
EERC
UNIVERSITY OF NORTH DAKOTA
Critical Challenges.
Practical Solutions.

Energy & Environmental Research Center (EERC)

PLAINS CO_2 REDUCTION (PCOR) PARTNERSHIP

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National Energy Technology Laboratory

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

August 13–16, 2018

Critical Challenges. Practical Solutions.

PRESENTATION OUTLINE

- PCOR Partnership Overview
- PCOR Partnership Accomplishments
- CO_2 Life Cycle Assessment
- Integrating Monitoring, Verification, and Accounting (MVA) Techniques
- Technology Transfer and Outreach

A TRUE PARTNERSHIP!

PCOR Partnership 2003 – Present

8/18

A GROWING PARTNERSHIP!

PCOR Partnership 2003 – Present

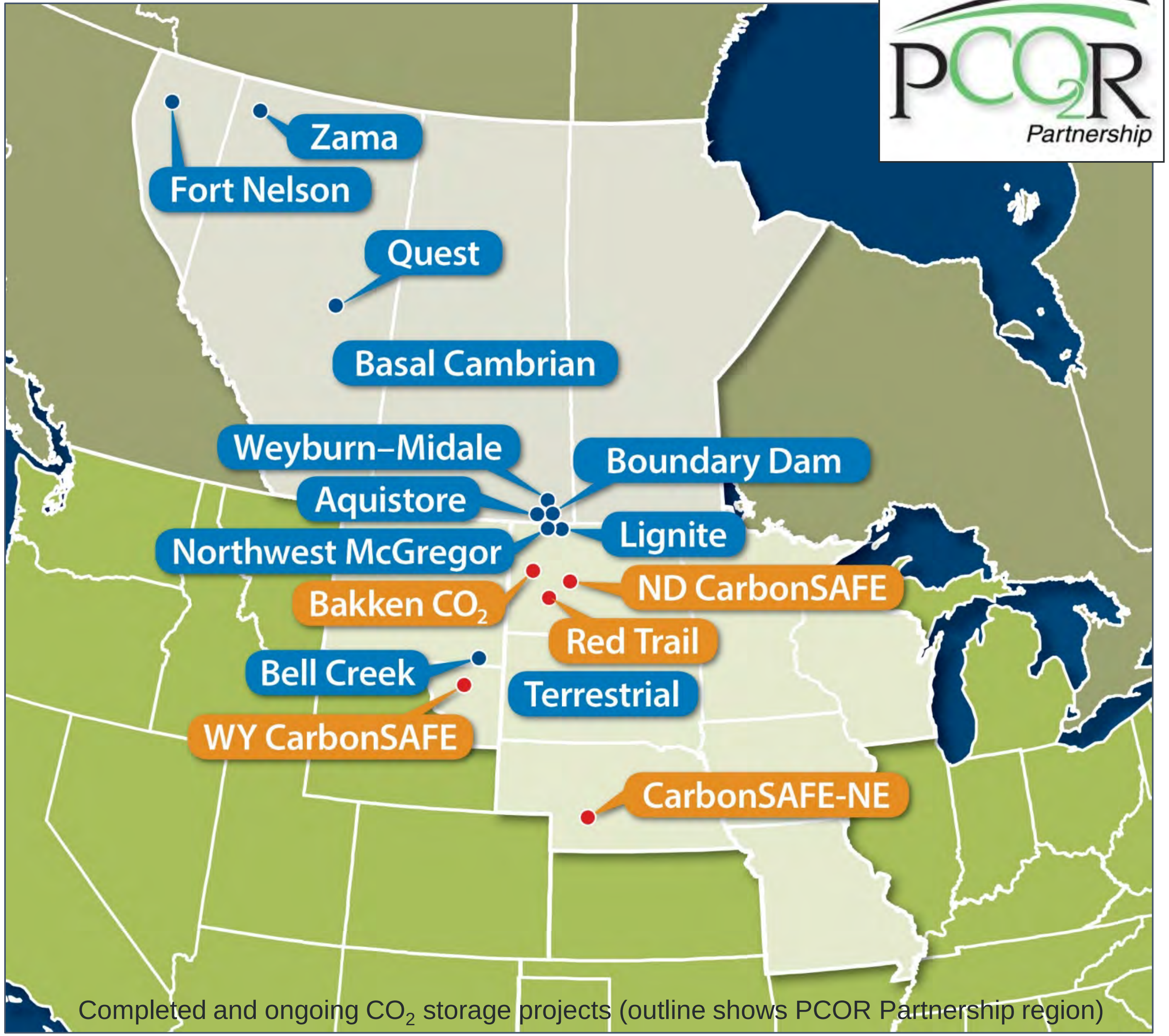
AN ENGAGED PARTNERSHIP

Images Credit – EERC

AN EFFECTIVE PARTNERSHIP

AN ACTIVE REGION

Encouraging the commercial deployment of carbon capture, utilization, and storage (CCUS) in the region.



Completed and ongoing CO_2 storage projects (outline shows PCOR Partnership region)

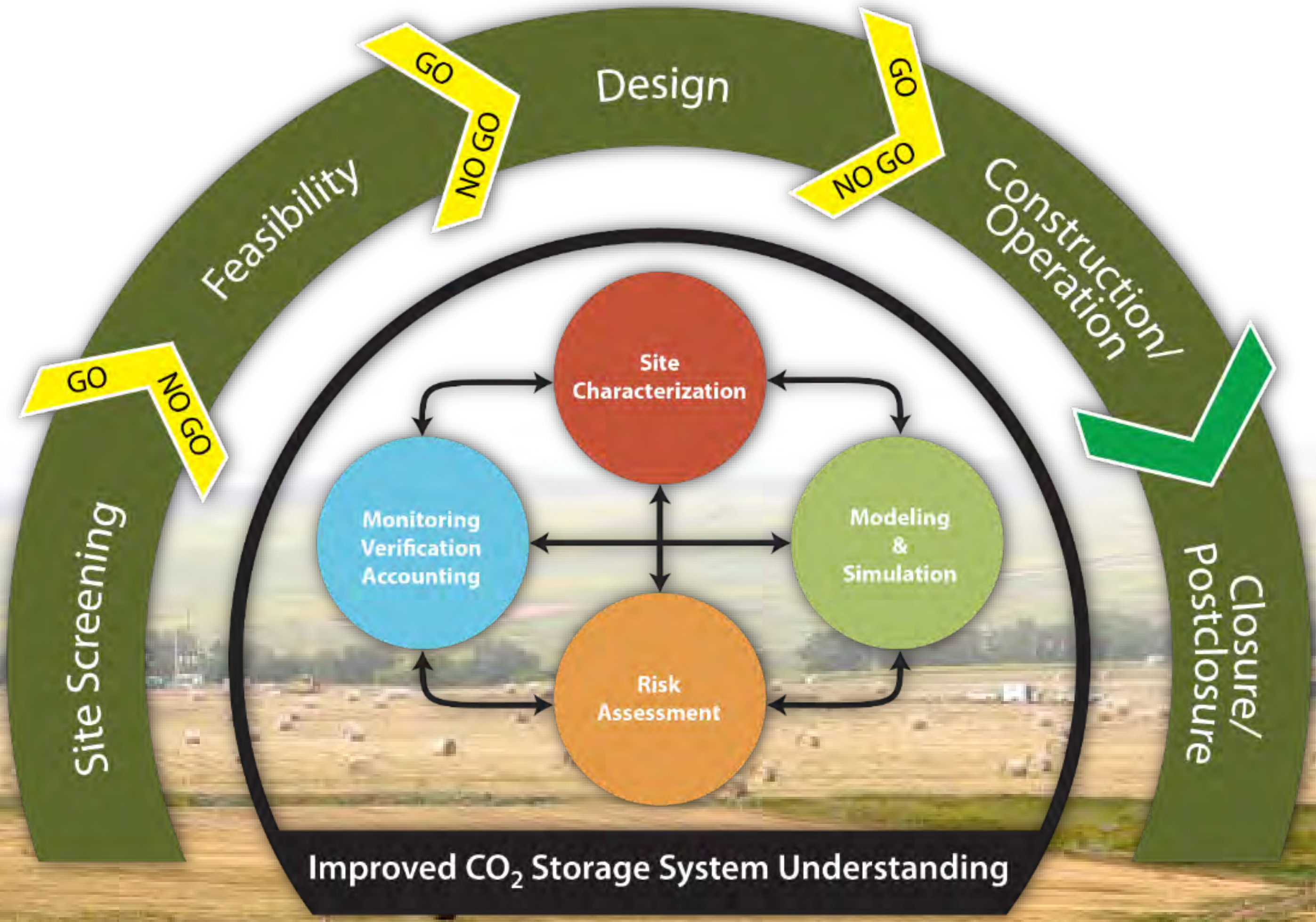
Image Credit – EERC

ACCOMPLISHMENTS TO DATE

The PCOR Partnership has successfully:

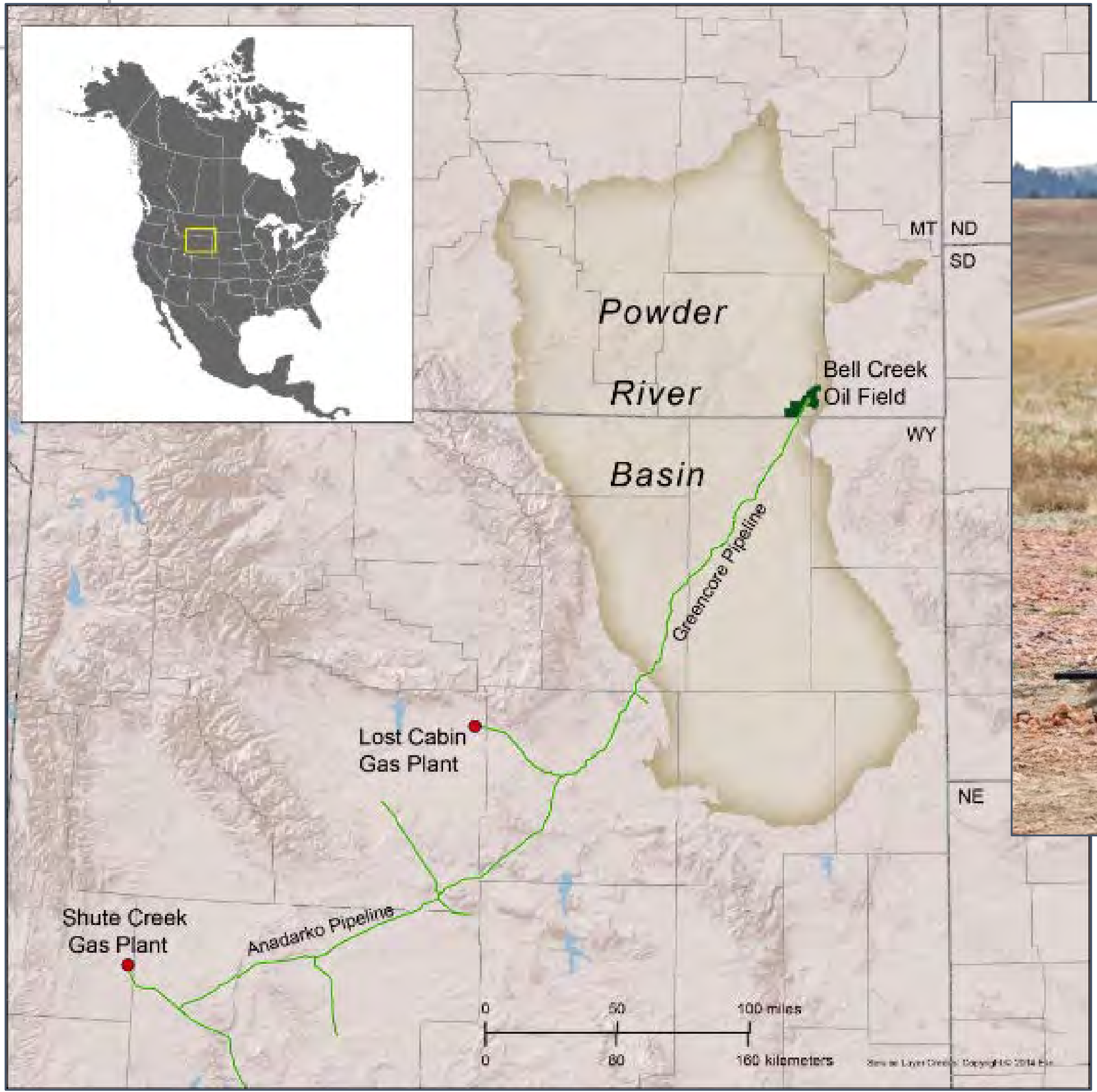
- Integrated technical data using an adaptive management approach to demonstrate secure carbon dioxide (CO_2) storage.
- Applied MVA strategies to track the presence and movement of injected CO_2, and found no evidence of out-of-zone migration of CO_2.
- Developed a regional vision for carbon capture and storage (CCS), and fostered active engagement from the partners, resulting in a pathway to commercial-scale CCS deployment.

CCUS WORKS!

