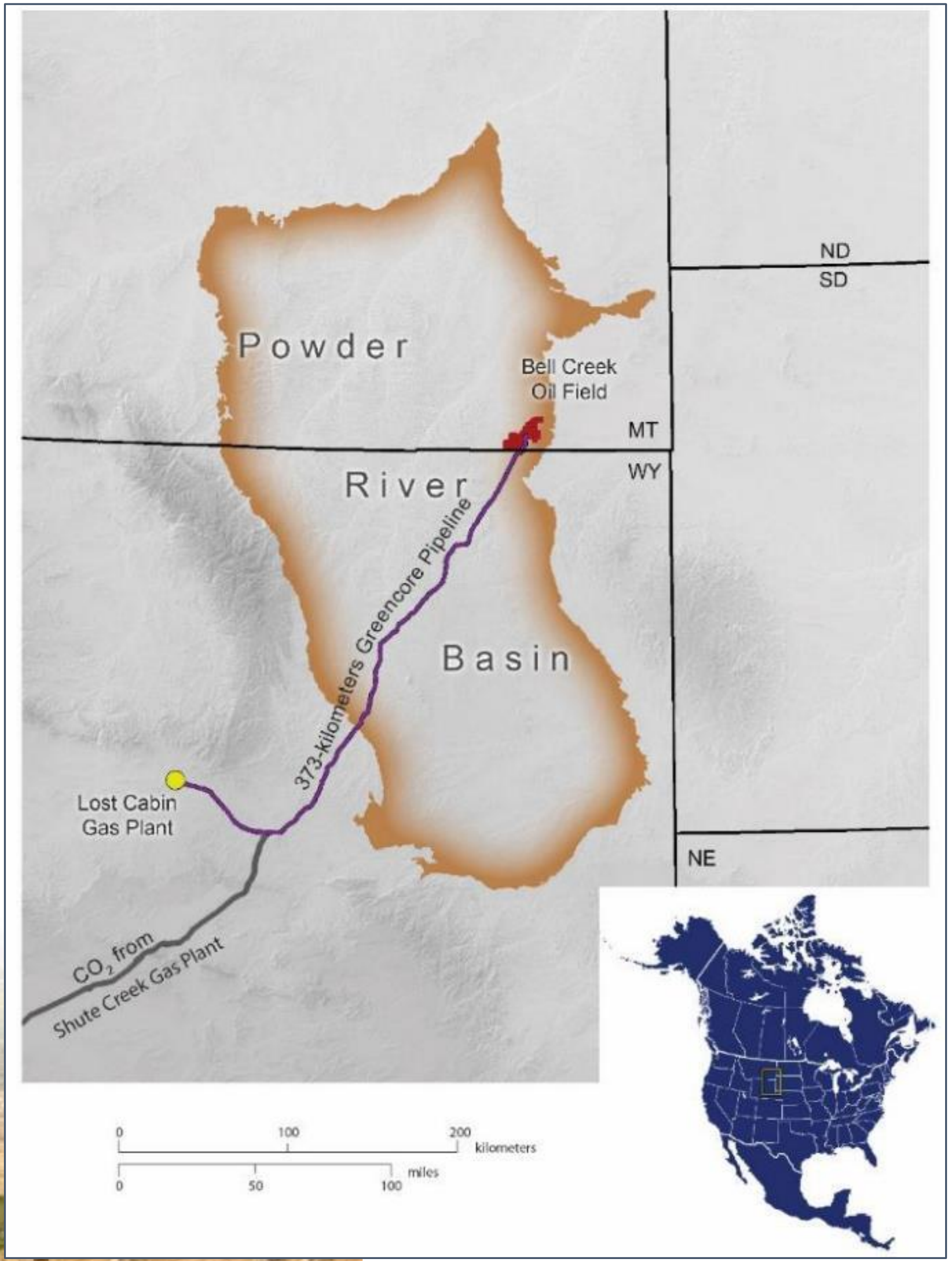
Abstract: This study presents the results of a detailed life cycle analysis of greenhouse gas (GHG) emissions associated with carbon dioxide enhanced oil recovery (CO_2 EOR) where the CO_2 is sourced from a coal-fired power plant. This work builds upon previous investigations and integrates new information to provide more plausible ranges for CO_2 storage in the reservoir during CO_2 EOR. The system model includes three segments: upstream, gate-to-gate, and downstream processes. Our base case model using Ryan-Holmes gas separation technology for the CO_2 EOR site determined the emissions from upstream, gate-to-gate, and downstream processes to be 117, 98, and 470 kg CO_2e/bbl (CO_2 equivalents per barrel of incremental oil produced), respectively, for total emissions of 685 kg CO_2e/bbl. However, these emissions are offset by CO_2 storage in the reservoir and the resulting displacement credit of U.S. grid electricity, which results in a net life cycle emission factor of 438 kg CO_2e/bbl. Therefore, CO_2 EOR produces oil with a lower emission factor than conventional oil (~500 kg CO_2e/bbl). Optimization scenarios are presented that define a performance envelope based on the CO_2 capture rate and net CO_2 utilization and suggest that lower emission factors below 300 kg CO_2e/bbl are achievable. Based on these results, CO_2 EOR where the CO_2 is sourced from a coal-fired power plant provides one potential means for addressing the energy demand–climate change conundrum, by simultaneously producing electricity and oil to meet growing energy demand and reducing GHG emissions to abate global warming.

View the journal article here.

http://www.undeerc.org/pcor/technicalpublications/CO2-EOR-Life-Cycle-Analysis.aspx

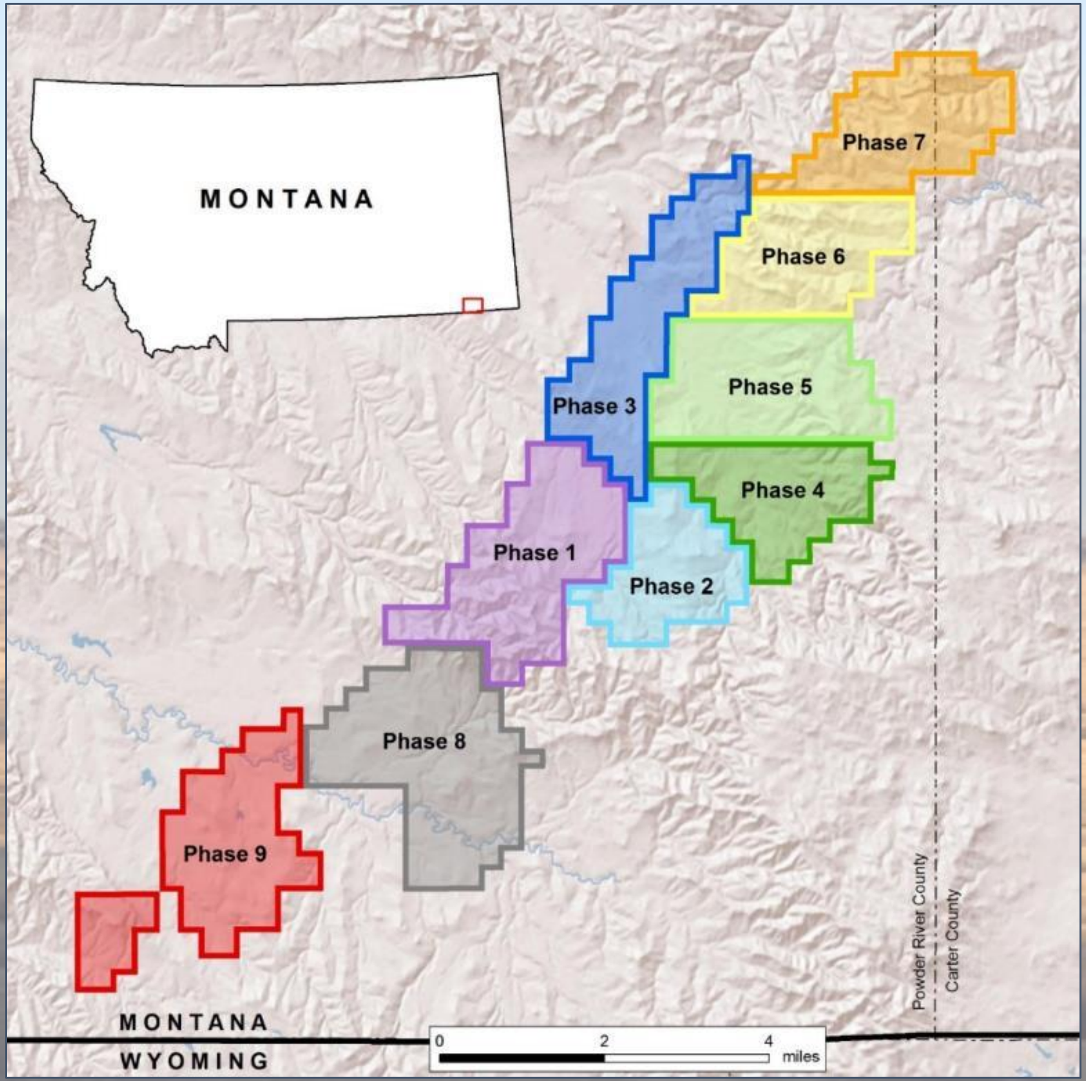
BELL CREEK PROJECT OVERVIEW

- Operated by Denbury Onshore LLC.
- CO_2 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 CO_2 storage associated with the commercial CO_2 EOR project.



BELL CREEK FIELD

- Phased development.
- Primary production and waterflooding produced ~37.5% original oil in place (OOIP)
- CO_2 EOR is under way in Phases 1–5.

