EERC | UND UNIVERSITY OF NORTH DAKOTA

Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

PLAINS CO_2 REDUCTION (PCOR) PARTNERSHIP

U.S. Department of Energy National Energy Technology Laboratory
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting
August 26–30, 2019

Charles Gorecki
CEO and PCOR Partnership Program Manager

PRESENTATION OUTLINE

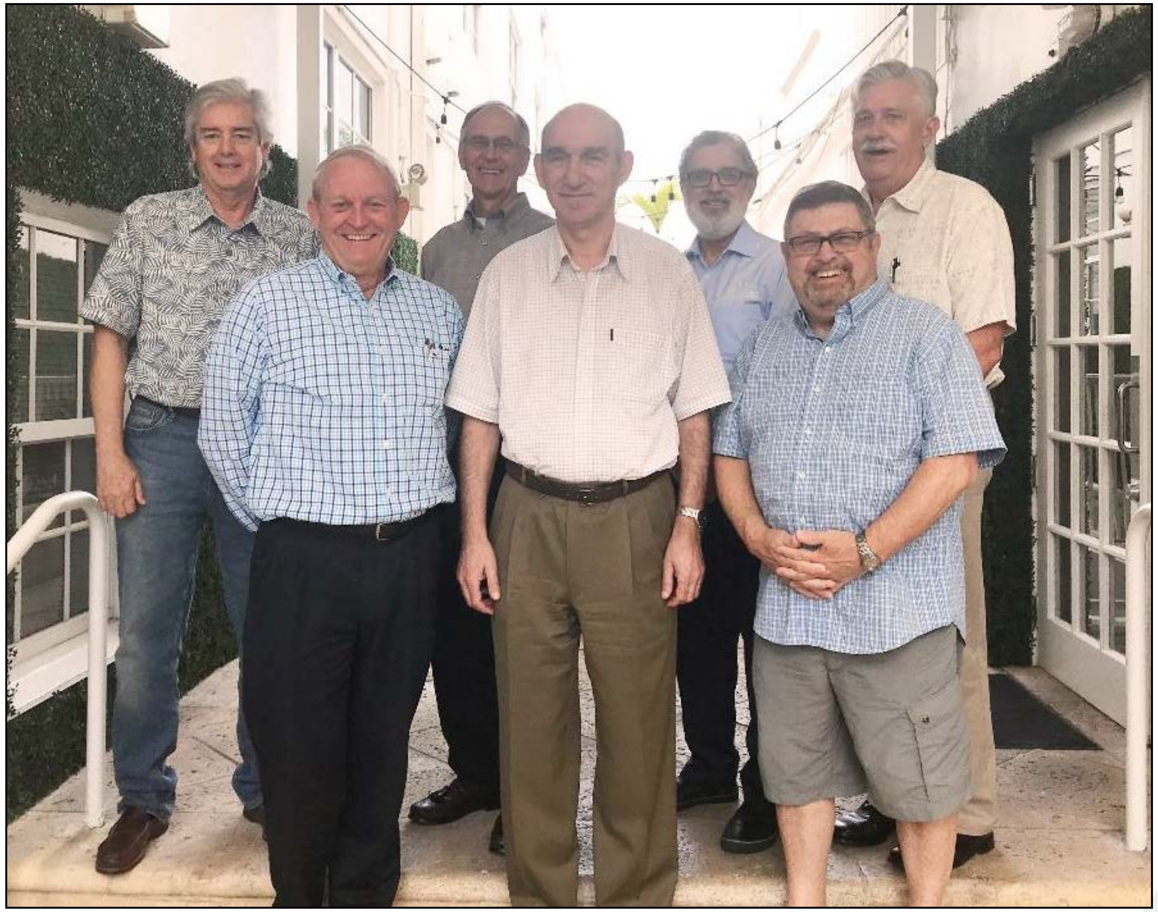
Five key messages from the PCOR Partnership relate to:

1. Our engaged membership.
2. Regional deployment potential.
3. ***CCUS (carbon capture, utilization, and storage) works***!
4. Economic and environmental benefits.
5. Our active public outreach.