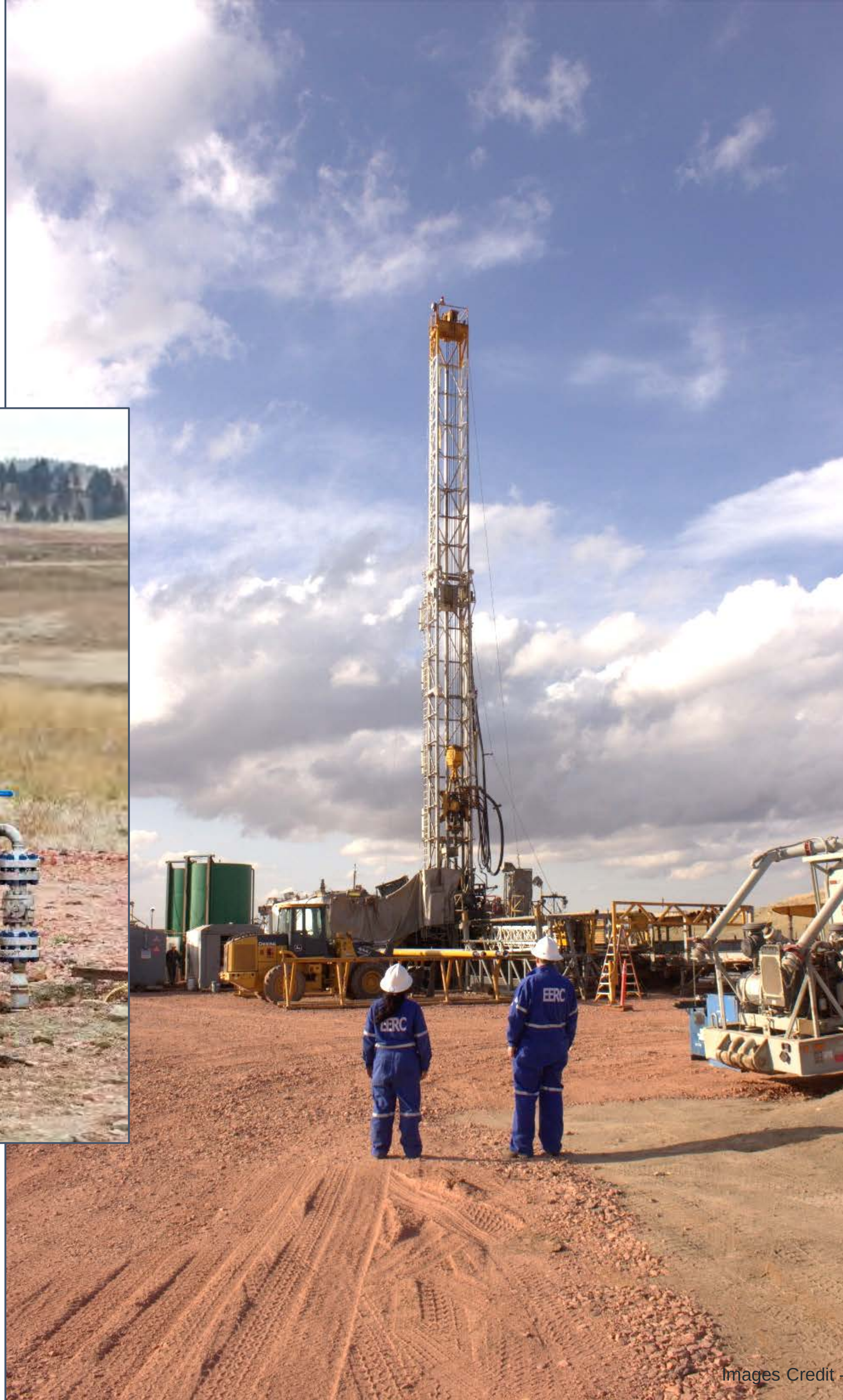


Images Credit – EERC

BELL CREEK


MT
ND
SD
Powder
River
Basin
Bell Creek
Oil Field
WY
Greencore Pipeline
Lost Cabin
Gas Plant
NE
Shute Creek
Gas Plant
Anadarko Pipeline
0
50
100 miles
0
80
160 kilometers


Denbury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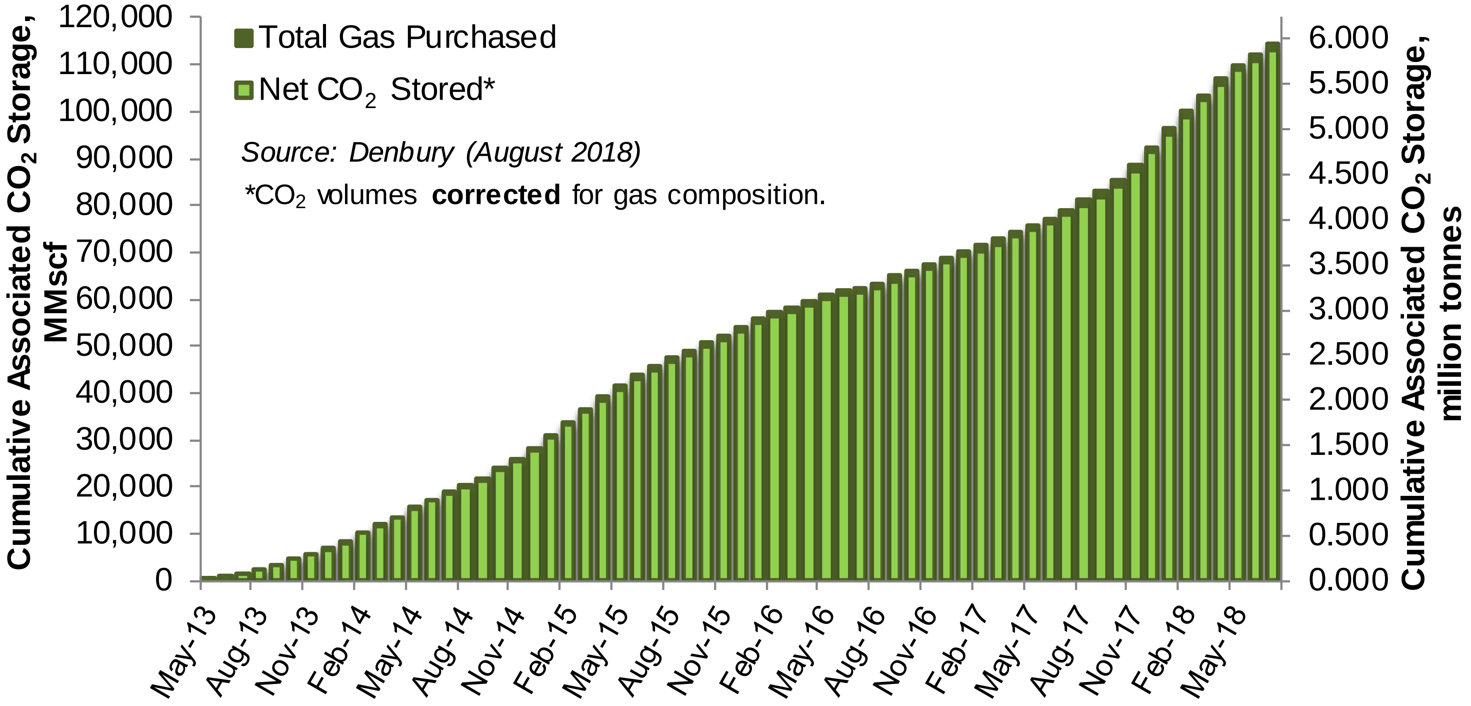
Images Credit

BELL CREEK ASSOCIATED CO_2 STORAGE

Associated CO_2 Storage:

As of March 2016 – ~3.0 million tonnes

As of July 2018 – ~5.9 million tonnes *(source: Denbury)*



As much as 15 million tonnes of CO_2 may be stored through enhanced oil recovery (EOR).

ENVIRONMENTAL AND ECONOMIC BENEFITS

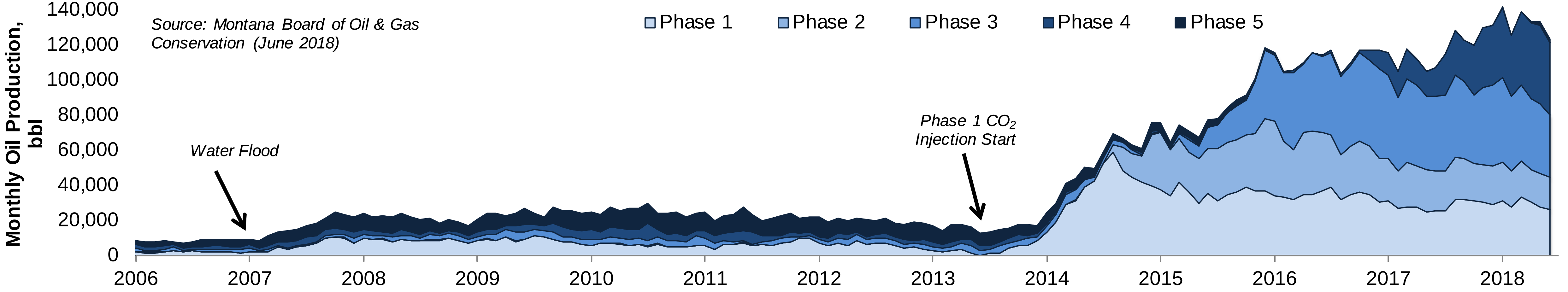


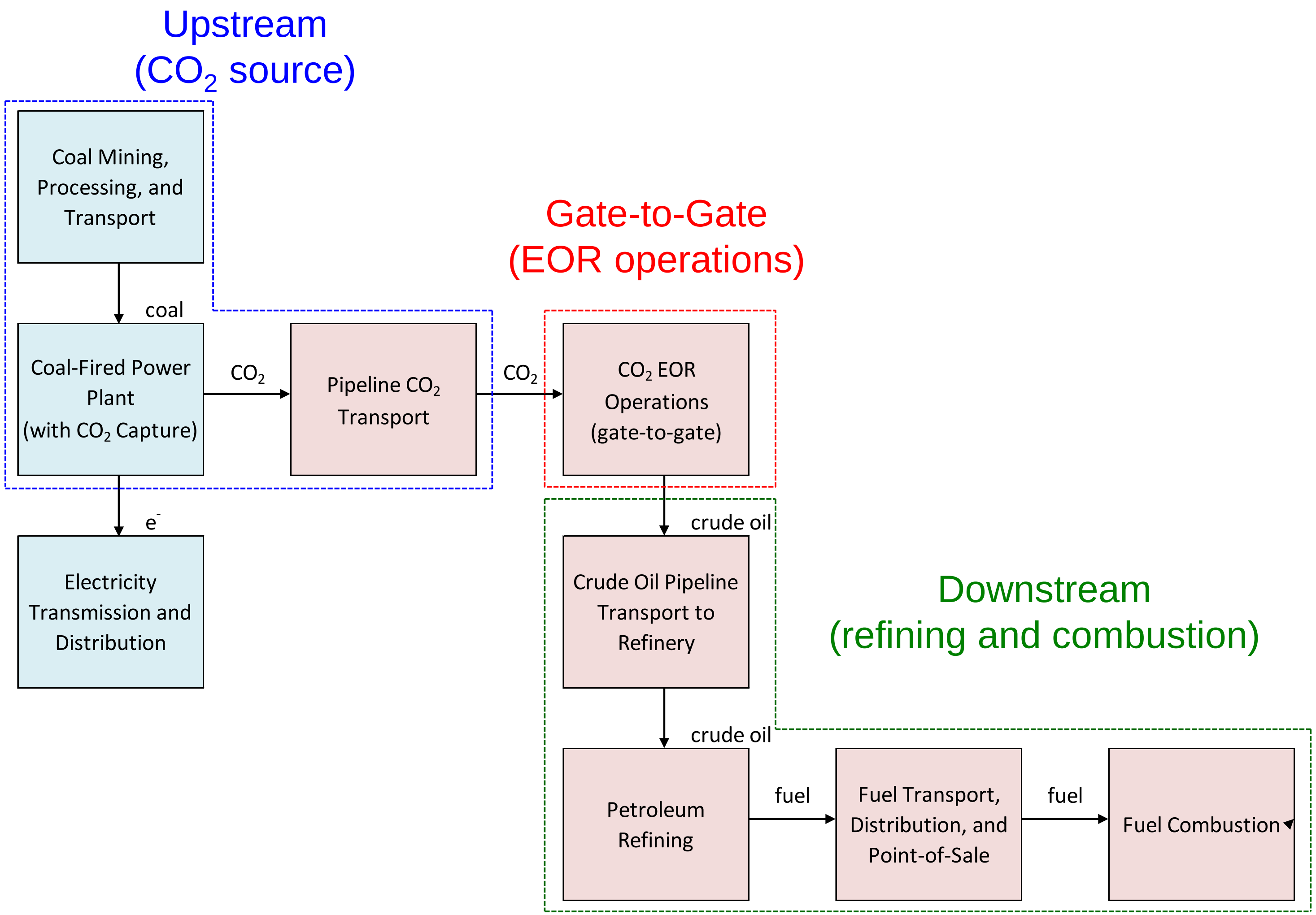
Image Credit – EERC

At Bell Creek:

- **Estimated 20–40 MMbbl of oil.**(1)
- **Nearly ~5.6 million bbls of oil has been produced since CO_2 EOR commenced.**

(1) Estimated proved plus potential tertiary reserves. Denbury, 2018, Presentation at the J.P. Morgan 2018 Global High Yield & Leveraged Finance Conference, February 26: http://s1.q4cdn.com/594864049/files/doc_presentations/2018/JP-Morgan-2017-Global-High-Yield-Leveraged-Finance-Conference-FINAL.pdf

EERC SYSTEM MODEL CAPTURES UPSTREAM → GATE-TO-GATE → DOWNSTREAM



GATE-TO-GATE = CARBON-NEGATIVE OIL

Upstream | Gate-to-Gate | Downstream

Emits: + 100 kg CO_2e/bbl

Stores: – 450 kg CO_2e/bbl

Net: – 350 kg CO_2e/bbl

- The EOR field stores more CO_2 than it emits.
- Ignores the source of CO_2.
- Ignores crude oil refining and combustion.