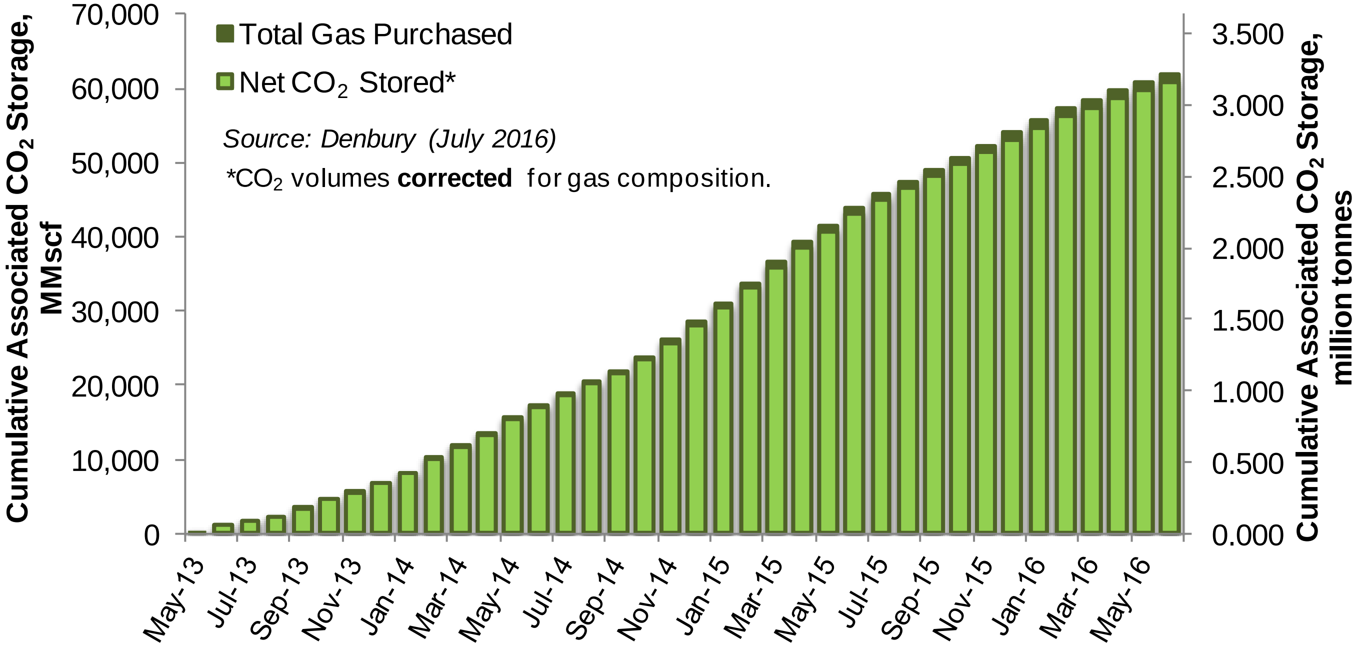


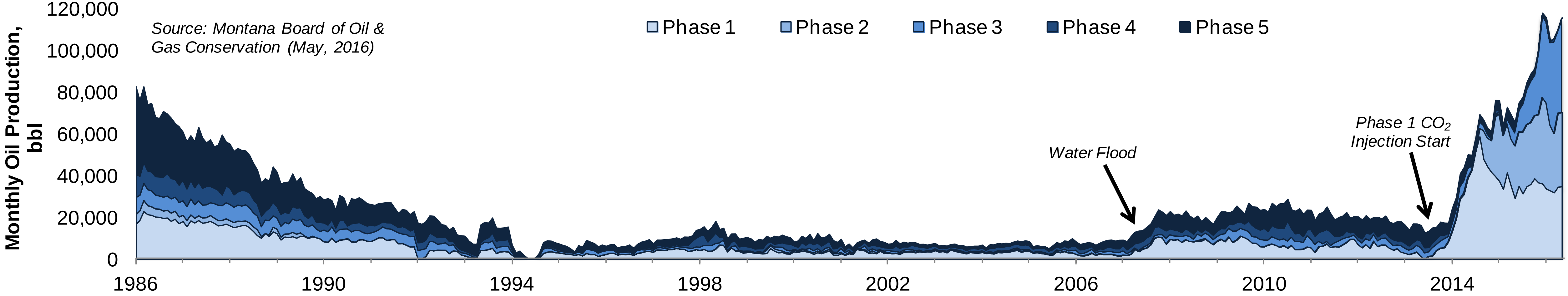
- **An estimated 40–50 million incremental bbl of oil will be recovered.**
- **An estimated 12.7 million tonnes of CO_2 will be stored.**

CO_2 INJECTION

As of June 2016

- Oil Produced: ~2.5 million barrels
  (source: Montana Board of Oil and Gas Database)
- CO_2 stored: ~3.2 million tonnes
  (source: Denbury)





EERC

Critical Challenges. **Practical Solutions.**

BELL CREEK – SITE CHARACTERIZATION

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

Era	Age Units	Seals, Sinks, and USDW*	Powder River Basin	Group
Cenozoic	Quaternary	USDW		
Cenozoic	Tertiary	USDW	Fort Union Fm	
Mesozoic	Cretaceous	USDW	Hell Creek Fm	
Mesozoic	Cretaceous	USDW	Fox Hills Fm	
Mesozoic	Cretaceous	Upper Seal	Bearpaw Fm	Pierre Fm
Mesozoic	Cretaceous	Upper Seal	Judith River Fm	Pierre Fm
Mesozoic	Cretaceous	Upper Seal	Claggett Fm	Pierre Fm
Mesozoic	Cretaceous	Upper Seal	Eagle Fm	Pierre Fm
Mesozoic	Cretaceous	Upper Seal	Telegraph Creek Fm	Pierre Fm
Mesozoic	Cretaceous	Upper Seal	Niobrara Fm	Colorado Group
Mesozoic	Cretaceous		Carlile Fm	Colorado Group
Mesozoic	Cretaceous		Greenhorn Fm	Colorado Group
Mesozoic	Cretaceous	Upper Seal	Belle Fourche Fm	Colorado Group
Mesozoic	Cretaceous	Upper Seal	Mowry Fm	Colorado Group
Mesozoic	Cretaceous	Sink	Muddy Fm	Colorado Group
Mesozoic	Cretaceous	Lower Seal	Skull Creek Fm	Colorado Group

*USDW = Underground Source of Drinking Water

MODEL REFINEMENT

Version 1 (2009–2012)

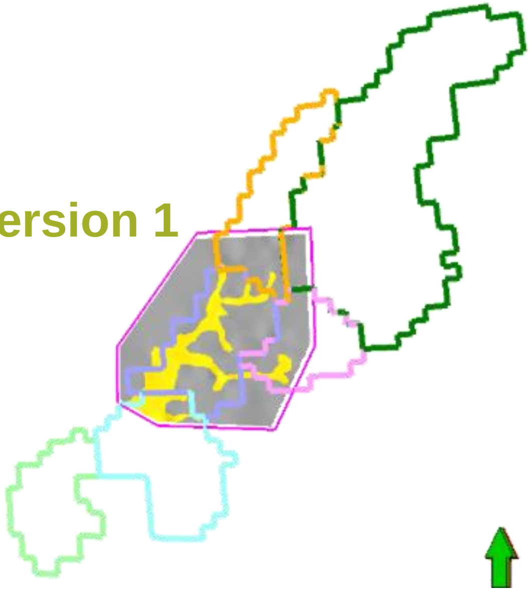
- Phase 1 geomodel
- Simulation model
  - Phase 1 history-matched (pre-CO_2) and performance forecasts

Version 2 (2012–2015)

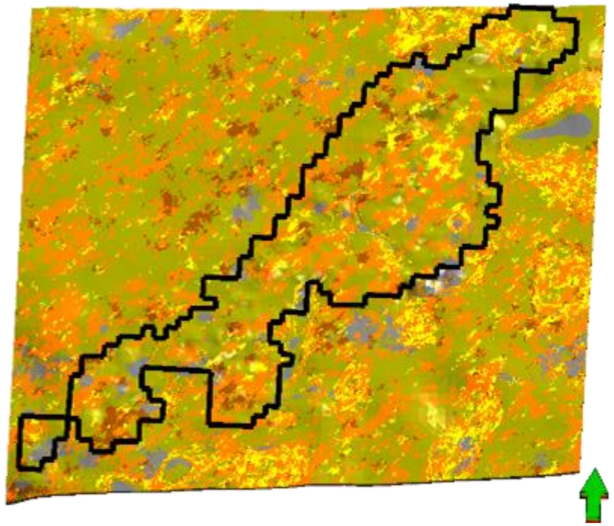
- Full-field geomodel
  - Electrofacies
- Phases 1 and 2 history-matched and performance forecasts

Version 3 (under development)