TECHNICAL ADVISORY BOARD

PCOR Partnership Technical Advisory Board (TAB)

- Reviewed technical activities and consistency with program objectives
- ***Instrumental in shaping key messages from program activities***



Current PCOR Partnership TAB members (not pictured: Ms. Stacey Dahl and Mr. Mike Holmes).

1. ENGAGED MEMBERSHIP, SUCCESSFUL COLLABORATION

The PCOR Partnership: over 120 industry, government, and research organizations collaborate to encourage CCUS commercial deployment.

PCOR PARTNERSHIP: ENGAGED AND FORWARD-FOCUSED

PCOR Partnership 2003 – Present

AN ENGAGED PARTNERSHIP

Images Credit – EERC

2. REGIONAL POTENTIAL FOR CCUS DEPLOYMENT

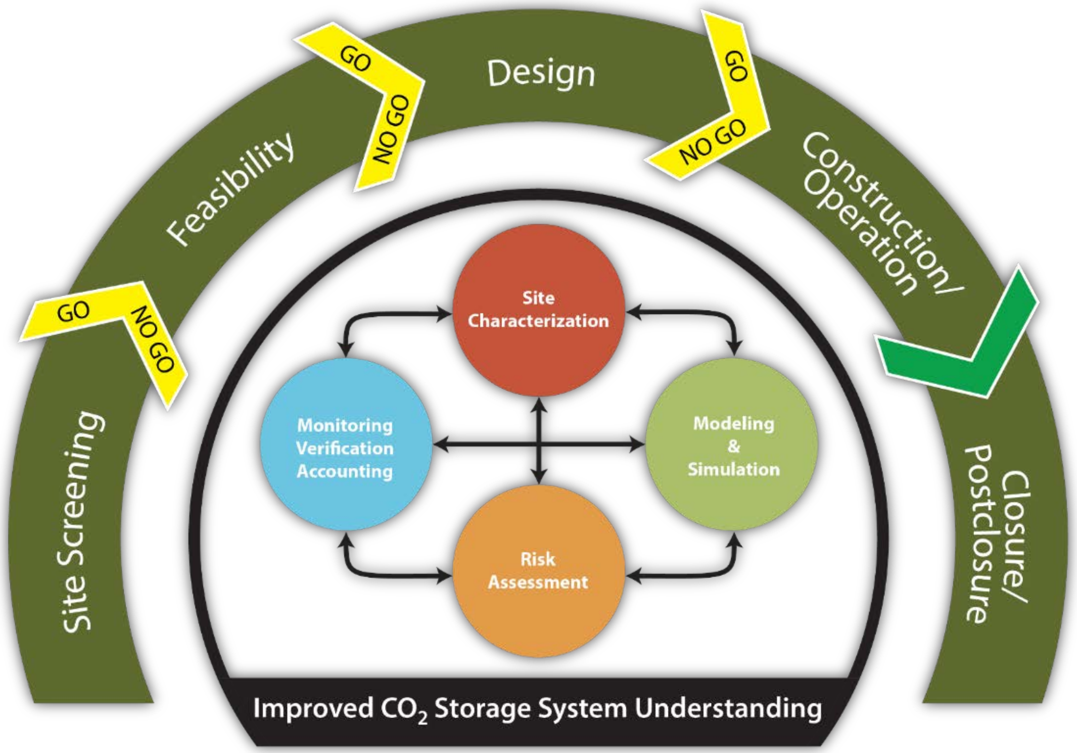
The PCOR Partnership region provides an ideal opportunity to deploy CCUS:

- **Suitable geology**
- **Fossil fuel resources**
- **An industrial and energy development base**

3. CCUS WORKS: ADAPTIVE MANAGEMENT APPROACH

Carefully selected and monitored storage sites:

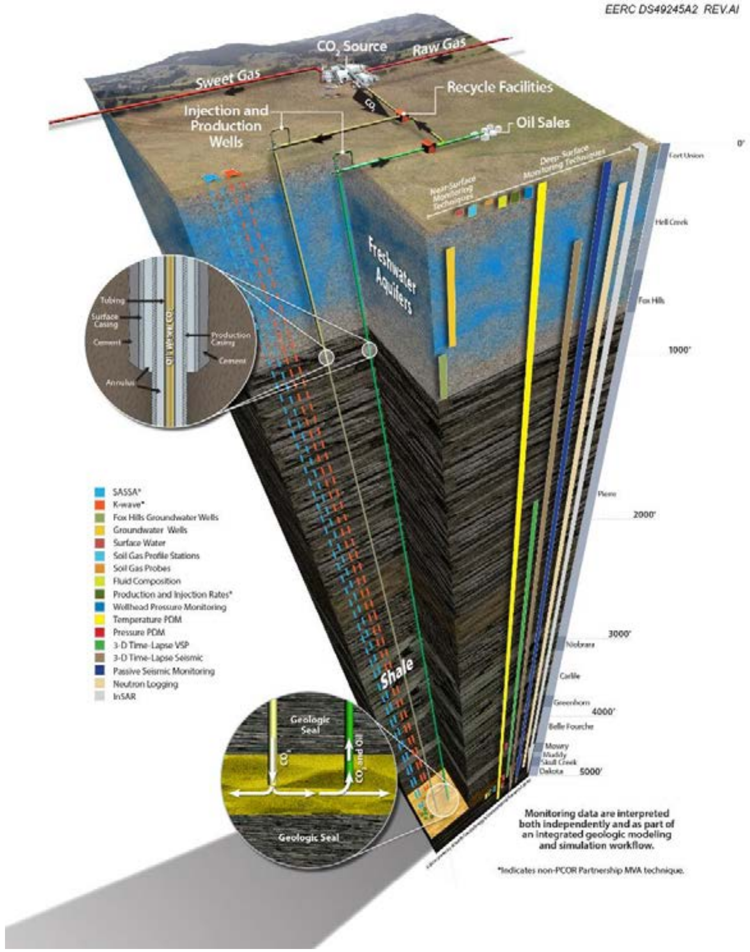
very low and manageable levels of risk to the environment.