GATE-TO-GRAVE IS CARBON-POSITIVE, BUT STILL VERY GOOD

Upstream

Gate-to-Gate

Emits: + 100 kg CO_2e/bbl

Stores: – 450 kg CO_2e/bbl

Net: – 350 kg CO_2e/bbl

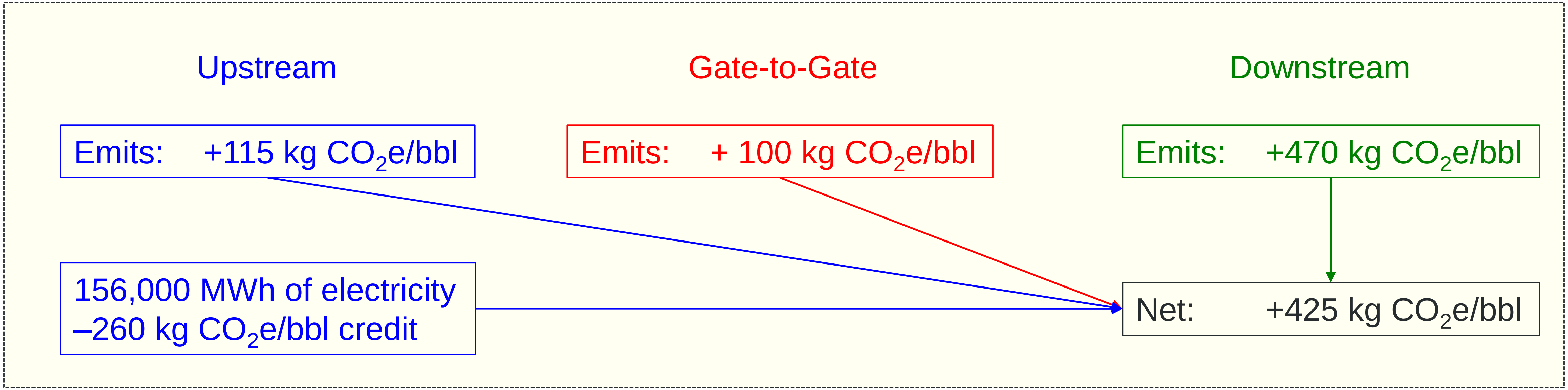
Downstream

Emits: +470 kg CO_2e/bbl

Net: +120 kg CO_2e/bbl

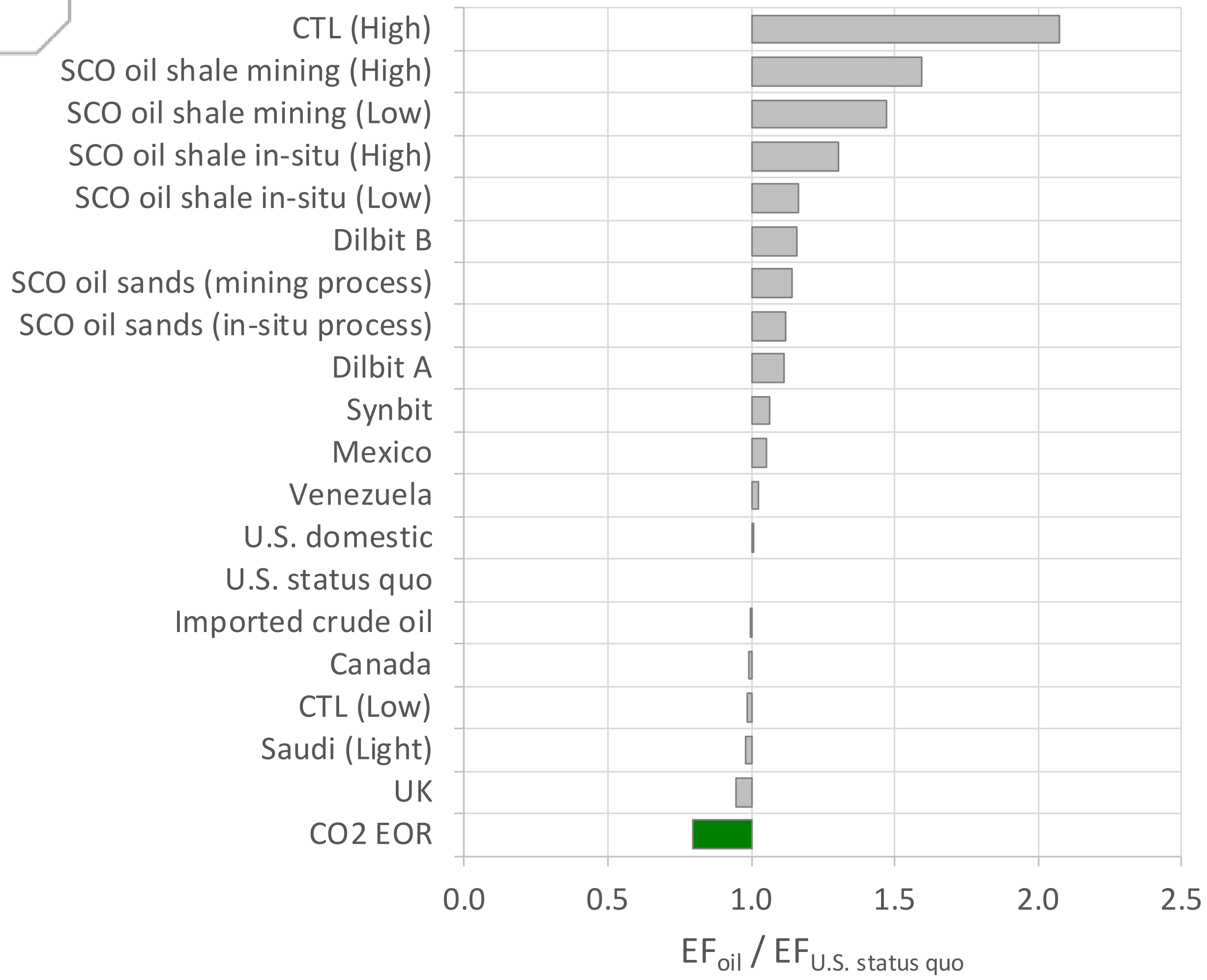
- The EOR field + refining and combustion result in carbon-positive oil – BUT – the net result is very low.
- Still ignores the source of CO_2.

CRADLE-TO-GRAVE



- Cradle-to-grave estimates of power–oil systems require additional calculations to account for electricity displacement.
- Results suggest that incremental oil is “lower-carbon oil,” with cradle-to-grave emission factors of **15% to 50% less** than conventional oil production (500 kg CO_2e/bbl).

COMPARISON TO OTHER SOURCES OF CRUDE OIL



- Example of <u>associated</u> CO_2 storage.
- CO_2 captured from a lignite coal-fired power plant.
- Displace electricity from the MRO NERC Region (Midwest Reliability Organization, North American Electric Reliability Corporation).
- **Oil via CO_2 EOR ~20% lower emission factor (EF).**

Adapted from:

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

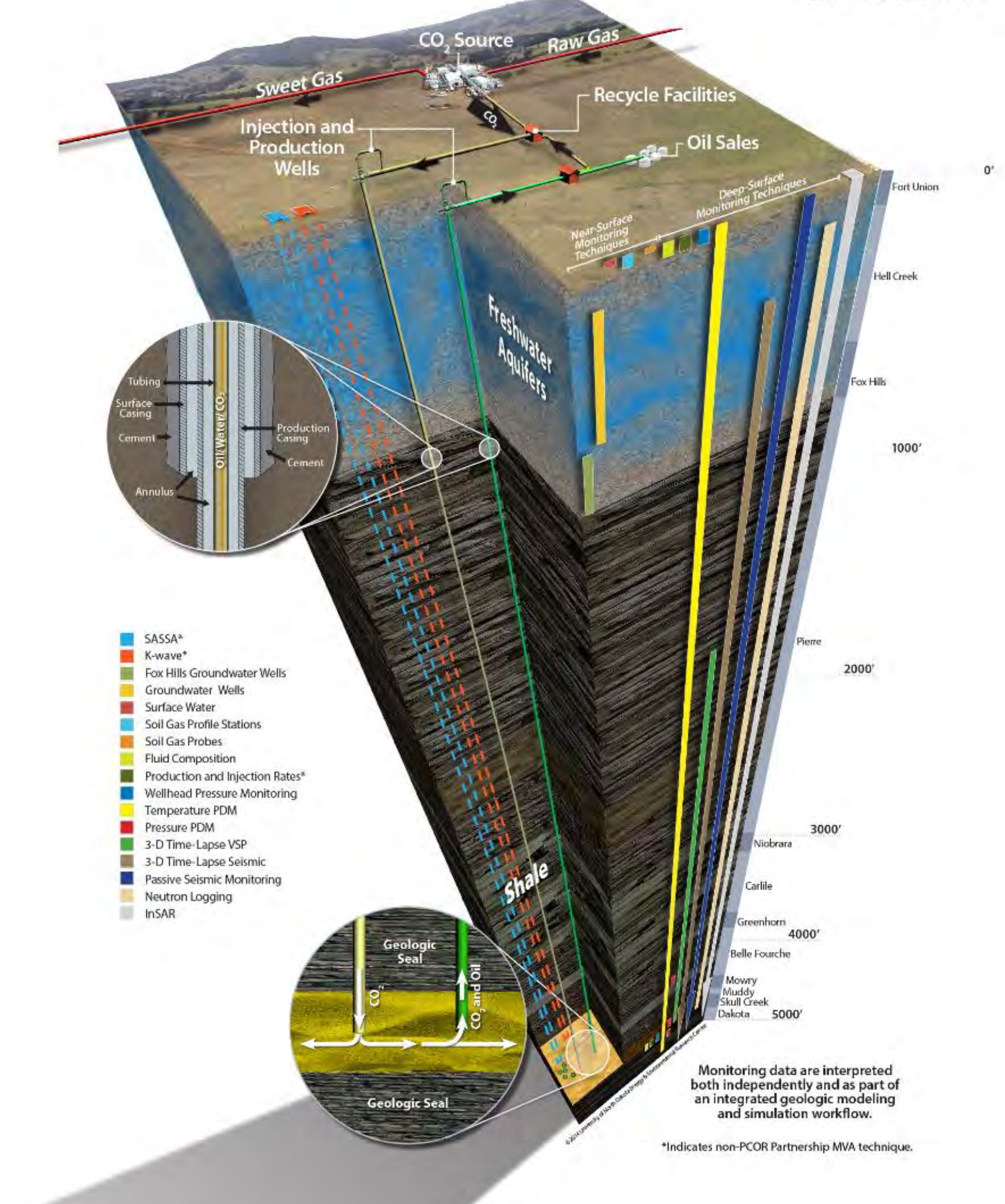
Azzolina, N.A.; Peck, W.D.; Hamling, J.A.; Gorecki, C.D.; Ayash, S.C.; Doll, T.E.; Nakles, D.V.; and Melzer, L.S. 2016. How green is my oil? A detailed look at greenhouse gas accounting for CO_2-enhanced oil recovery (CO_2-EOR) sites. *International Journal of Greenhouse Gas Control*, 51:369–379.

SUCCESSFUL MONITORING

Image Credit – EERC

Image Credit – Annette Tait

EERC DS49245A2 REV.AI



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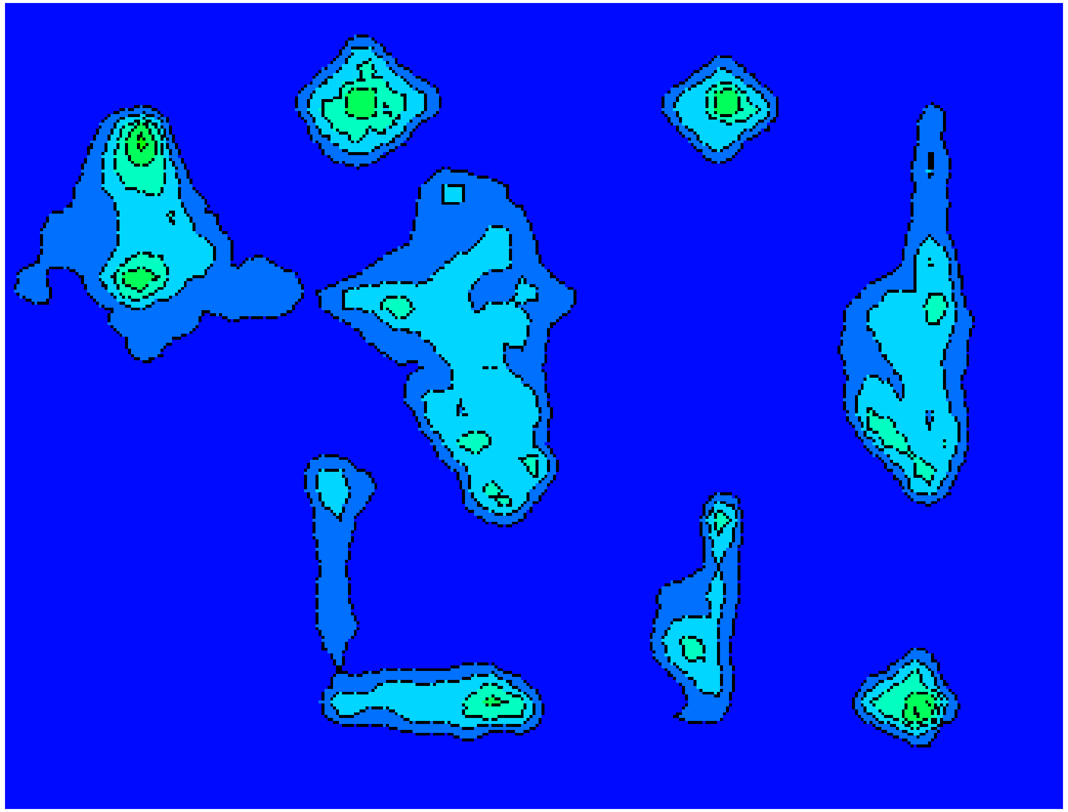
QUESTION: CAN WE USE MONITORING AND SIMULATION DATA TO QUANTIFY AND LOCATE CO_2 IN A RESERVOIR?



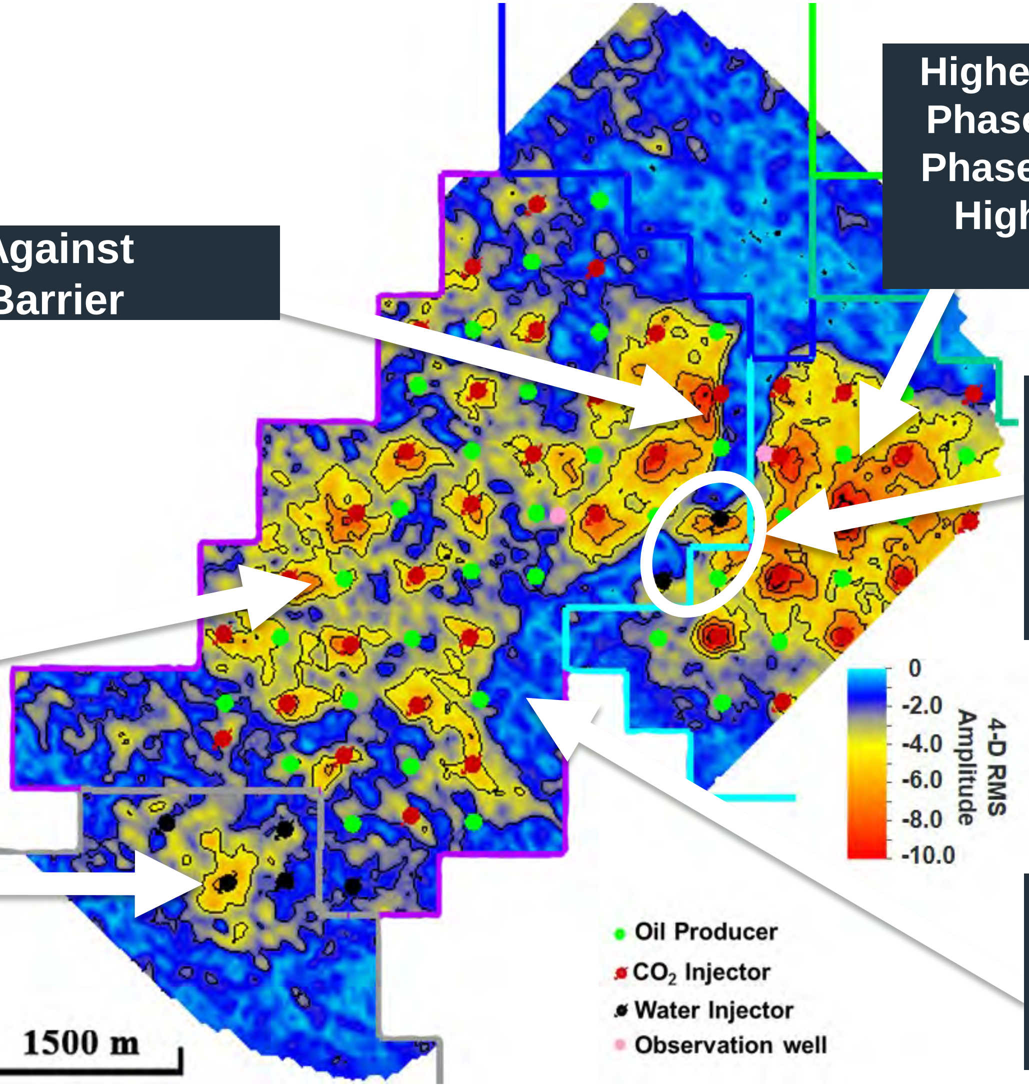
- The distribution of CO_2 strongly relates to geologic/reservoir properties and the injection schedule.
- In a reservoir with strong heterogeneity and high-conductivity flow channels, the CO_2 distribution profile can be quite different, even for two nearby wells.
- Monitoring and simulation data combined with production behavior can provide support to conformance control and improve EOR performance.