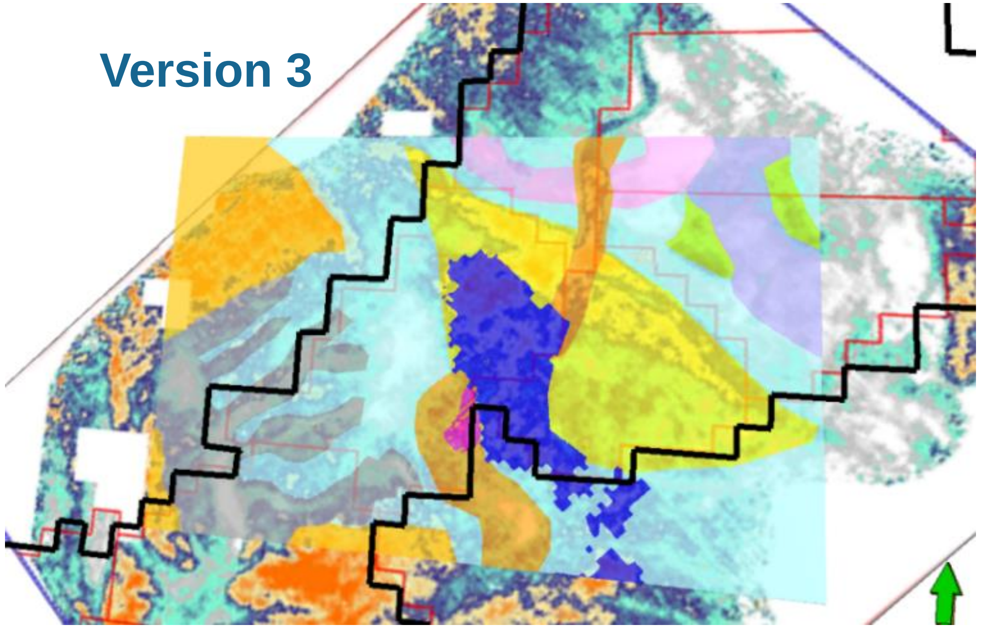
- Geobody interpretations and facies model
  - Trained with seismic data, logs, and core
  - Multiple-point statistics to populate facies with realistic heterogeneity
- Phases 1–4 history-matched and performance forecasts (pending)



Version 1



Version 2



Version 3

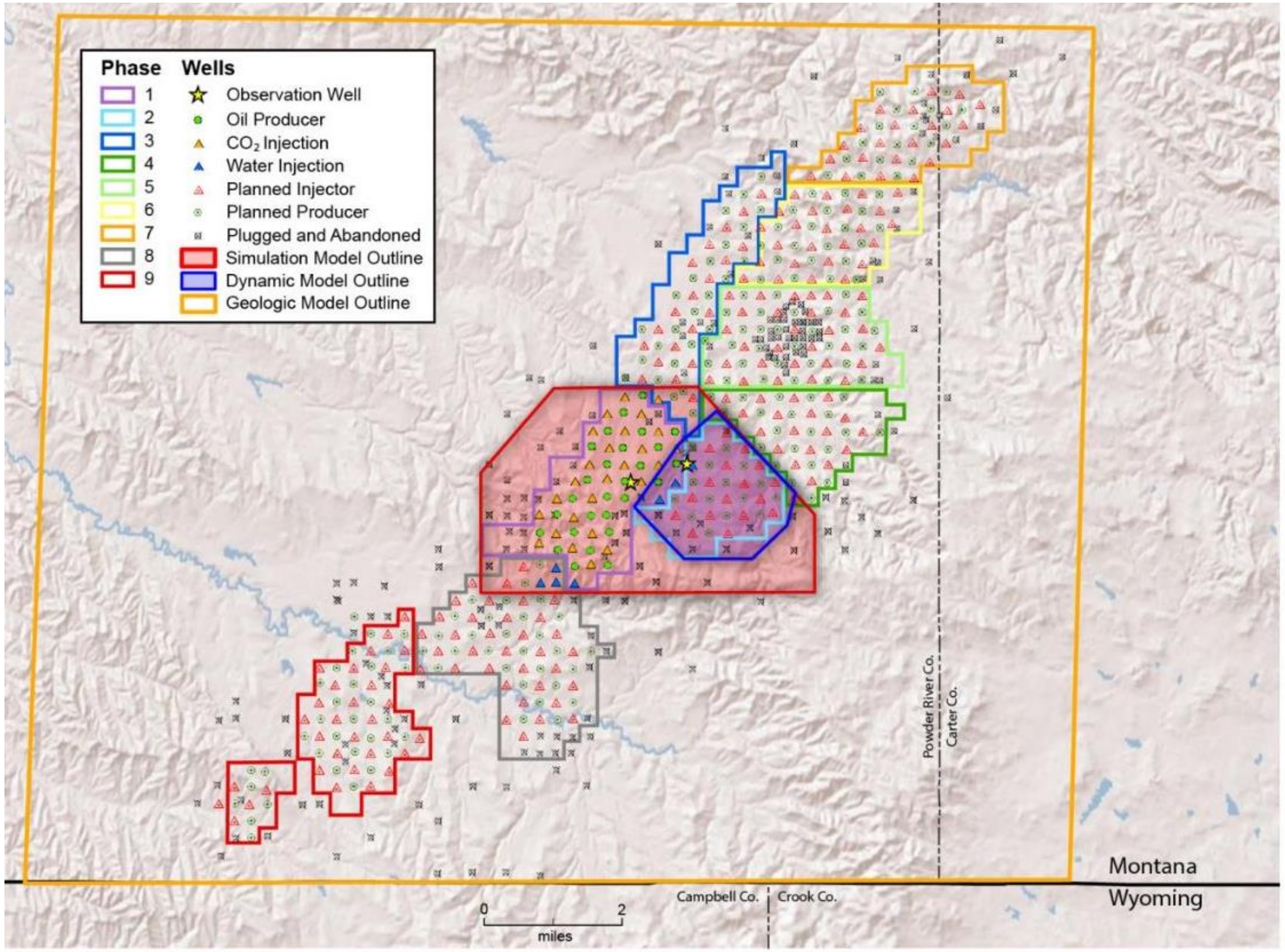
SIMULATION MODELS – COMBINED

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.



SIMULATION MODELS – WELL DISTRIBUTION

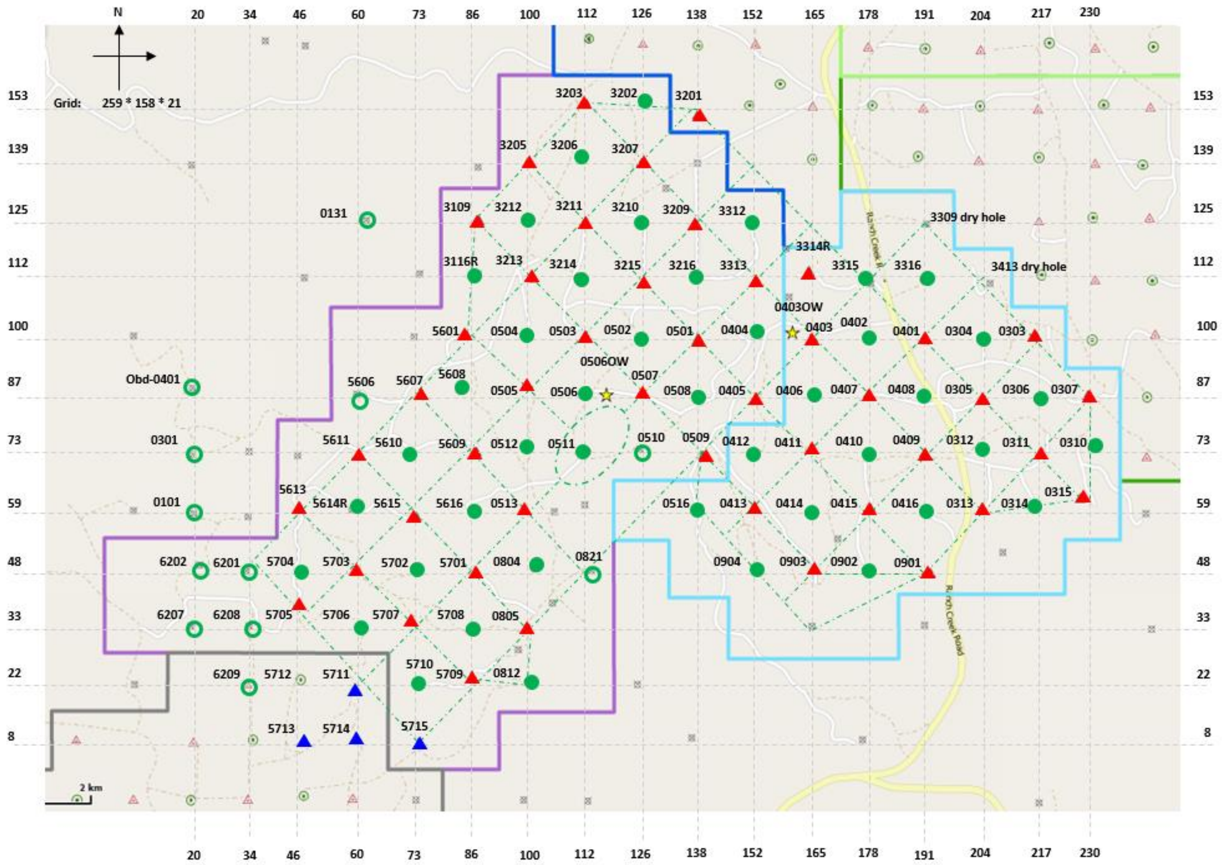
- CO$_2$/Water Injector
- Pure Water Injector
- Producer