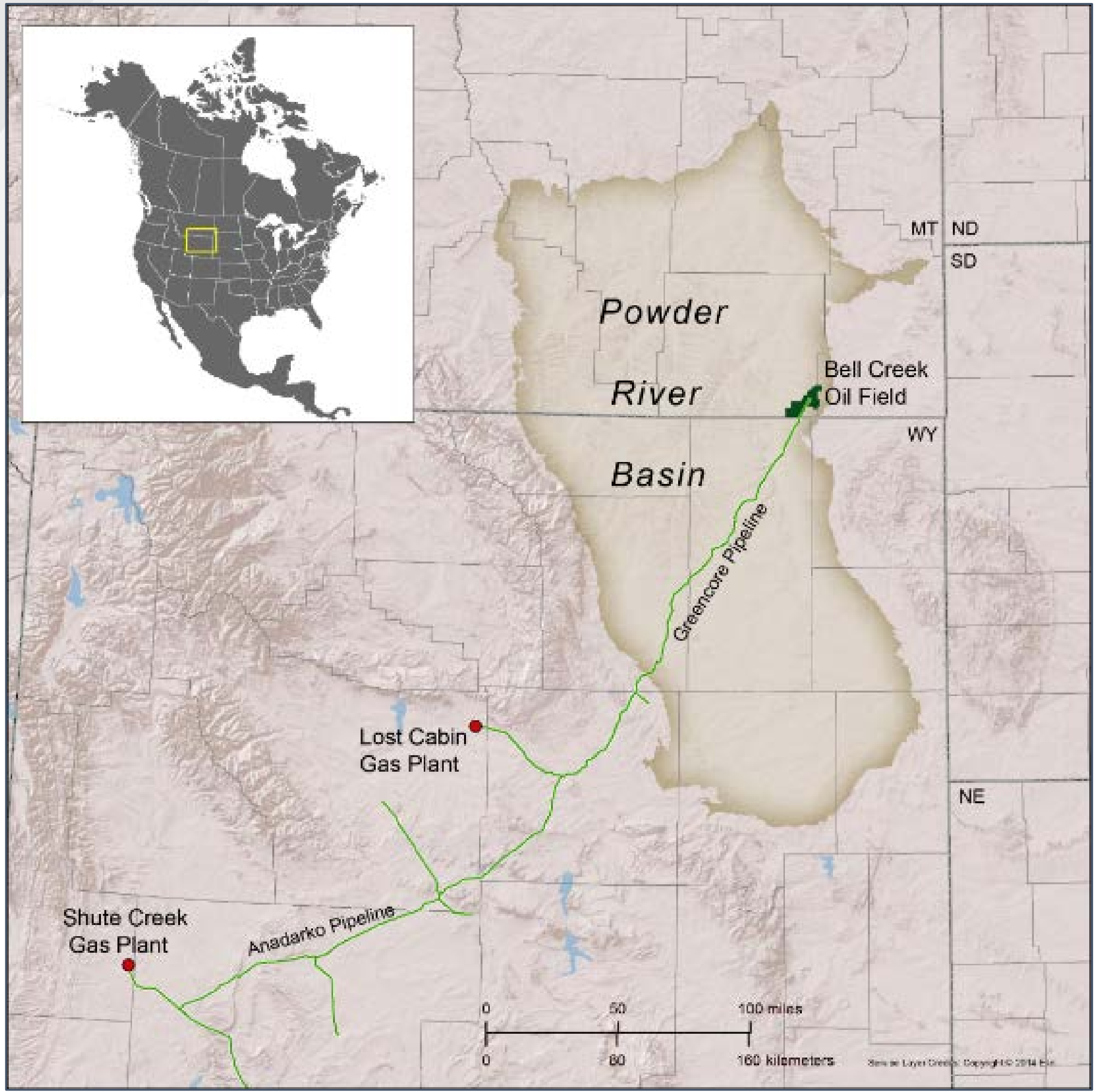
3. CCUS WORKS: SUCCESSFUL MONITORING OF STORAGE