4-D SEISMIC AMPLITUDE DIFFERENCE MAP (1ST REPEAT)

CO_2 Banking Against Permeability Barrier

CO_2 and Pressure Moving Updip Away from the Injector Toward Producer

Pressure Buildup from Water Injection

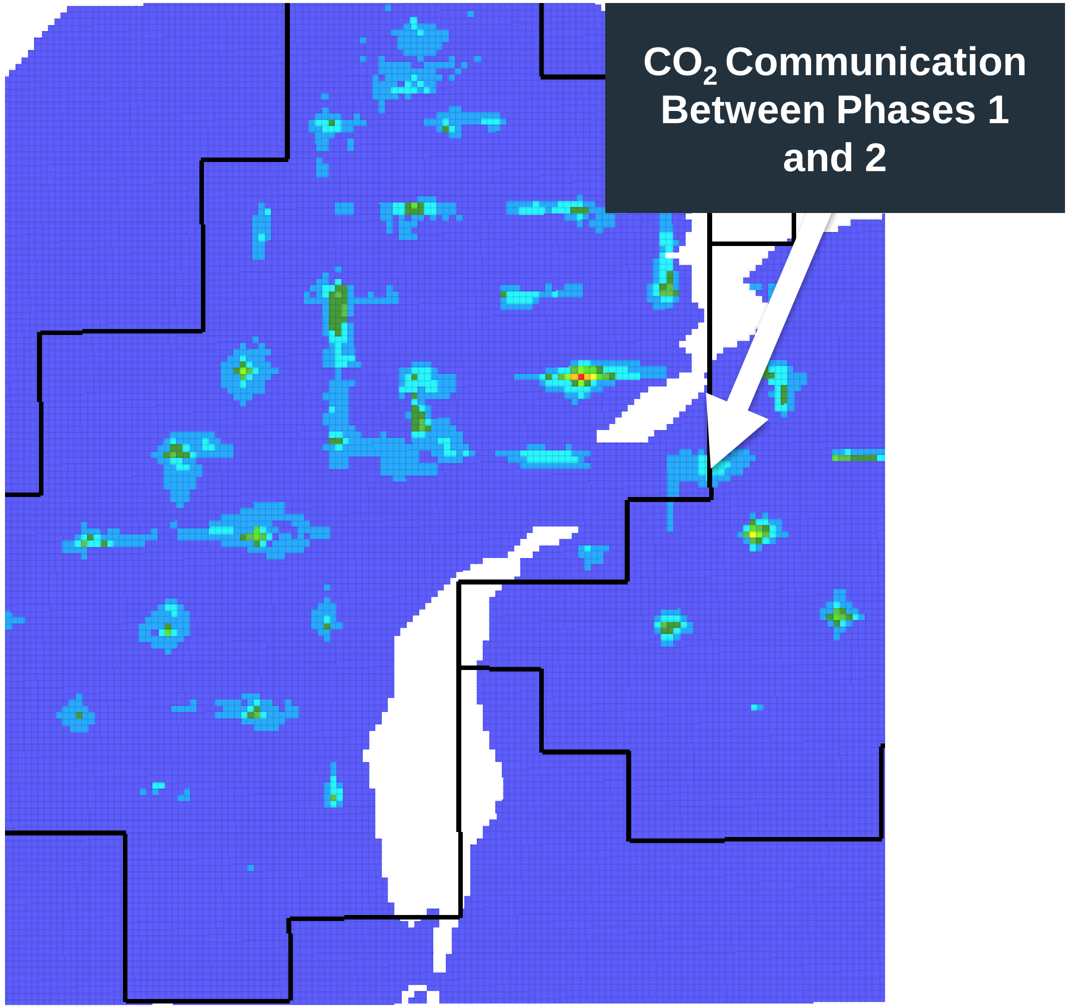


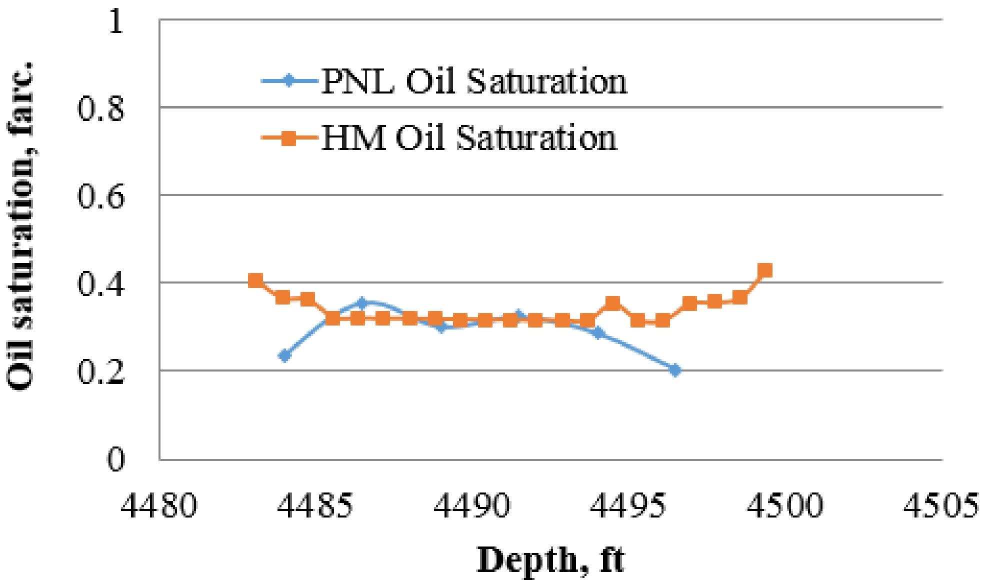
Higher Amplitude in Phase 2 Relative to Phase 1 Because of Higher Pressure Buildup

Fluid and Pressure Communication Between Phases 1 and 2

Southeastern Extension of the Permeability Barrier

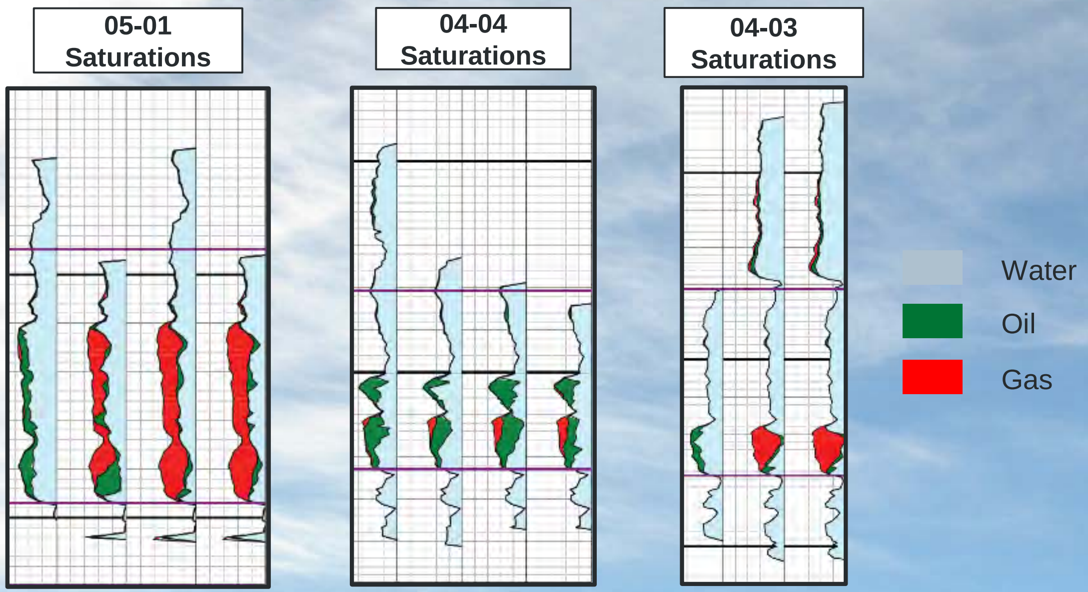
SIMULATED CO_2 DISTRIBUTION PHASES 1 AND 2 (SAME TIME AS 4-D SEISMIC)

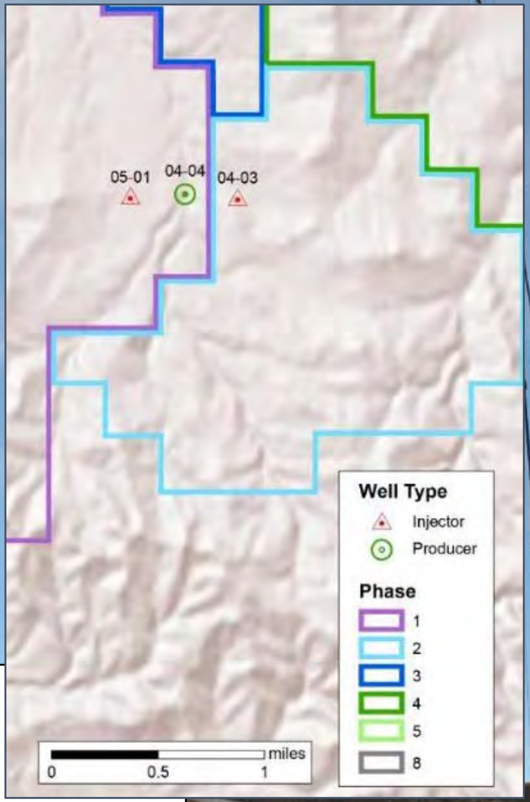


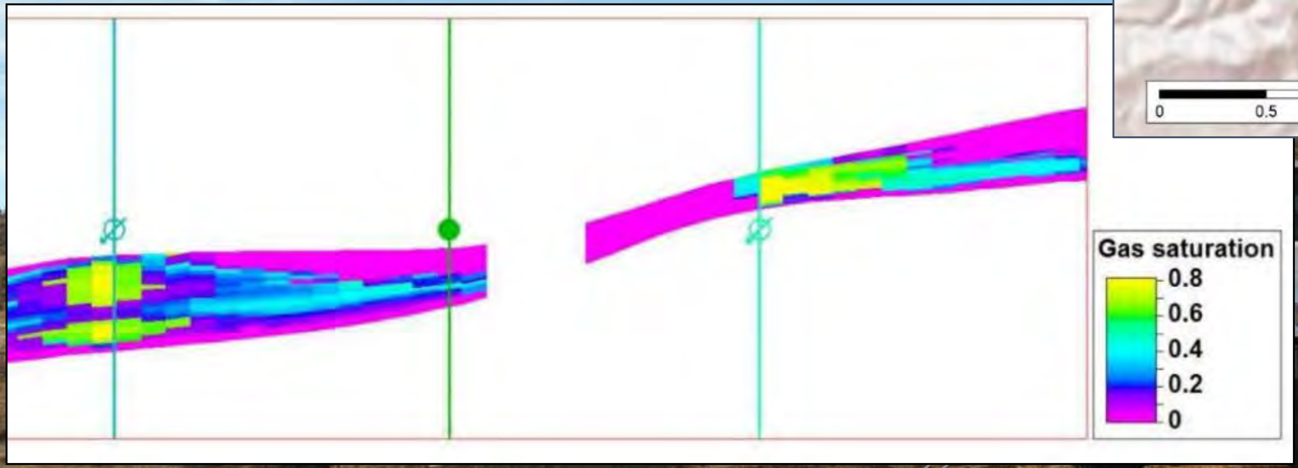


- By carefully matching the production data and oil saturation distribution along the selected wells based on pulsed-neutron log (PNL) measurements, the simulation model can capture the CO_2 communication between phases.