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

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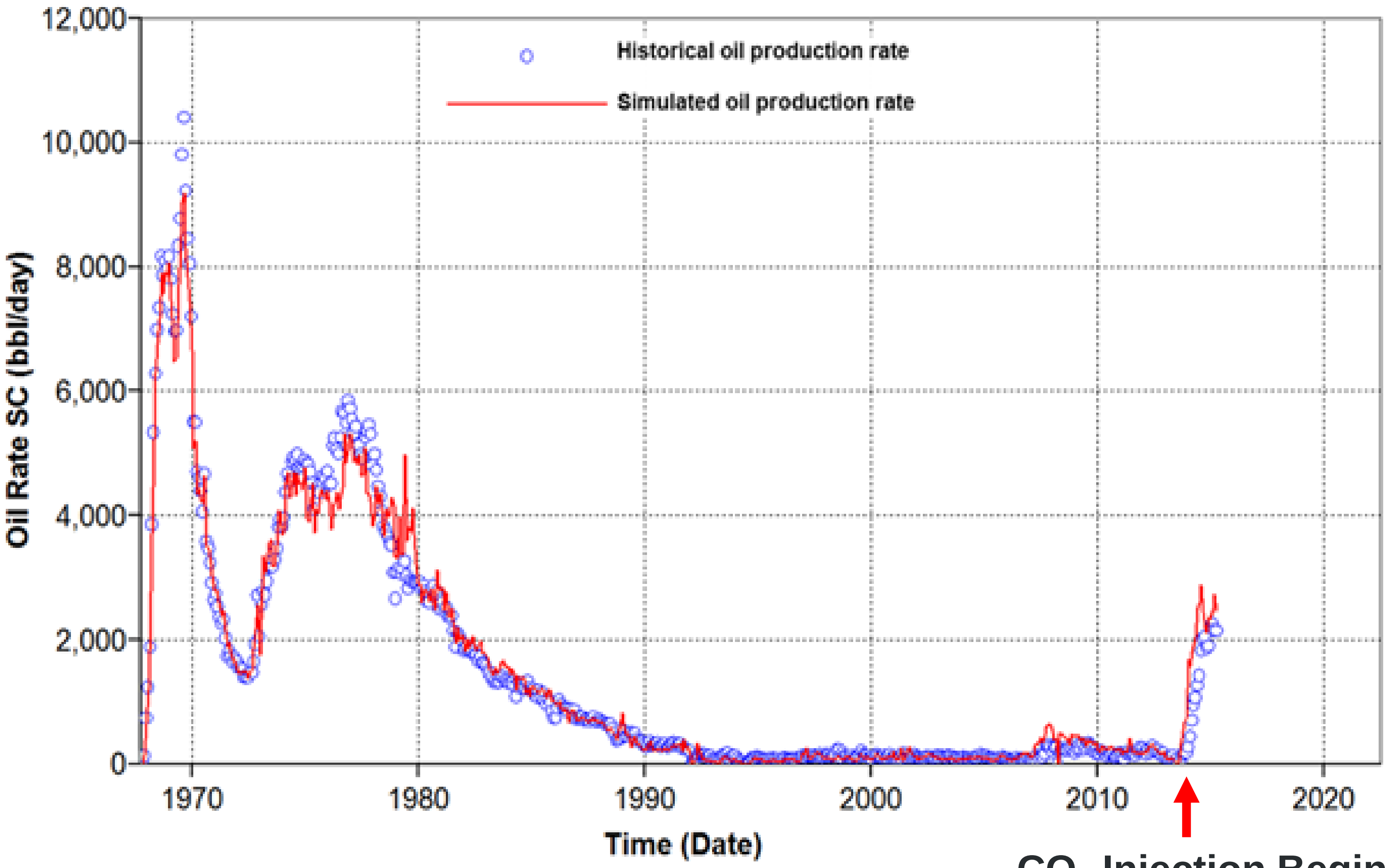
HISTORY MATCH RESULTS

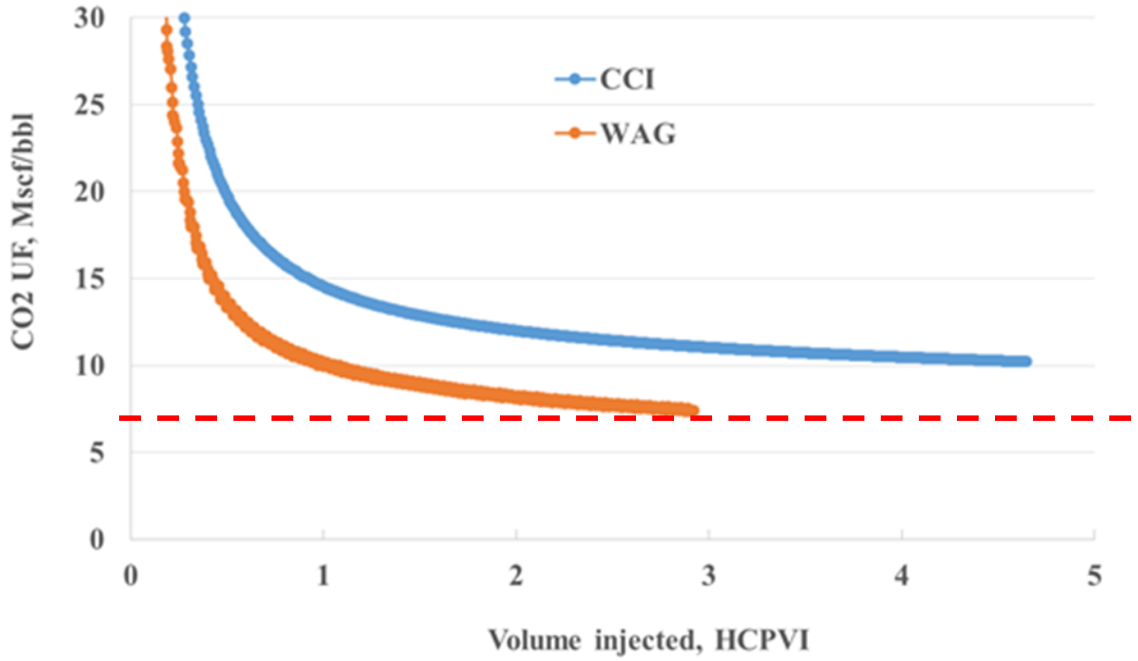


CO_2 Injection Begins

CO_2 UTILIZATION FACTOR

- CO_2 utilization factor (amount of CO_2 needed to produce 1 bbl of oil):
  - Water alternating gas (WAG): 10 mscf/bbl after 1 HCPVI, 7 mscf/bbl after 3 HCPVI
  - Continuous CO_2 injection (CCI): >10 mscf/bbl even after 4 HCPVI

Conclusion: WAG requires less CO_2 than CCI to produce the same amount of oil. In agreement with other CO_2 EOR projects.*

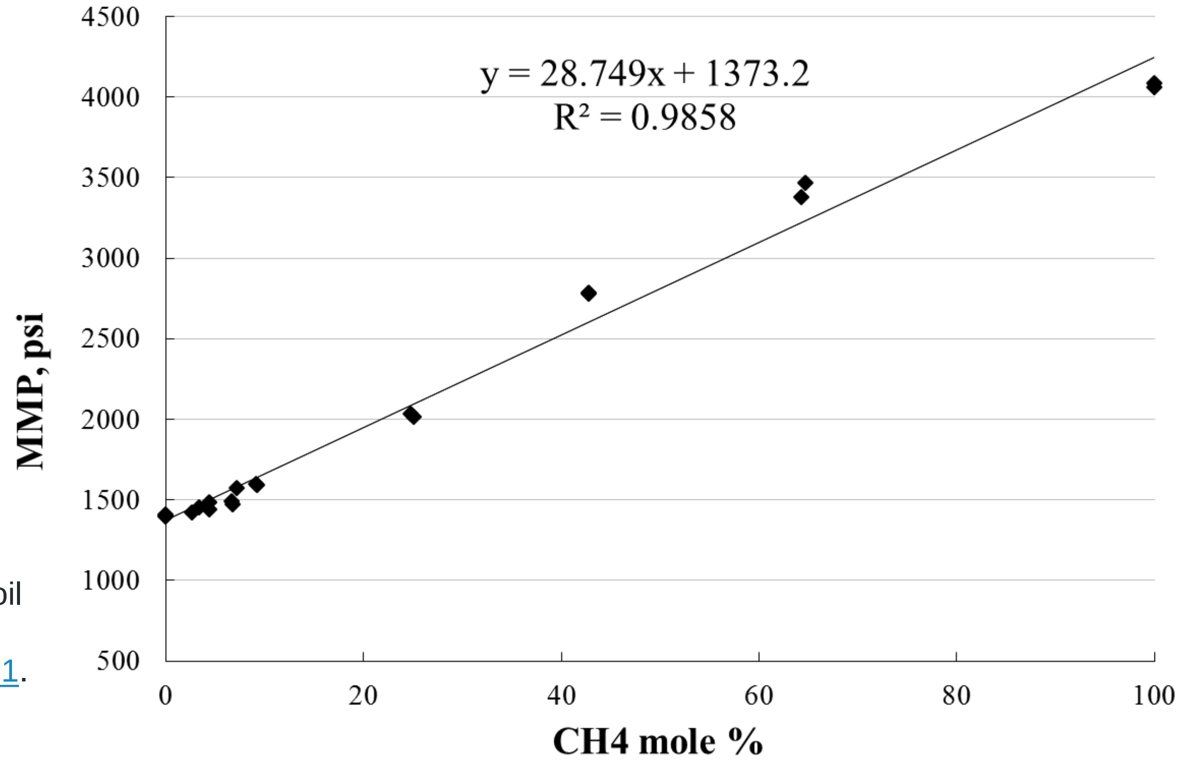


*Azzolina, N.A., Nakles, D.V., Gorecki, C.D., Peck, W.D., Ayash, S.C., Melzer, L.S., and Chatterjee, S., 2015, CO_2 storage associated with CO_2 enhanced oil recovery—a statistical analysis of historical operations: International Journal of Greenhouse Gas Control, v. 37, p. 384–397.

WHAT ARE THE EFFECTS OF SMALL AMOUNT OF CH_4 (1%~4%) IN THE PRODUCED CO_2?