Established and innovative technology:

- **Can be used to monitor injected CO_2 in the subsurface.**
- **Provides assurance that the environment is not being impacted.**

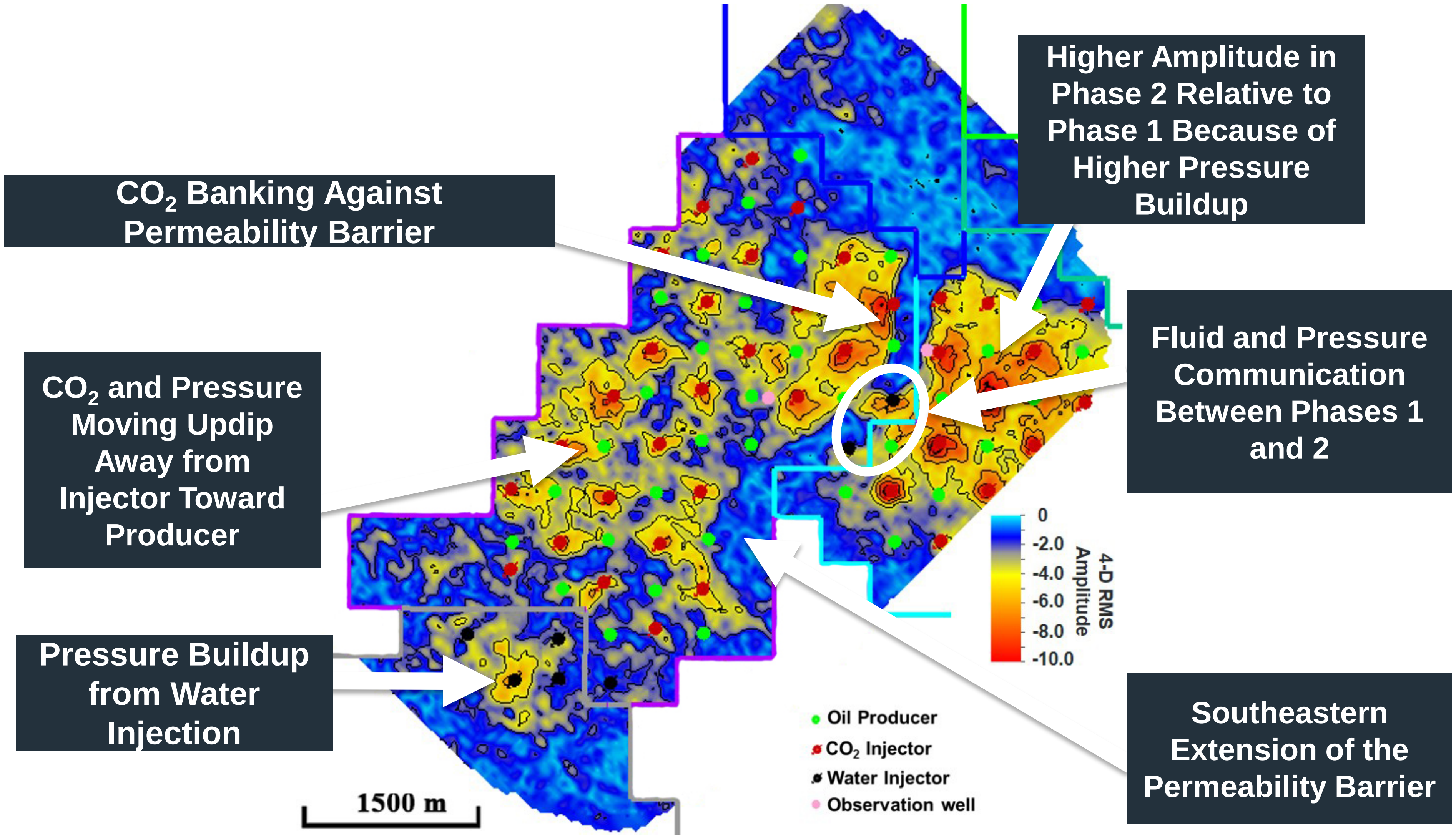


BELL CREEK

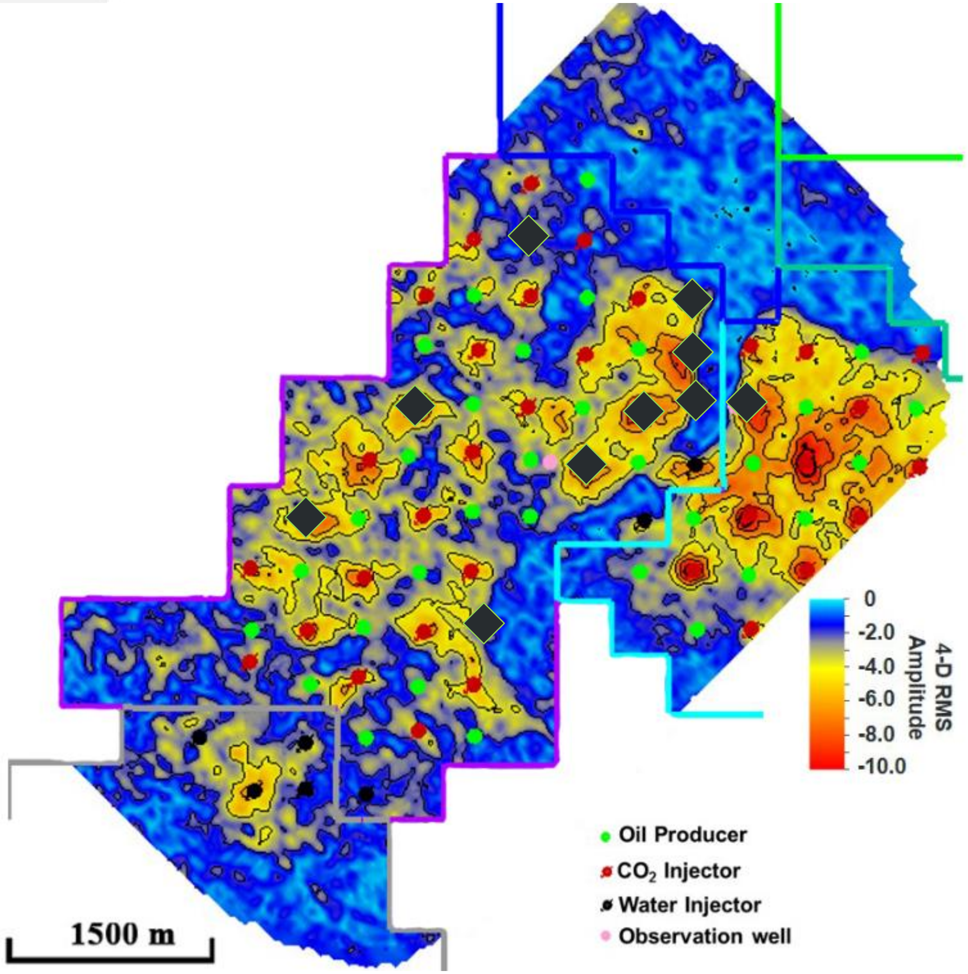