LINKING PULSED-NEUTRON LOGGING AND SIMULATION







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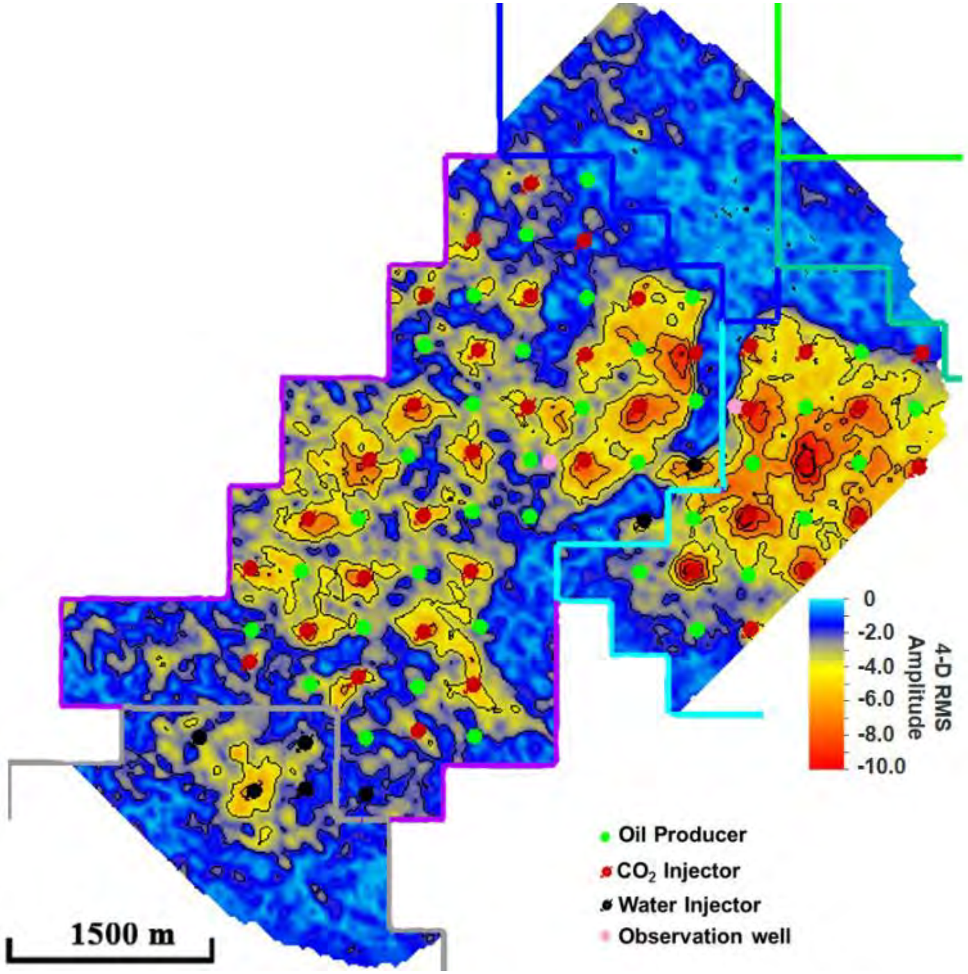
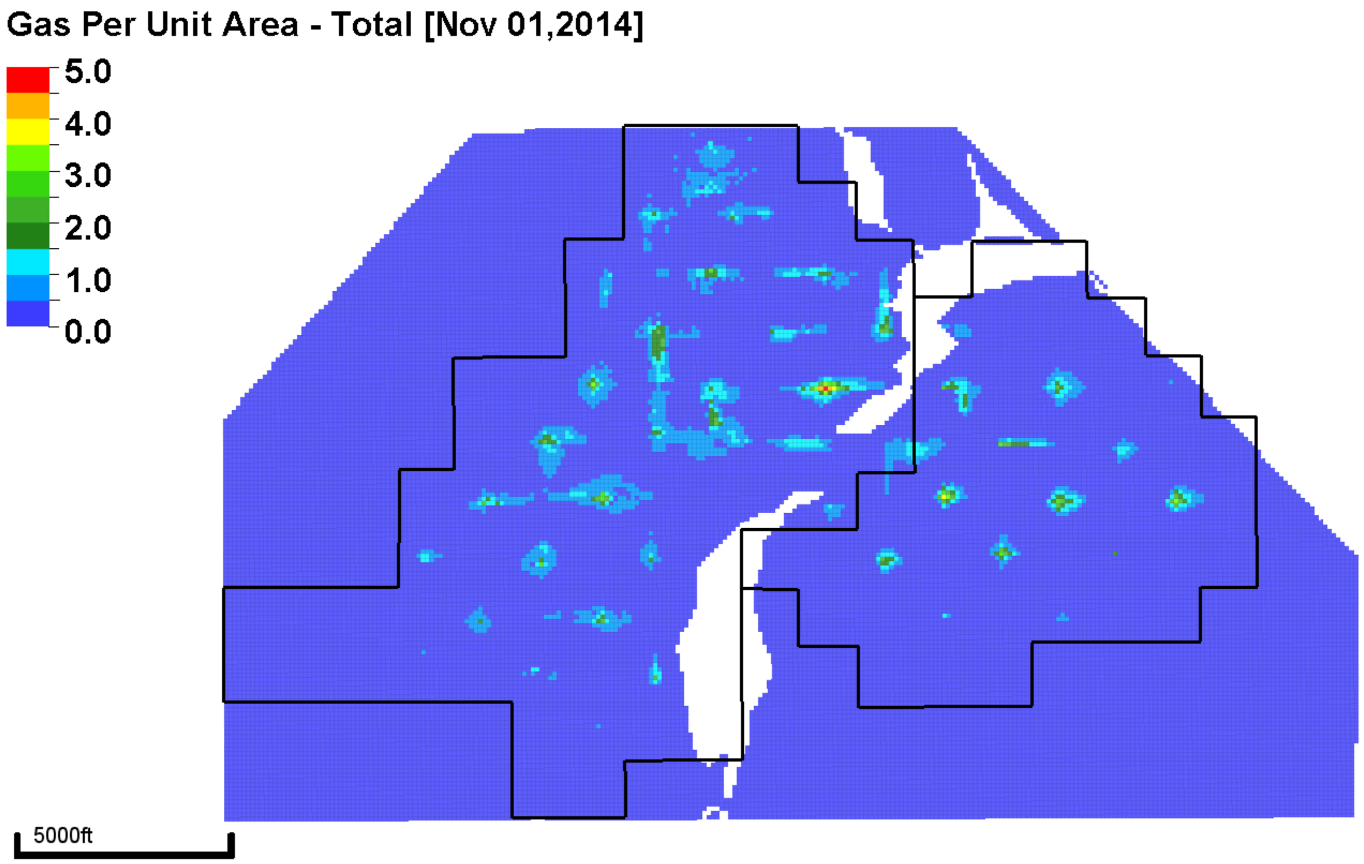
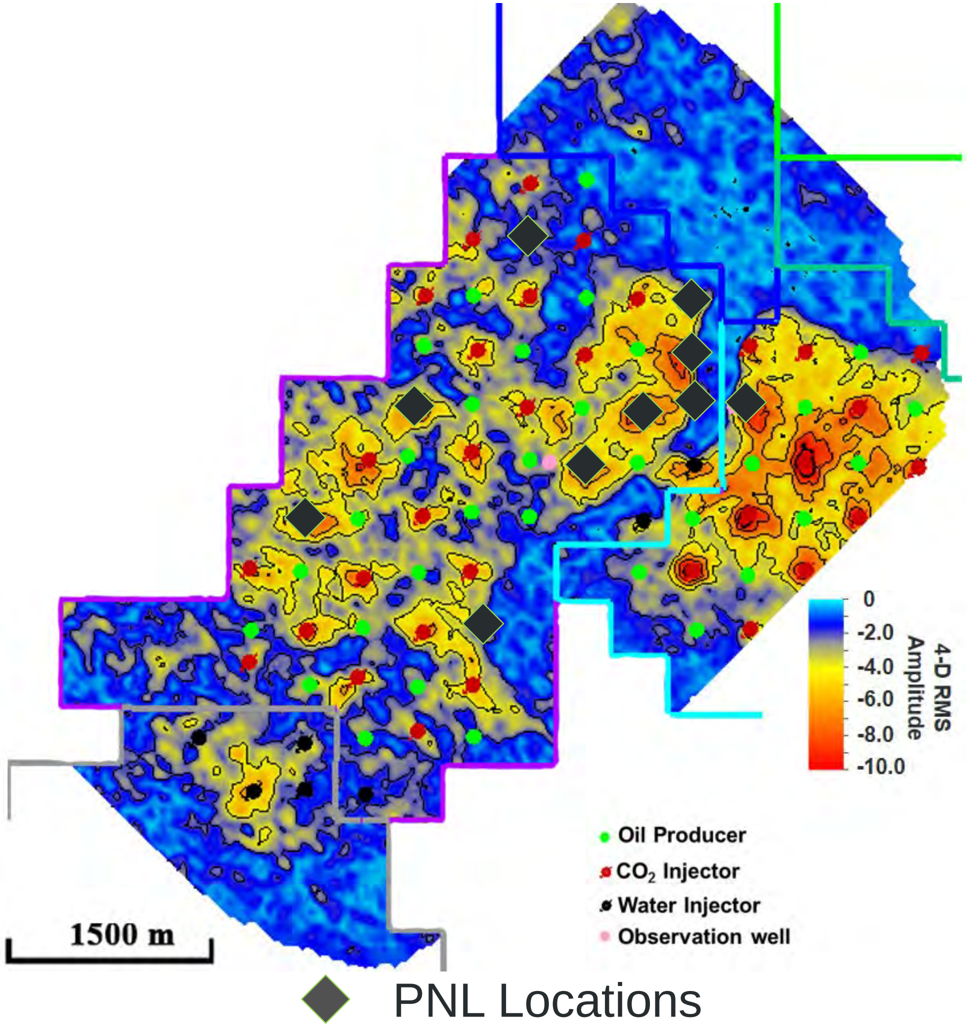
LINKING SEISMIC AND SIMULATION