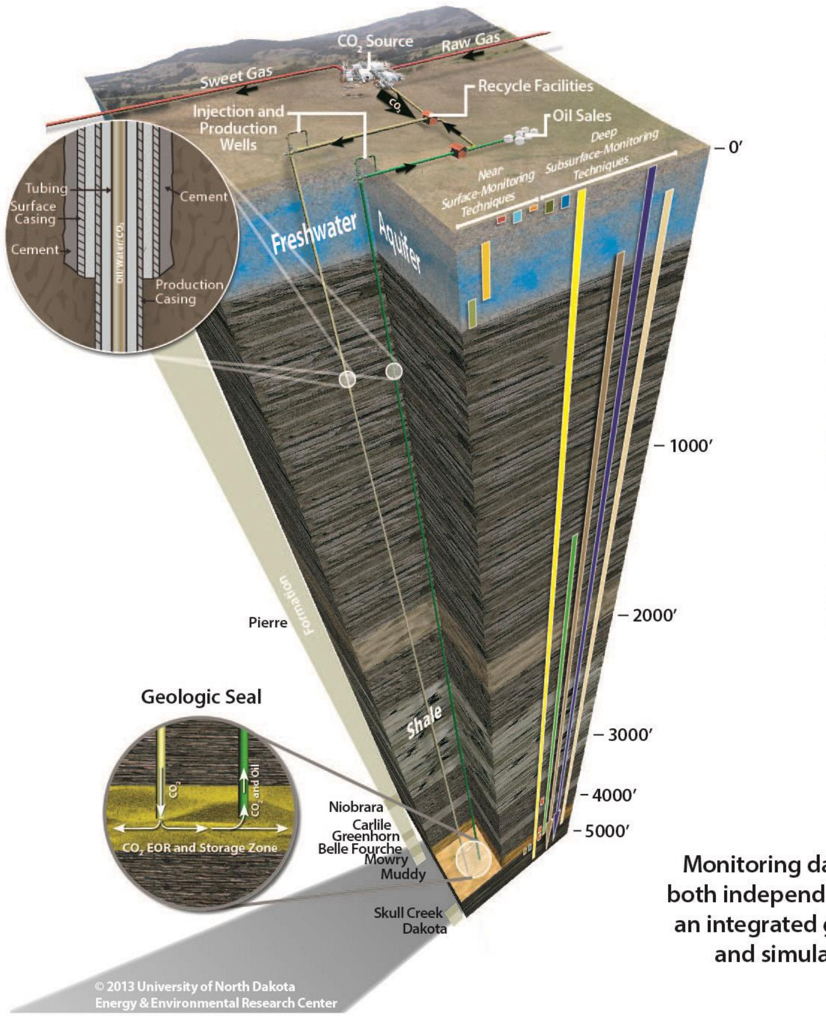
Vanishing interfacial tension (VIT) methods were used to measure minimum miscibility pressure (MMP) as CH_4 mole percentage increases from 0 to 100% in the solvent phase (T = 42°C).

Miscible flooding is still reachable when CH_4 is less than 36% and reservoir pressure is above 2500 psi.



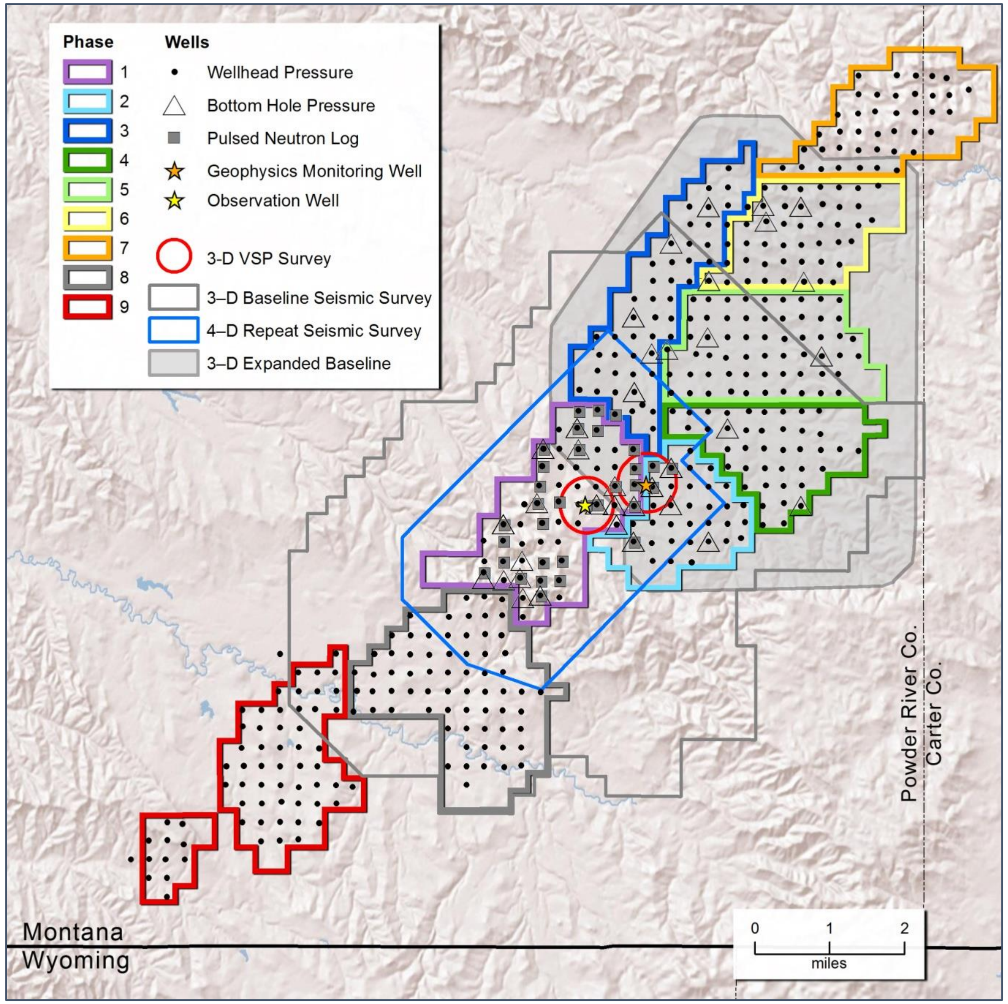
Hawthorne, S.B., Miller, D.J., Jin, L., and Gorecki, C.D., 2016, Rapid and simple capillary-rise/vanishing interfacial tension method to determine crude oil minimum miscibility pressure—pure and mixed CO_2, methane, and ethane: Energy & Fuels, http://pubs.acs.org/doi/abs/10.1021/acs.energyfuels.6b01151.

BELL CREEK – OPERATIONAL MVA

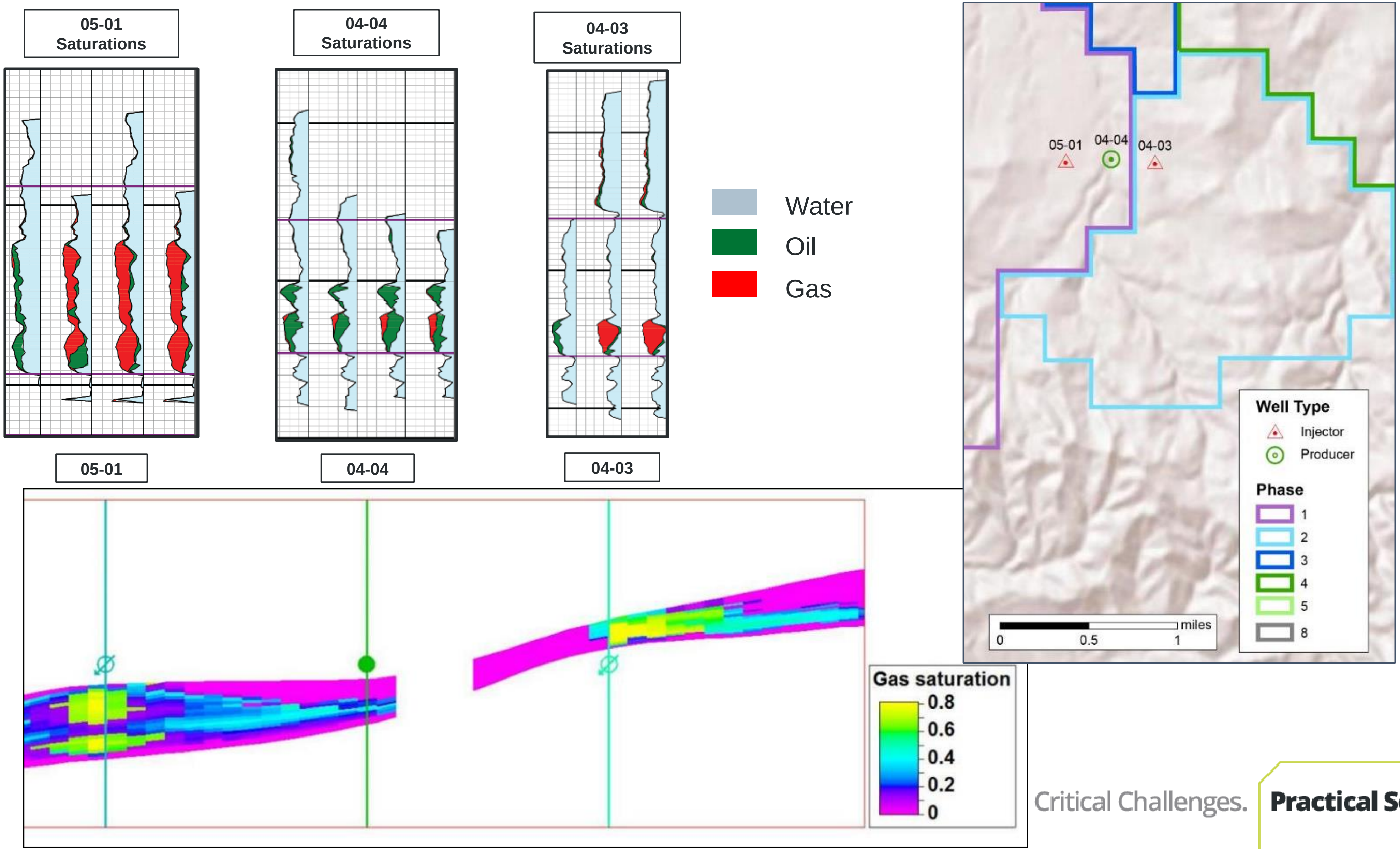


- Fox Hills Groundwater Wells
- Groundwater Wells
- Surface Water
- Soil Gas Profile Stations
- Soil Gas Probes
- Production and Injection Rates
- Wellhead Pressure Monitoring
- Temperature PDM
- Pressure PDM
- 3-D Time-Lapse VSP
- 3-D Time-Lapse Seismic
- Passive Seismic Monitoring
- Neutron Logging

Monitoring data are interpreted both independently and as part of an integrated geologic modeling and simulation workflow.