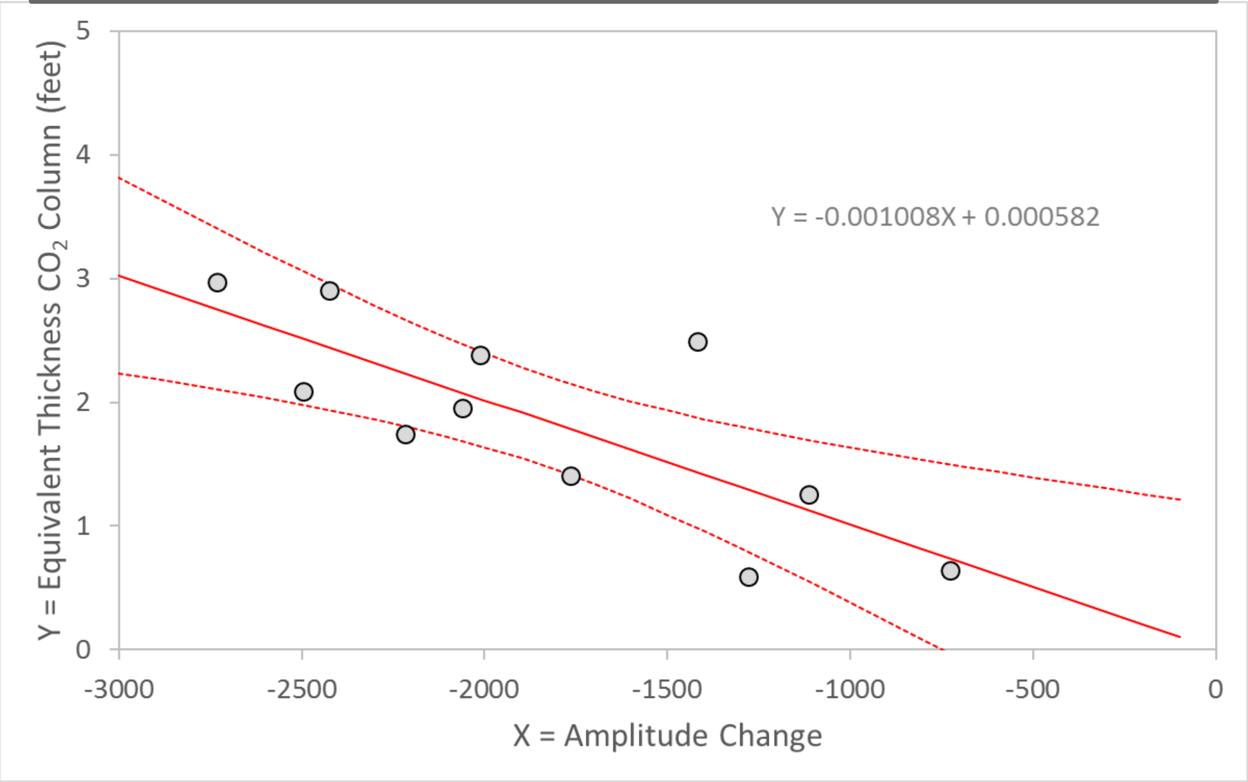




LINKING SEISMIC AND PNL

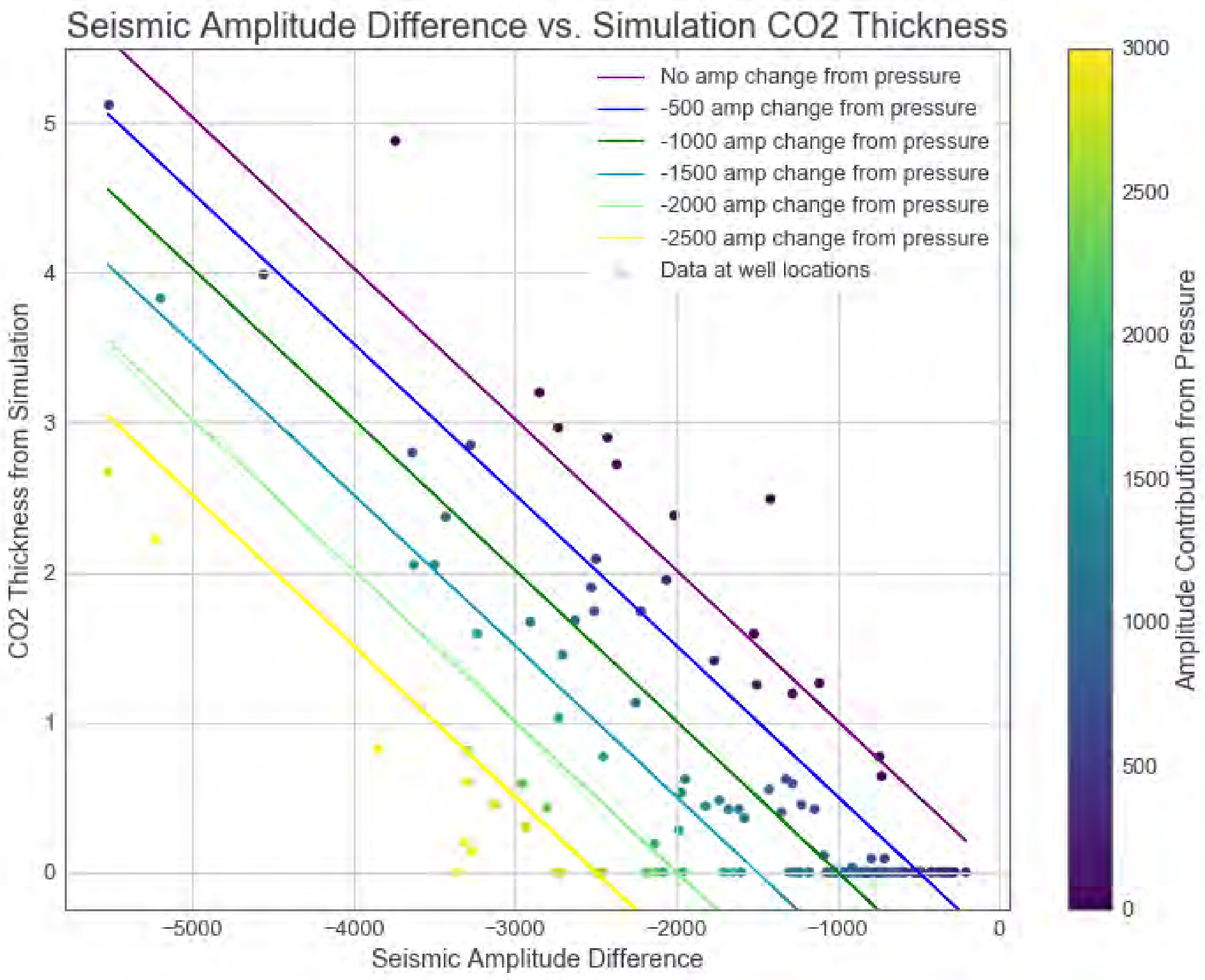


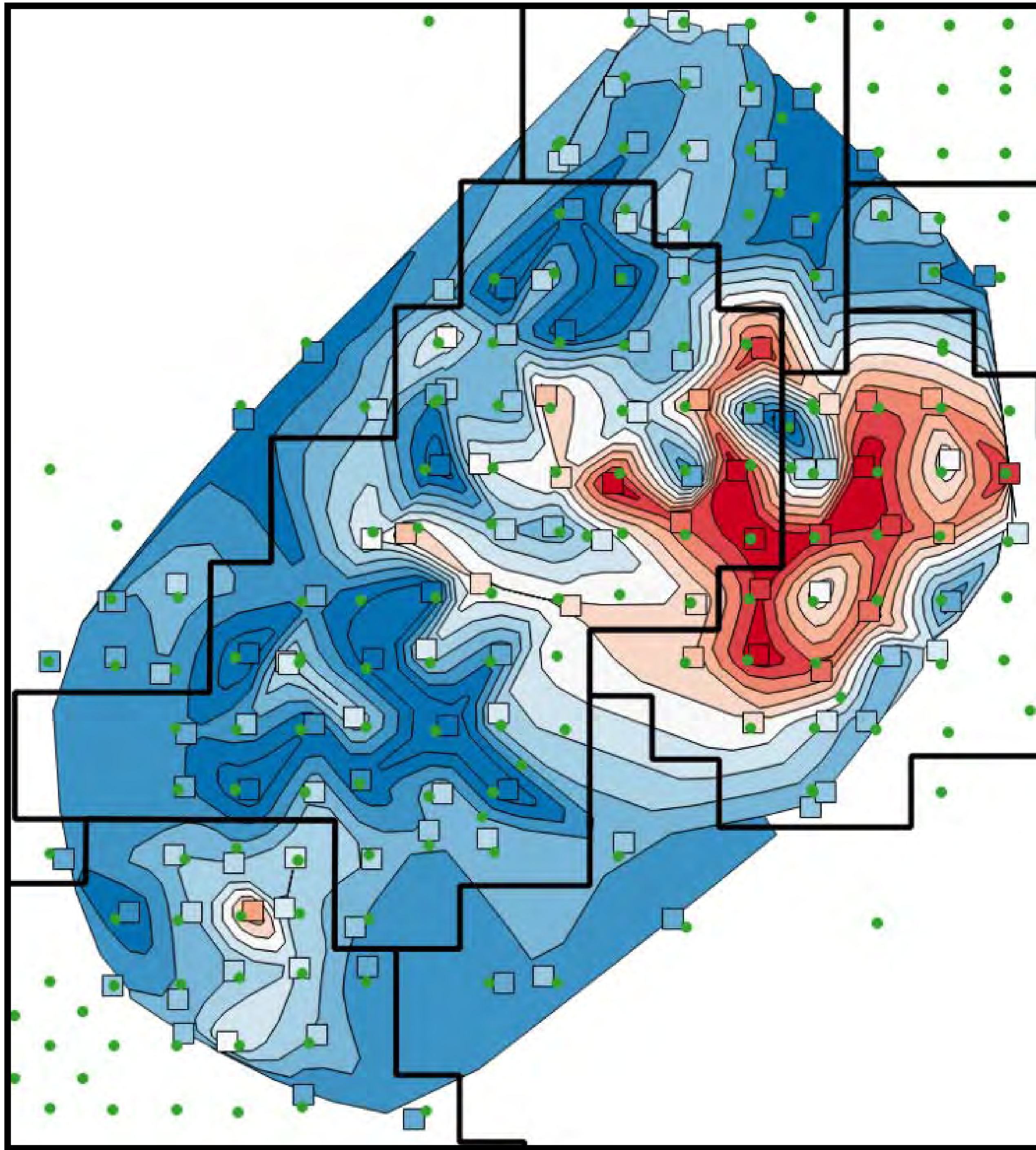
Relationship Between Seismic Amplitude Change and CO_2 Column Thickness from PNL at Wells Where We Expect MINIMAL Pressure Contribution



Critical Challenges. **Practical Solutions.**

CONNECTING THE DOTS





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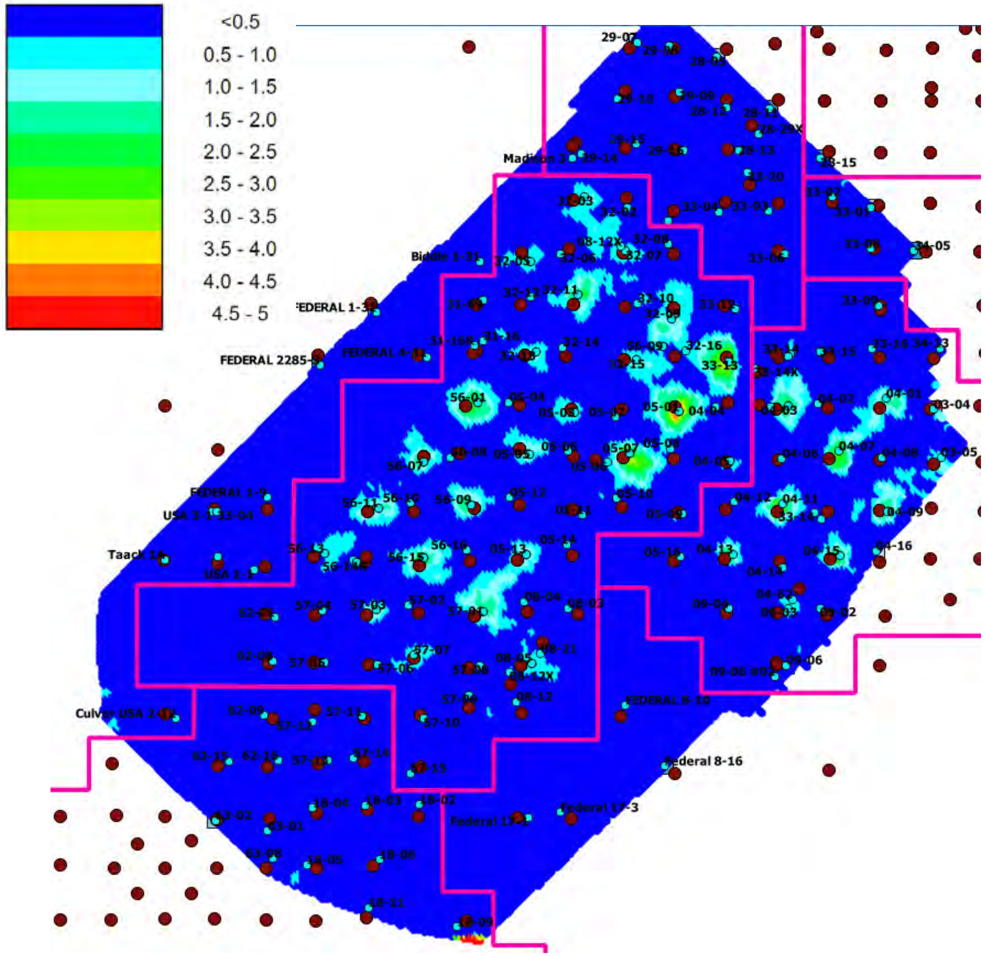
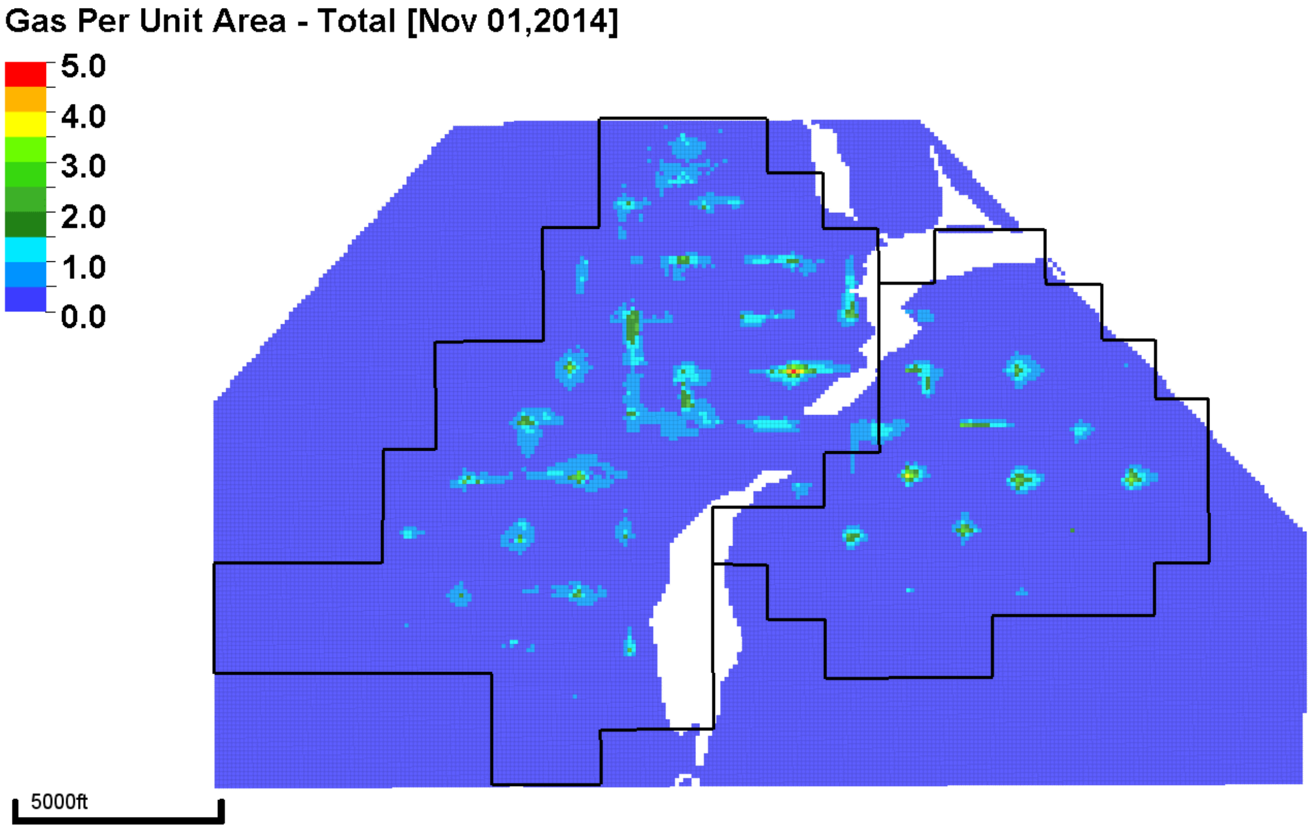
PREDICTED CO_2 FROM SEISMIC NEXT TO SIMULATED GPUAT





Tons CO_2 from seismic correlation = 1,389,700

Tons CO_2 from simulation (mass balance) = 1,449,000

Coming in 2018!

ELSEVIER

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

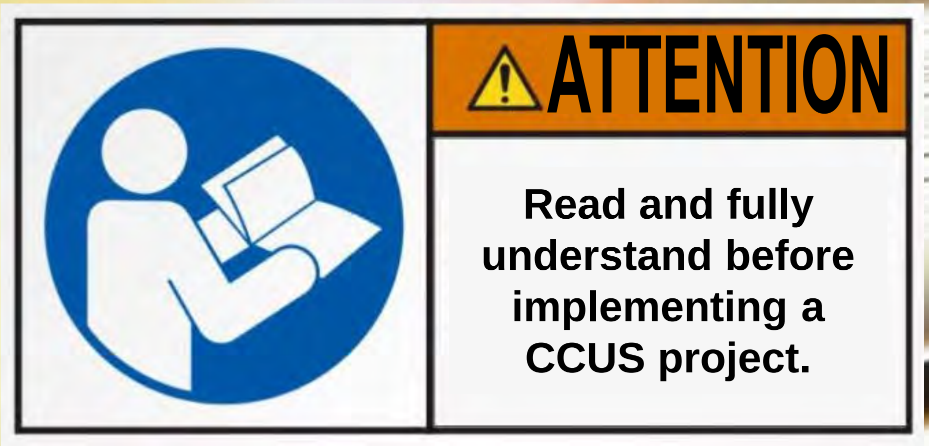
journal homepage: www.elsevier.com/locate/ijggc

ieaghg

Topics will include:

- Geologic Characterization for Associated Storage
- Correlating PNLs and Seismic Data
- Environmental Monitoring for CO_2 Storage
- Life Cycle Analysis
- 4-D Seismic
- Effect of Gas Solubility and Hysteresis on Associated Storage
- And more!

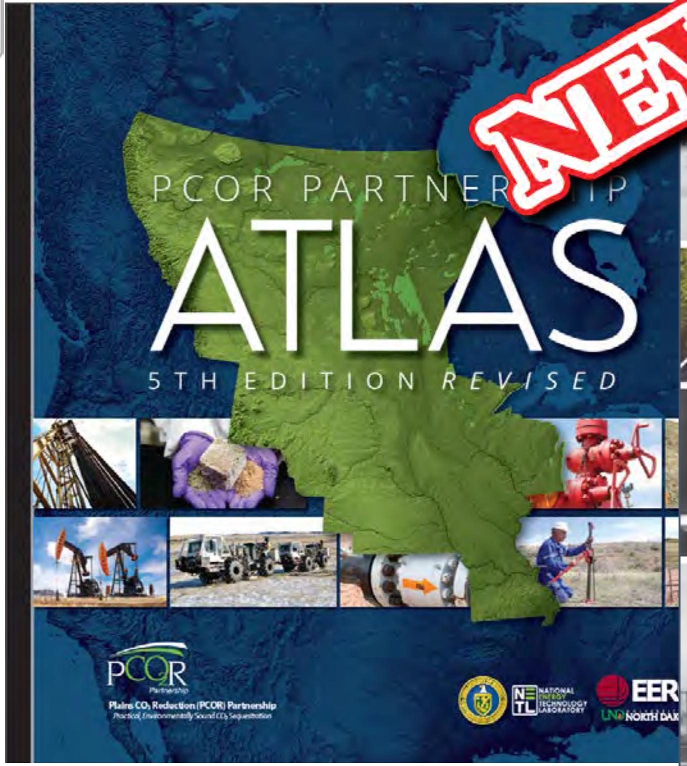
BEST PRACTICES MANUALS

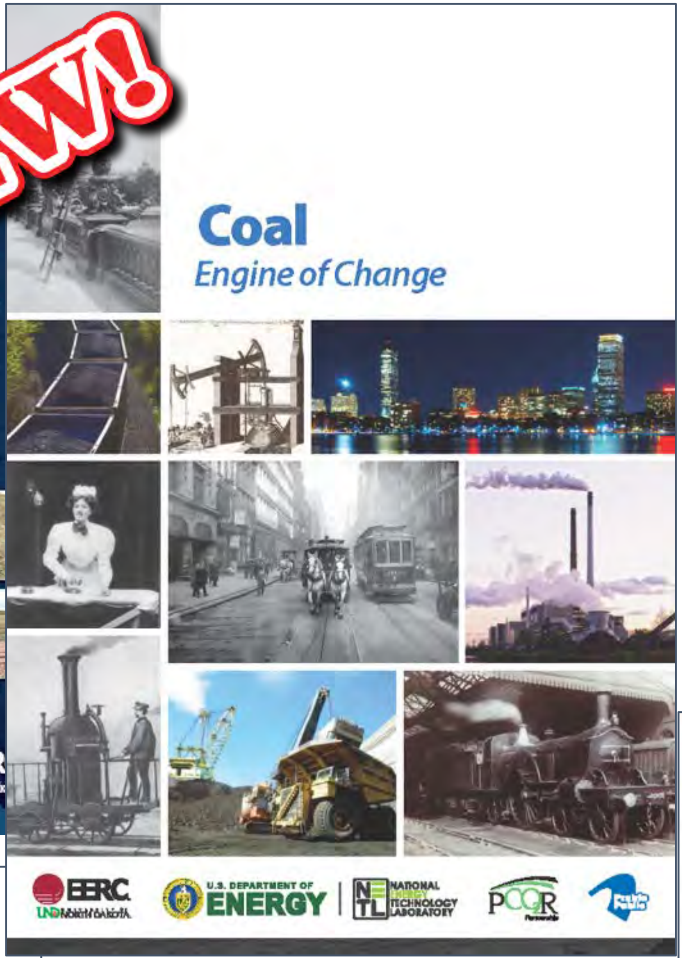


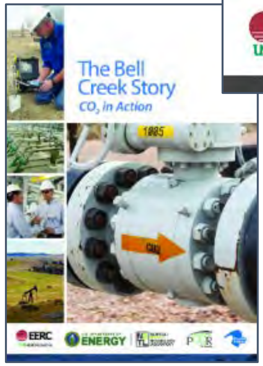
- Adaptive Management Approach
- Site Characterization
- Risk Assessment
- Modeling and Simulation
- Monitoring, Verification, and Accounting

Image Credit – Med One

ONGOING OUTREACH





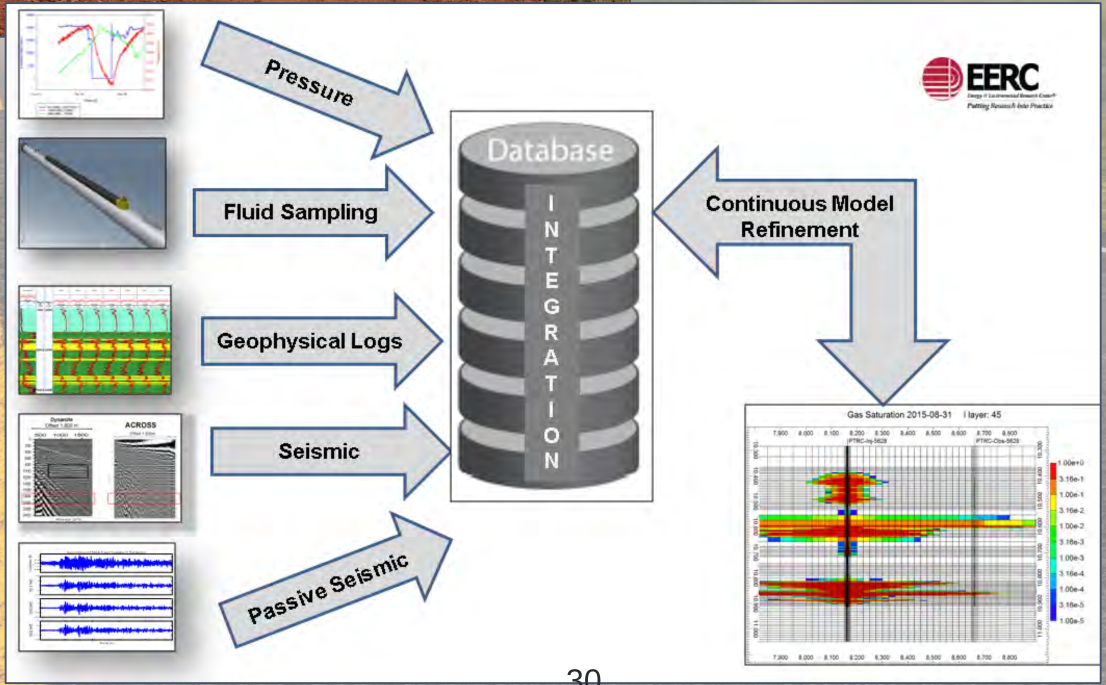


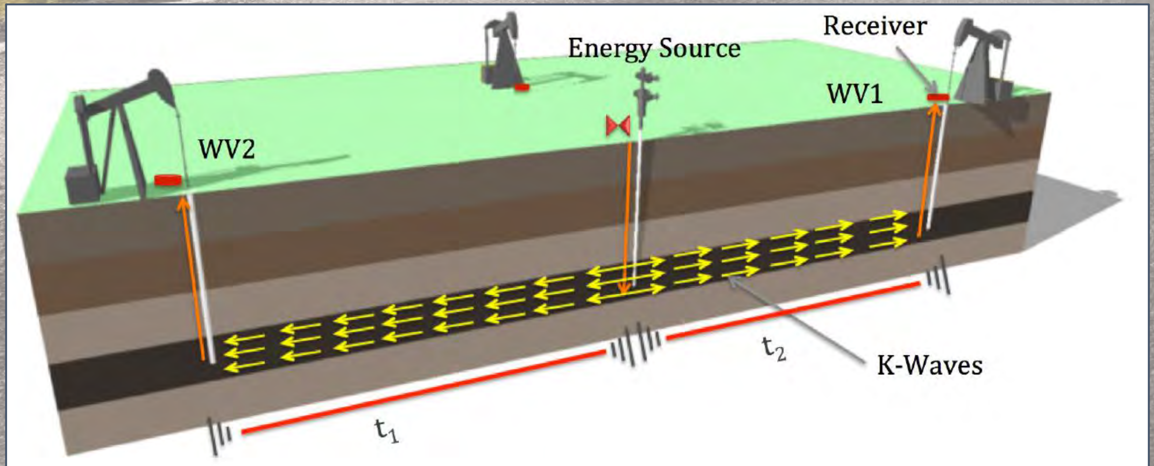
Premiered March 27! Now available online!

Images Credit – EERC

SYNERGY OPPORTUNITIES: MVA EVOLUTION

- Faster processing for quicker integration
  - Improve performance predictions
  - Inform operational decisions with actionable results
- Intelligent monitoring
- Low environmental impact
- No impact on operations
- Semiautonomous and scalable
- Viable and cost-effective long term





PROJECT SUMMARY:
PCOR PARTNERSHIP KEY MESSAGES

- CCUS Requires Active Public Engagement!
- CCUS Provides Economic and Environmental Benefits!
- We Can Successfully Monitor CO_2 Storage!
- The PCOR Partnership Region Is Ideal for CCUS Deployment!
- Stakeholder Collaboration Is Essential for CCUS Deployment!
- CCUS Works!

Image credit – EERC

THANK YOU!

Image Credit – EERC

CONTACT INFORMATION

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THANK YOU!

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BENEFIT TO THE PROGRAM: ADDRESSING RCSP PROGRAM GOALS

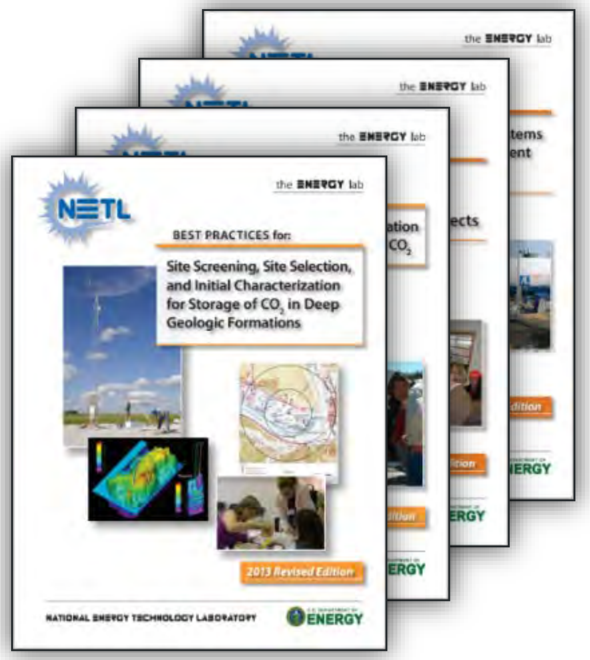
- Develop technologies that will support the industry's ability to predict CO_2 storage capacity in geologic formations to within ±30%:
  - *Conducting pilot tests and demonstration projects in hydrocarbon reservoirs, saline formations, and coal seams to improve understanding of sweep and storage efficiency.*
  - *Evaluating oil fields, saline formations, and coal seams to estimate volumetric and dynamic storage resource through characterization and simulation.*
  - *Conducting complementary projects that incorporate lessons learned from the PCOR Partnership to improve methods to estimate CO_2 storage resource.*
    - *DOE project – Optimizing and Quantifying CO_2 Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs (2012–2016)*
    - *Joint IEAGHG and DOE projects – CO_2 Storage Efficiency in Deep Saline Formations – Stages 1 and 2*
    - *Identification of Residual Oil Zones in the Williston and Powder River Basins*
    - *North Dakota Integrated Carbon Storage Complex Feasibility Study (CarbonSAFE)*

BENEFIT TO THE PROGRAM: ADDRESSING RCSP PROGRAM GOALS, cont.

- 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 for improving both storage efficiency and hydrocarbon recovery in collaboration with commercial partner Denbury Onshore LLC (Denbury).*
- Develop and validate technologies to ensure 99% storage permanence:
  - *Evaluating the existing technologies used to monitor, verify, and account for the injected CO_2 to determine detection limits.*
  - *Multiple MVA techniques, including 4-D seismic and pulsed-neutron logs (PNLs), have been used at Bell Creek to successfully track the presence and movement of CO_2 in the reservoir and have shown no evidence of out-of-zone migration or negative environmental impact.*

BENEFIT TO THE PROGRAM: ADDRESSING RCSP PROGRAM GOALS, cont.

- Develop best practice manuals (BPMs) for MVA and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation:
  - Participated in updating several DOE BPMs
    - ♦ Site characterization
    - ♦ Risk assessment/simulation
    - ♦ MVA
    - ♦ Operations
    - ♦ Outreach
  - PCOR Partnership BPMs
    - ♦ Fort Nelson Test Site – Feasibility Study
    - ♦ Adaptive management approach
    - ♦ Site characterization
    - ♦ Modeling and simulation
    - ♦ Risk assessment
    - ♦ MVA
  - Produced videographic BPM: “Installing a Casing-Conveyed Permanent Downhole Monitoring (PDM) System.”