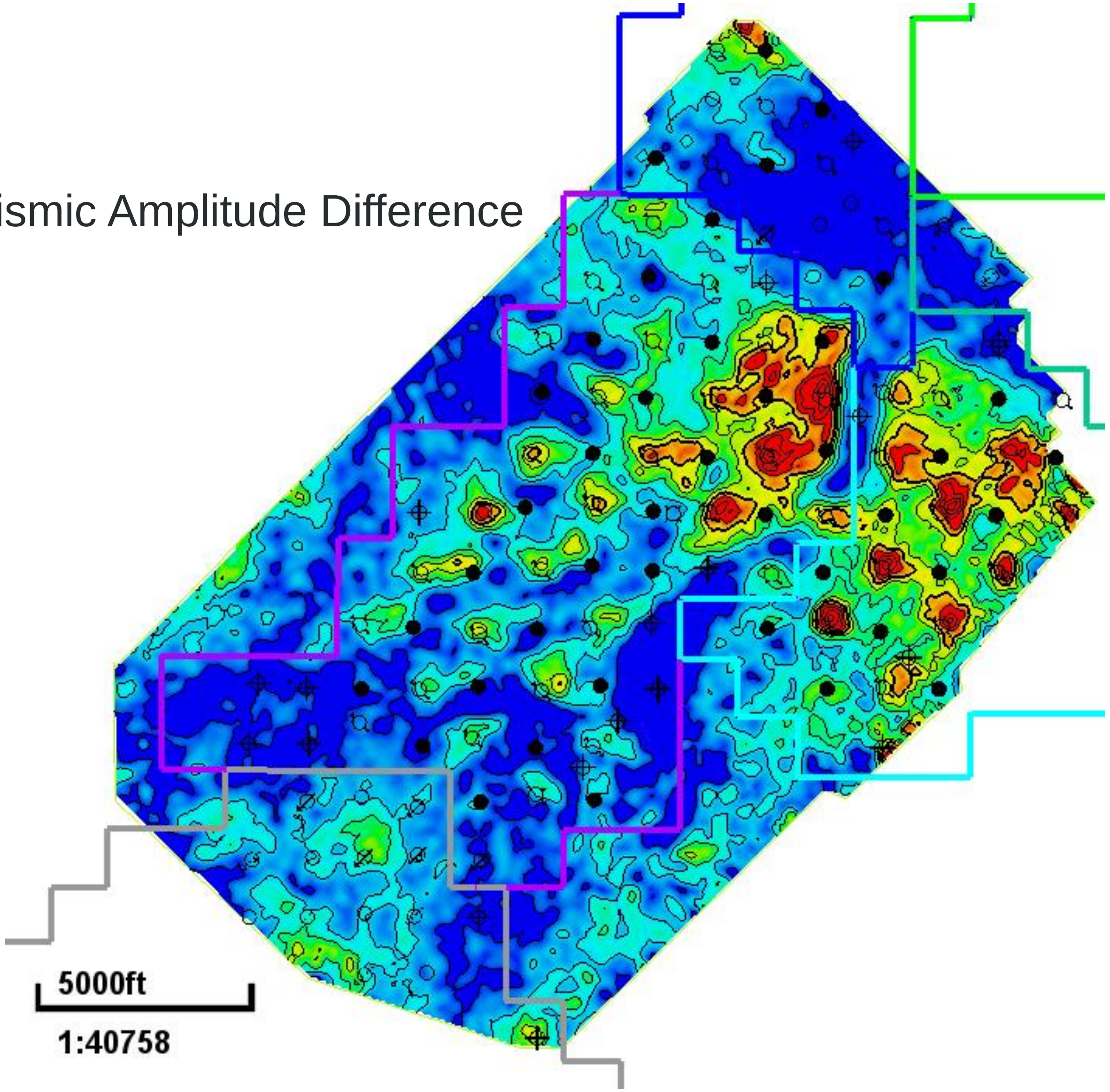


MVA FOR MODEL VALIDATION – PULSED-NEUTRON LOGGING

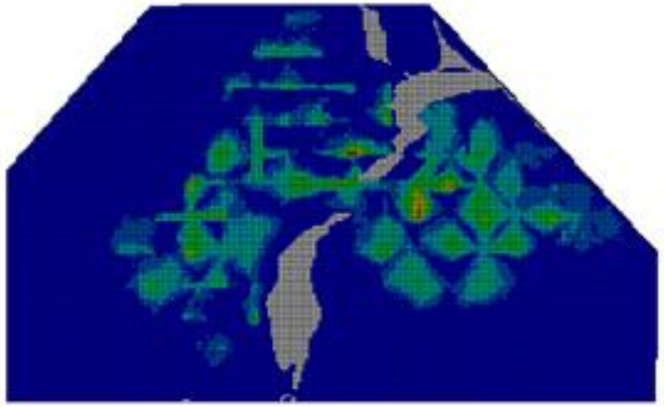


MVA FOR MODEL VALIDATION – SEISMIC

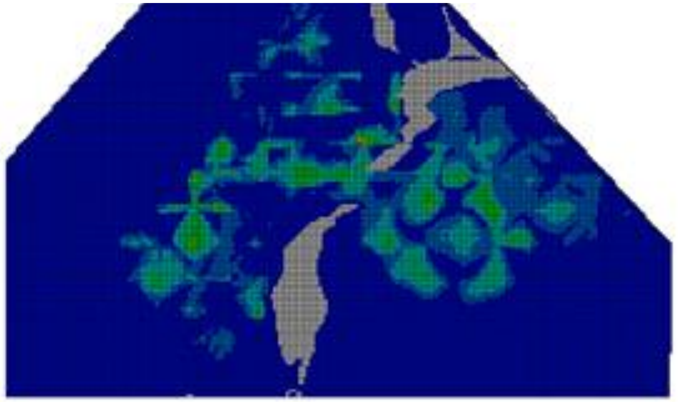
4-D Seismic Amplitude Difference



Simulation Results



CCI, 1 HCPVI



WAG, 1 HCPVI

AQUISTORE PROJECT

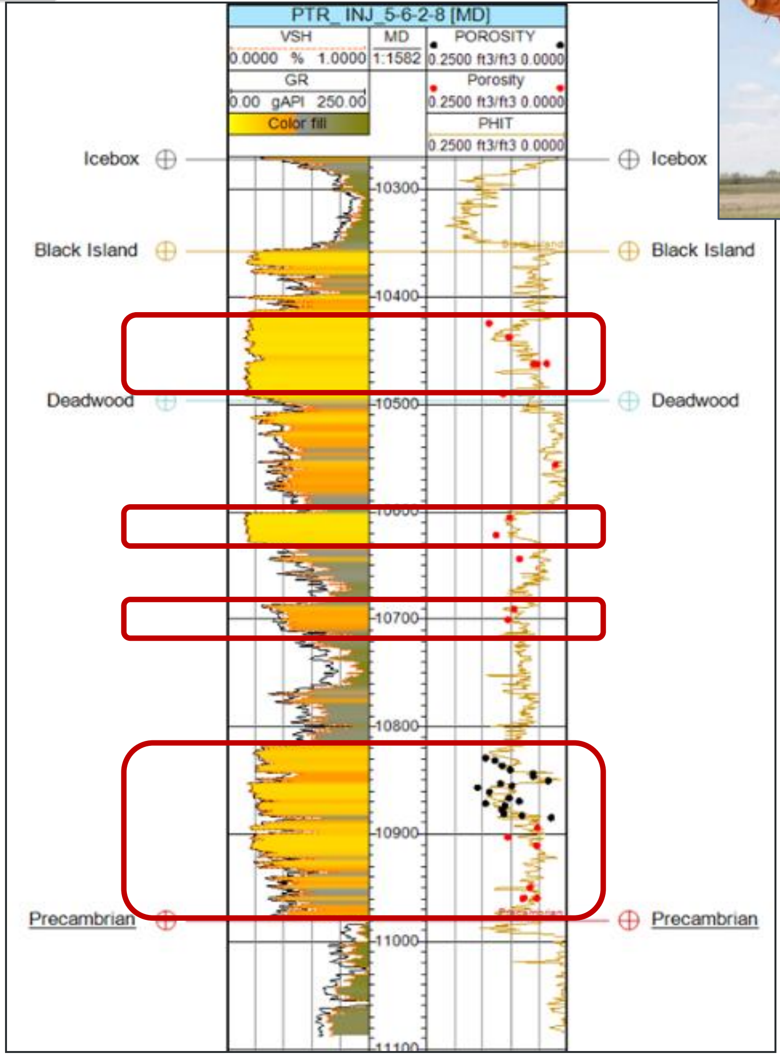
- Injection of CO_2 from the Boundary Dam Power Station in southeastern Saskatchewan began in April 2015.

- 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).

EERC

AQUISTORE INJECTION

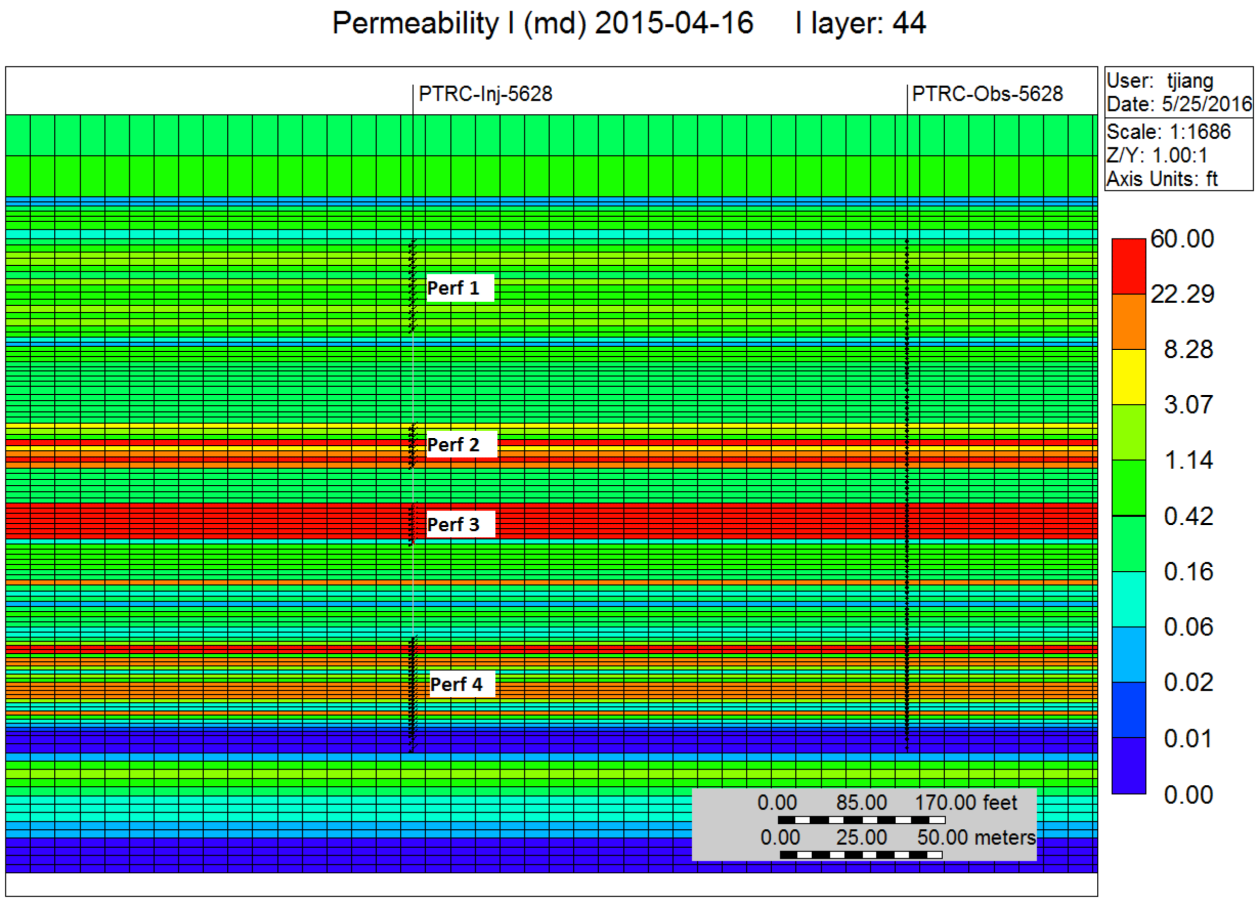


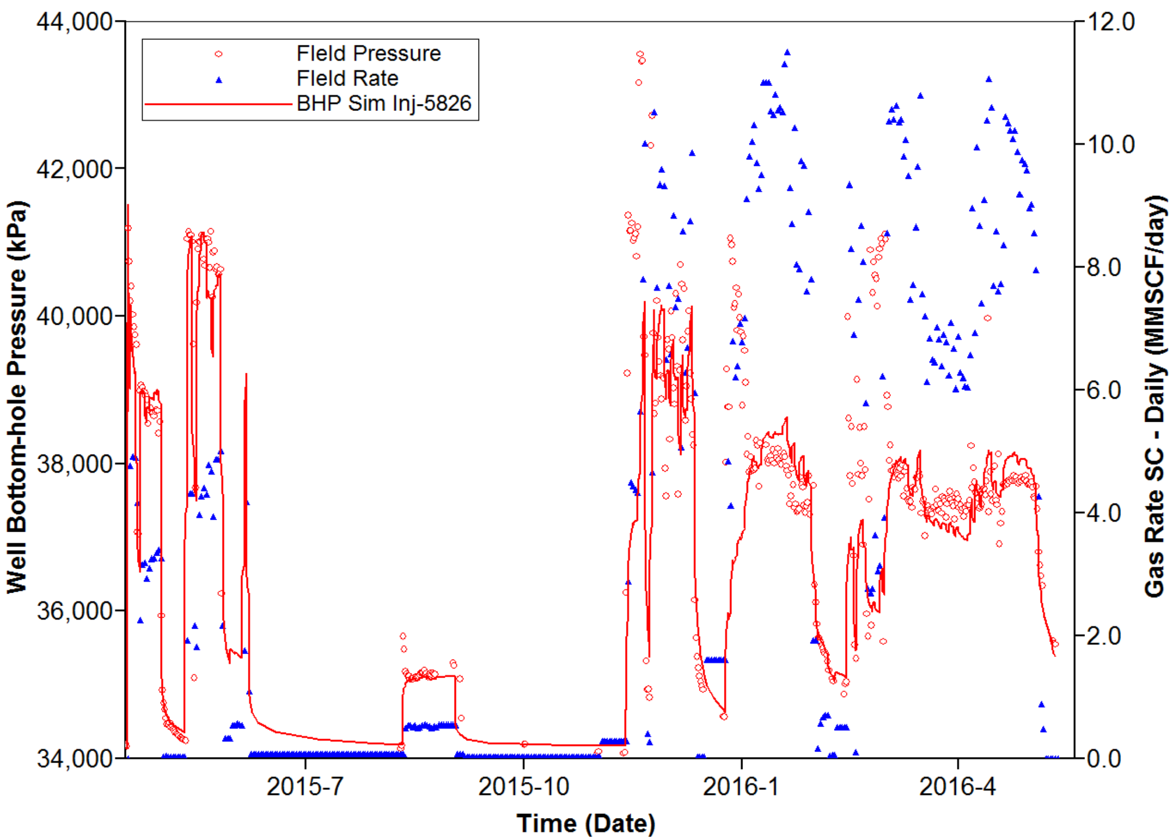
- Target saline formations:
  - Deadwood and Black Island Formations ~3200 m (10,500 ft) deep, >50 m (>150 ft) thick.
- ~75,000 tonnes of CO_2 injected (August 4, 2016)
- Injection rate of 350–550 tonnes/day

Critical Challenges. **Practical Solutions.**

HISTORY MATCH

- Injection data are being used to history-match in near-real time.
- MVA field activities are being used to validate the models.



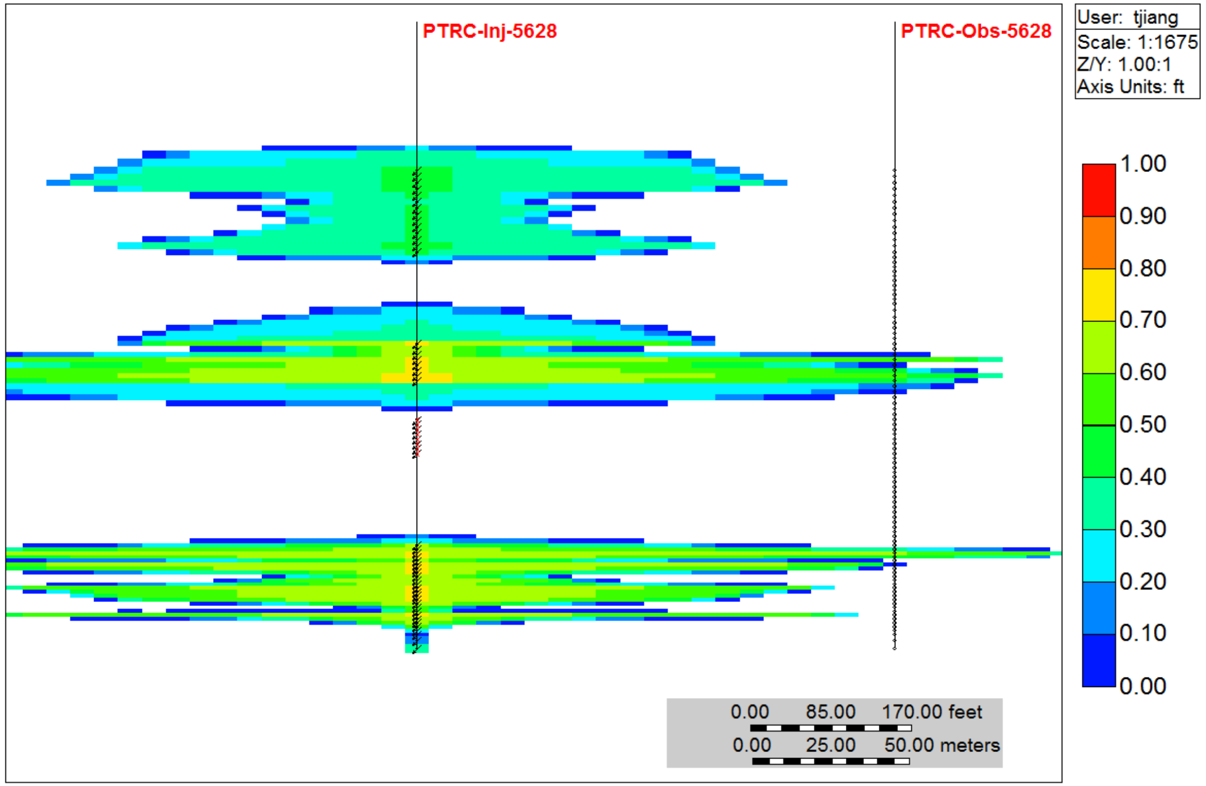


AQUISTORE

May 2016:

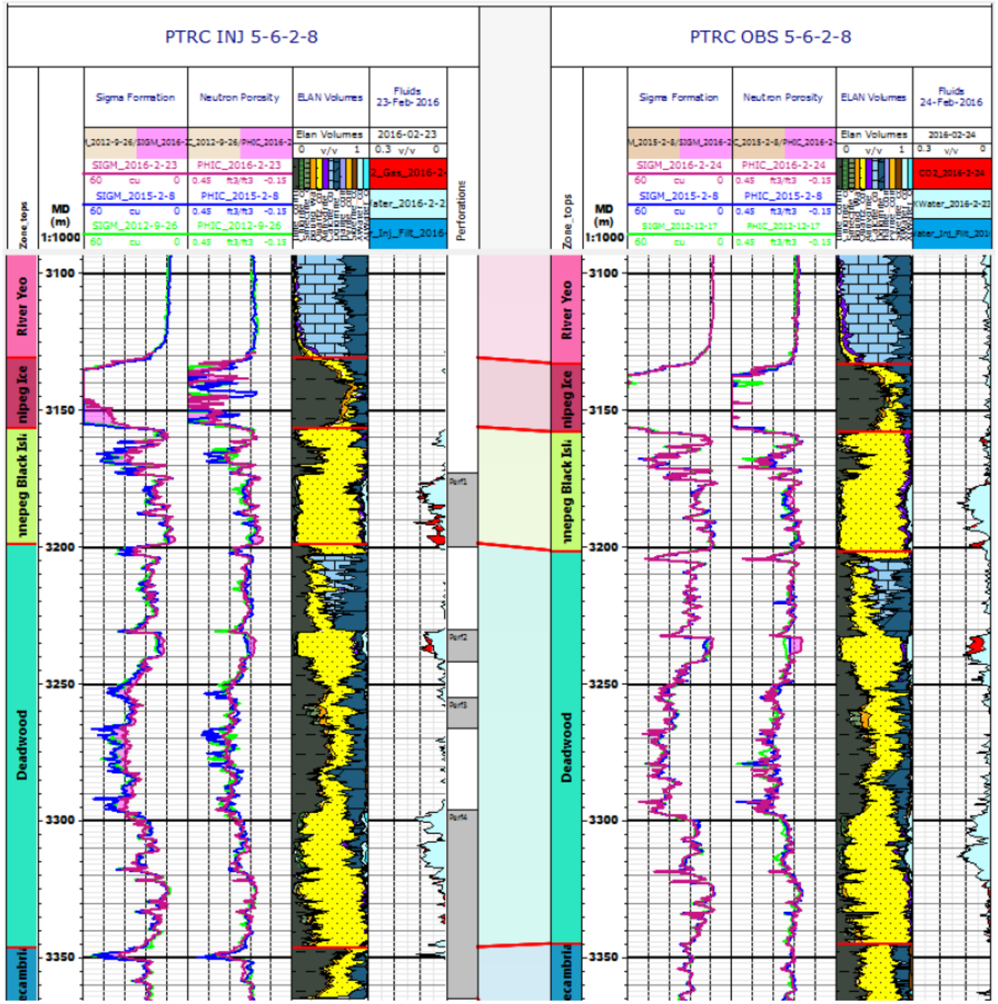
- CO_2 plume prediction: Plume reached the observation well (~68,000 tonnes cumulative injection).

Gas Saturation 2016-05-11   I layer: 44



February 2016:

- CO_2 breakthrough was observed in second perforation interval at observation well.

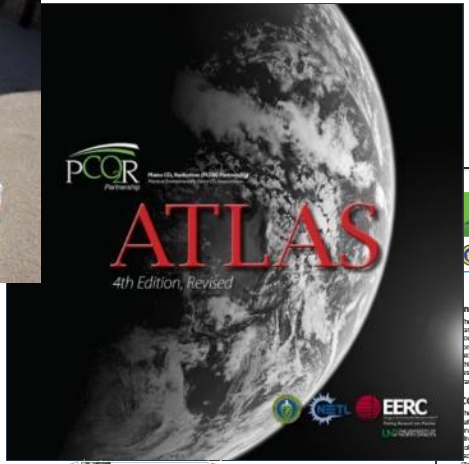


RST interpretation, *Schlumberger*

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

- **CO_2 EOR produces oil while also storing CO_2. Nearly all the CO_2 purchased for EOR is eventually stored.**
- **CO_2 storage associated with commercial CO_2 EOR is being investigated at the Bell Creek project. Over 3.2 million metric tons of associated CO_2 storage as of June 2016.**
- **CO_2 is being injected into a saline formation at Aquistore as buffer storage for CO_2 produced from a coal-fired electricity-generating facility.**
- **Characterization activities indicate the PCOR Partnership region has incredible potential for CO_2 storage in saline formations and through CO_2 EOR.**
- **Outreach activities and complementary projects continue to support the PCOR Partnership Program.**

ACKNOWLEDGMENT

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Disclaimer

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THANK YOU!

Critical Challenges. **Practical Solutions.**

BENEFIT TO THE PROGRAM

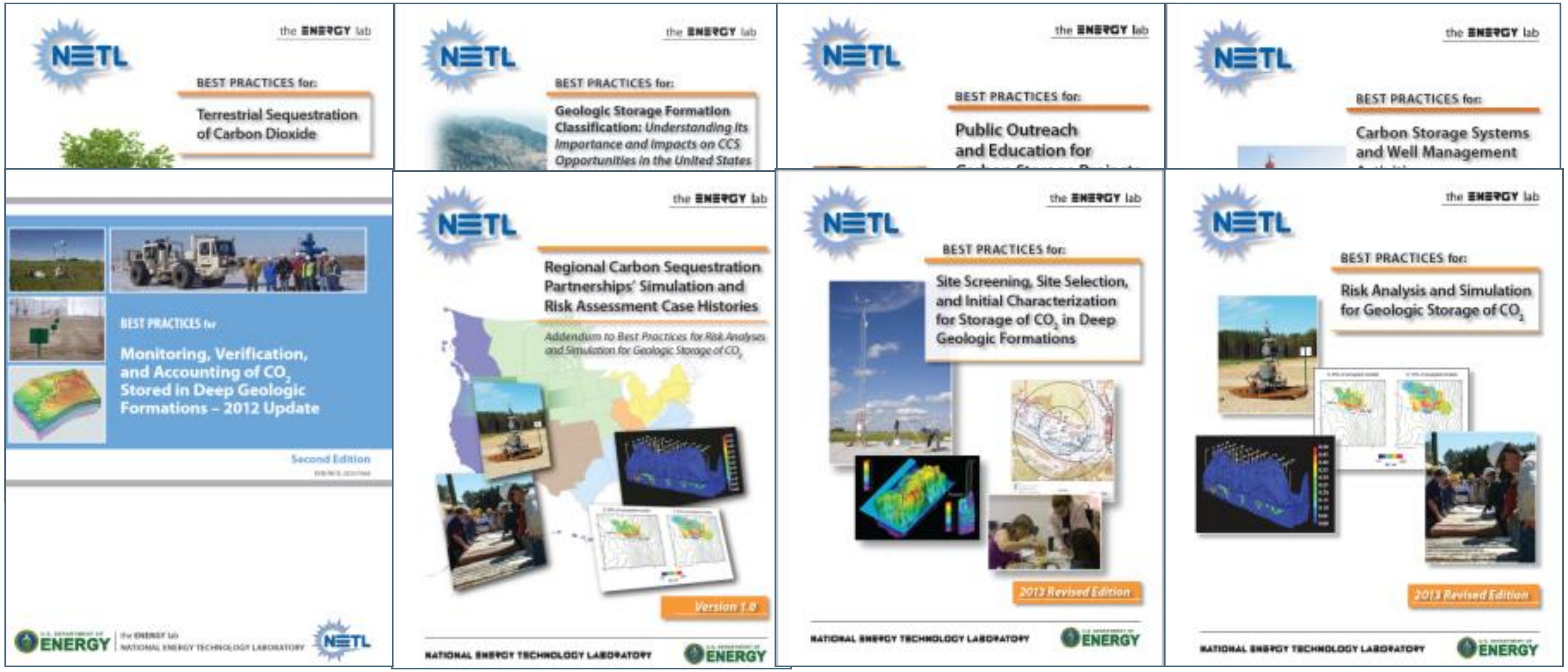
- Develop technologies that will support the industry's ability to predict carbon dioxide (CO_2) storage capacity in geologic formations to within ±30%:
  - *Conducting pilot tests and demonstration projects in hydrocarbon reservoirs, saline formations, and coal seams to study sweep and storage efficiency in each project.*
  - *Evaluating multiple oil fields, saline formations, and coal seams in the Plains CO_2 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 CO_2 storage resource in saline formations and hydrocarbon reservoirs.*
    - *Joint IEA Greenhouse Gas R&D Programme (IEAGHG) and U.S. Department of Energy (DOE) project – Development of Storage Coefficients for Carbon Dioxide Storage in Deep Saline Formations, Report No. 2009/13 (completed 2009)*
    - *DOE project – Optimizing and Quantifying CO_2 Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs (active 2012–2015)*
    - *Joint IEAGHG and DOE project – CO_2 Storage Efficiency in Deep Saline Formations (active 2013–2014)*

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.*



BENEFIT TO THE PROGRAM (con't)

- *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 CO_2 Storage and CO_2 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.

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