PCOR PARTNERSHIP BELL CREEK OBJECTIVES

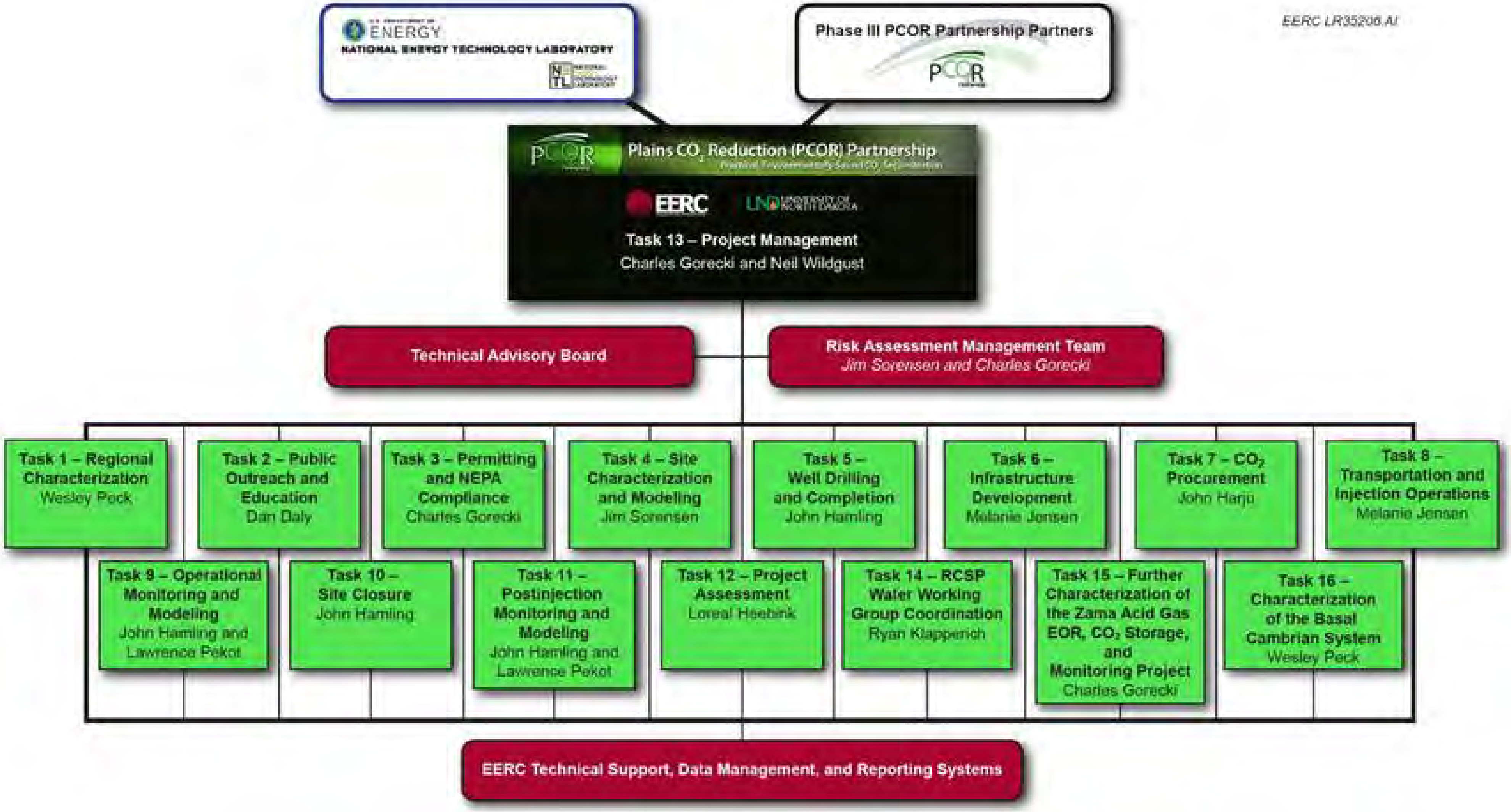
- Safely and permanently achieve CO_2 storage associated with commercial-scale EOR.
- Demonstrate that oil-bearing formations are viable sinks with significant storage capacity to help meet near-term CO_2 storage objectives.
- Establish MVA methods to safely and effectively monitor CO_2 storage.
- Use commercial oil/gas practices as the backbone of the MVA strategy, and augment with additional cost-effective techniques.
- Share lessons learned for the benefit of similar projects across the region.
- Establish a relationship between the CO_2 EOR process and long-term associated CO_2 storage.

LESSONS LEARNED

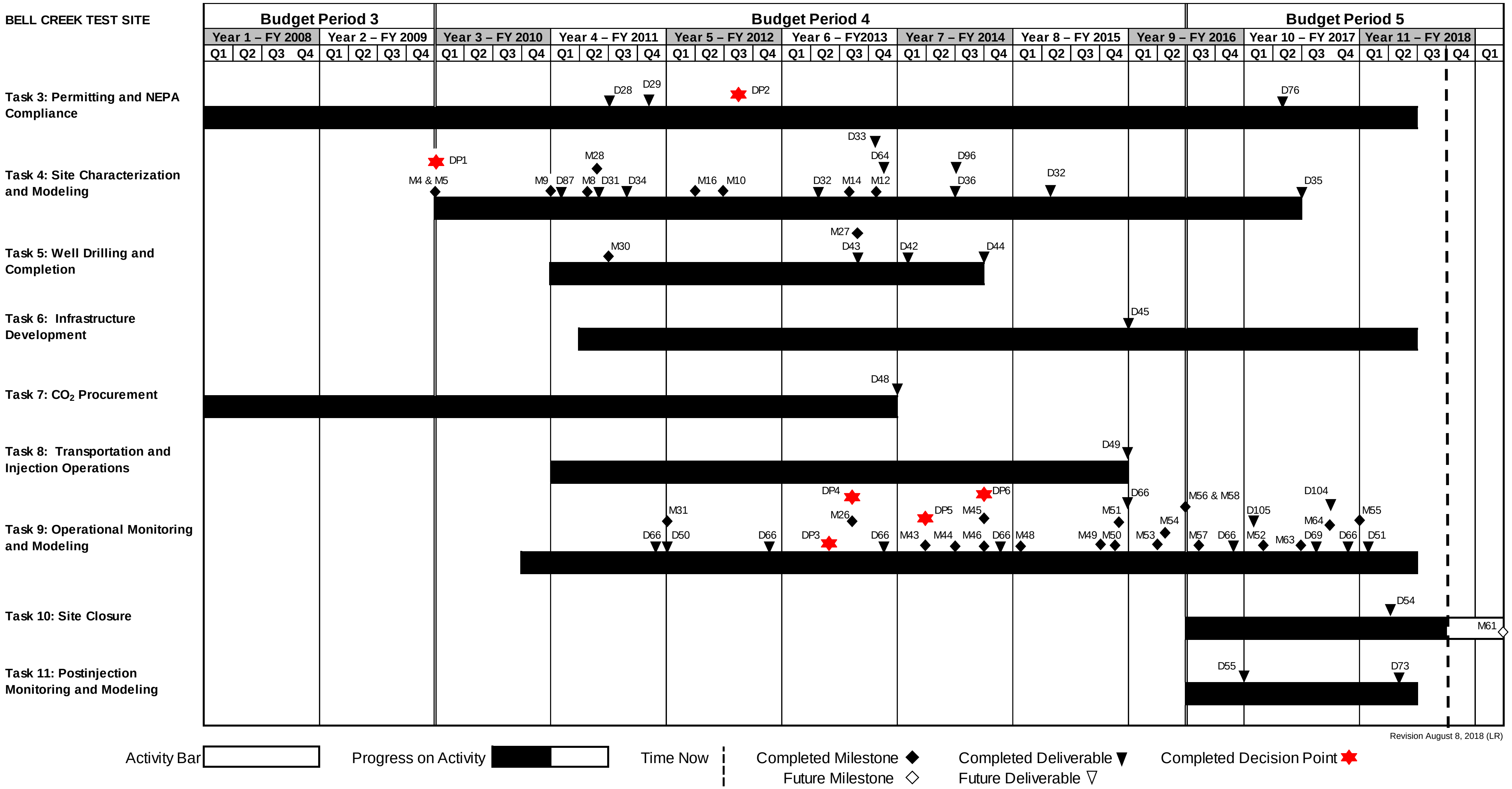
- Project advantages
  - Full-scale CO_2 EOR project provides opportunity to deploy an MVA program on a commercial project with hundreds of wells.
  - Integrate with established CO_2 operators and learn from their operational experiences.
  - CO_2 EOR has the potential to increase domestic production, produce oil with reduced carbon intensity, store millions of tonnes of CO_2, develop the infrastructure for wide-scale CCS deployment, and help develop the techniques for monitoring and accounting for CO_2 in all storage project types.

- Project limitations
  - Regional Carbon Sequestration Partnership (RCSP) Program is scheduled to end in 2018, but the commercial CO_2 EOR project will continue. If the program were extended, this would offer the opportunity to further refine operational monitoring at a commercial project.
  - No postinjection-monitoring period because of injection continuing beyond the time line of the PCOR Partnership Program; however, a conceptual postinjection-monitoring plan will be developed.
  - Some data are confidential because of commercial aspect of CO_2 EOR project.

ORGANIZATION CHART



PROJECT SCHEDULE



DELIVERABLES, MILESTONES, AND KEY DECISION POINTS

Key for Deliverables	
D28	Environmental Questionnaire
D29	Permitting Action Plan
D31	Geological Characterization Experimental Design Package
D32	Geomechanical Report
D33	Preinjection Geochemical Report
D34	Baseline Hydrogeological Experimental Design Package
D35	Best Practices Manual – Site Characterization
D36	Wellbore Leakage Final Report
D42	Injection Experimental Design Package
D43	Monitoring Experimental Design Package
D44	Drilling and Completion Activities Report
D45	Infrastructure Development Report
D48	Procurement Plan and Agreement Report
D49	Transportation and Injection Operations Report
D50	Site Characterization, Modeling, and Monitoring Plan
D51	Best Practices Manual – Monitoring for CO_2 Storage and CO_2 EOR
D54	Site Closure Procedures Report
D55	Cost-Effective Long-Term Monitoring Strategies Report
D64	Site Characterization Report
D66	Simulation Report
D69	Simulation Best Practices Manual
D73	Monitoring and Modeling Fate of CO_2 Progress Report
D76	Regional Regulatory Perspective
D87	Geomechanical Experimental Design Package
D96	3-D Seismic Acquisition and Characterization Report
D104	Analysis of Expanded Seismic Campaign
D105	Comparison of Non-EOR and EOR Life Cycle Assessment

Key for Milestones	
M4	Test Site Selected
M5	Data Collection Initiated
M8	Wellbore Leakage Data Collection Initiated
M9	Geological Model Development Initiated
M10	Wellbore Leakage Data Collection Completed
M12	Preinjection Geochemical Work Completed
M14	Geological Characterization Data Collection Completed
M16	Initiation of Production and Injection Simulations
M26	CO_2 Injection Initiated
M27	MVA Equipment Installation and Baseline MVA Activities Completed
M28	Geological Characterization Experimental Design Package Completed
M30	Baseline MVA Activities Initiated
M31	Site Characterization, Modeling, and Monitoring Plan Completed
M43	First Full-Repeat Sampling of the Groundwater- and Soil Gas- Monitoring Program Completed
M44	First 3-D VSP Repeat Surveys Completed
M45	First Full-Repeat of Pulsed-Neutron Logging Campaign Completed
M46	First Year of Injection Completed
M48	1 Million Metric Tons of CO_2 Injected
M49	1.5 Million Metric Tons of CO_2 Injected
M50	Two Years of Near-Surface Assurance Monitoring Completed
M51	Initial Analysis for First Large-Scale Repeat Pulsed-Neutron Logging Campaign Post-Significant CO_2 Injection Completed
M52	Initial Analysis of Extended Pulsed-Neutron Logging Campaign Data Completed
M53	Expanded Baseline and Time-Lapse 3-D Surface Seismic Survey Completed
M54	Initial Processing and Analysis of Historic InSAR Data Completed
M55	Initial Investigation of Crude Oil Compositional Changes During CO_2 EOR Completed
M56	Life Cycle Analysis for Primary and Secondary Recovery Oil Completed
M57	Life Cycle Analysis for EOR Completed
M58	Completion of 2.75 Million Metric Tons of CO_2 Stored
M61	Site Closure for Bell Creek Test Completed
M63	Initial Analysis of Processed InSAR Data Completed
M64	Initial Analysis of Expanded Seismic Campaign Data Completed

Key for Decision Points	
DP1	Site Selected
DP2	NEPA Requirements Met and Permitting Completed - Cleared for Injection
DP3	Injection Date Scheduled
DP4	Initiate Performance Monitoring
DP5	Determination to Extend Program into Next Commercial Development Area of the Field
DP6	Determination to Continue with Monitoring Program

PUBLICATIONS

Azzolina, N.A., Peck, W.D., Hamling, J.A., Gorecki, C.D., Ayash, S.C., Doll, T.E., Nakles, D.V., and Melzer, L.S., 2016, 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, v. 51, p. 369–379.

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.

Levine, J.S., Fukai, I., Soeder, D.J., Bromhal, G., Dilmore, R.M., Guthrie, G.D., Rodosta, T.D., Sanguinito, S., Frailey, S., Gorecki, C.D., Peck, W.D., and Goodman, A.L., 2016, U.S. DOE NETL methodology for estimating the prospective CO_2 storage resource of shales at the national and regional scale: International Journal of Greenhouse Gas Control, v. 51, p. 81–94.

Jin, L., Hawthorne, S.B., Sorensen, J.A., Pekot, L.J., Kurz, B.A., Smith, S.A., Heebink, L.V., Herdegen, V., Bosshart, N.W., Torres, J., Dalkhaa, C., Peterson, K.J., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2017, Advancing CO2 enhanced oil recovery and storage in unconventional oil play—experimental studies on Bakken shales: Applied Energy, v. 208, p. 171–183.

Peck, W.D., Azzolina, N.A., Ge, J., Bosshart, N.W., Burton-Kelly, M.E., Gorecki, C.D., Gorz, A.J., Ayash, S.C., Nakles, D.V., and Melzer, L.S., 2018, Quantifying CO2 storage efficiency factors in hydrocarbon reservoirs—a detailed look at CO2 enhanced oil recovery: International Journal of Greenhouse Gas Control, v. 69, p. 41–51.

Bosshart, N.W., Azzolina, N.A., Ayash, S.C., Peck, W.D., Gorecki, C.D., Ge, J., Jiang, T., and Dotzenrod, N.W., 2018, Quantifying the effects of depositional environment on deep saline formation CO2 storage efficiency and rate: International Journal of Greenhouse Gas Control, v. 69, p. 8–19.

Azzolina, N.A., Bosshart, N.W., Burton-Kelly, M.E., Hamling, J.A., and Peck, W.D., 2018, Statistical analysis of pulsed-neutron well logs in monitoring injected carbon dioxide: International Journal of Greenhouse Gas Control, v. 75, p. 125–133.

Jin, L., Pekot, L.J., Smith, S.A., Salako, O., Peterson, K.J., Bosshart, N.W., Hamling, J.A., Mibeck, B.A.F., Hurley, J.P., Beddoe, C.J., and Gorecki, C.D., 2018, Effects of gas relative permeability hysteresis and solubility on associated CO2 storage performance: International Journal of Greenhouse Gas Control, v. 75, p. 140–150.

Jin, L., Pekot, L.J., Hawthorne, S.B., Salako, O., Peterson, K.J., Bosshart, N.W., Jiang, T., Hamling, J.A., Wildgust, N., and Gorecki, C.D., 2018, Evaluation of recycle gas injection on CO2 enhanced oil recovery and associated storage performance: International Journal of Greenhouse Gas Control, v.75, p. 151–161.

Smith, S.A., Mibeck, B.A.F., Hurley, J.P., Beddoe, C.J., Jin, L., Hamling, J.A., and Gorecki, C.D., 2018, Laboratory determination of oil draining CO2 hysteresis effects during multiple floods of a conventional clastic oil reservoir: International Journal of Greenhouse Gas Control, v. 78, p. 1–6.