Images Credit

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

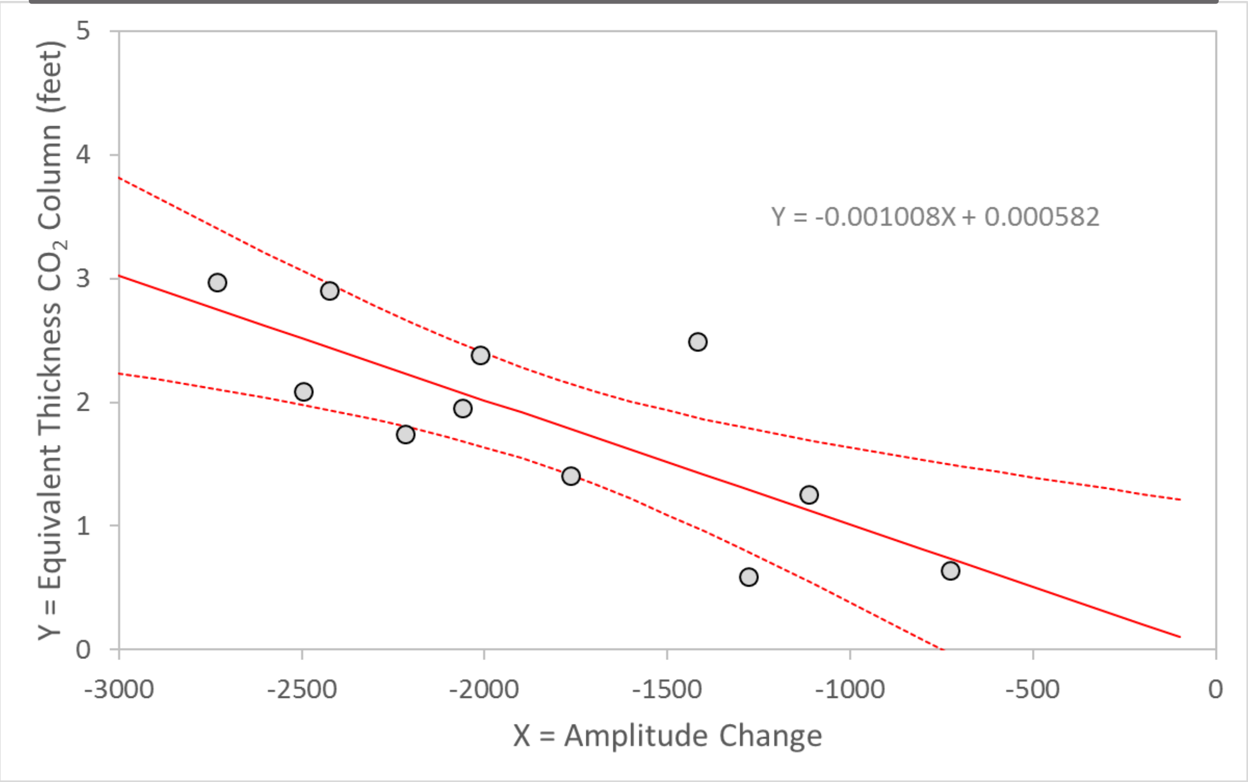


LINKING SEISMIC AND PULSED-NEUTRON LOGS (PNL)



PNL Locations

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

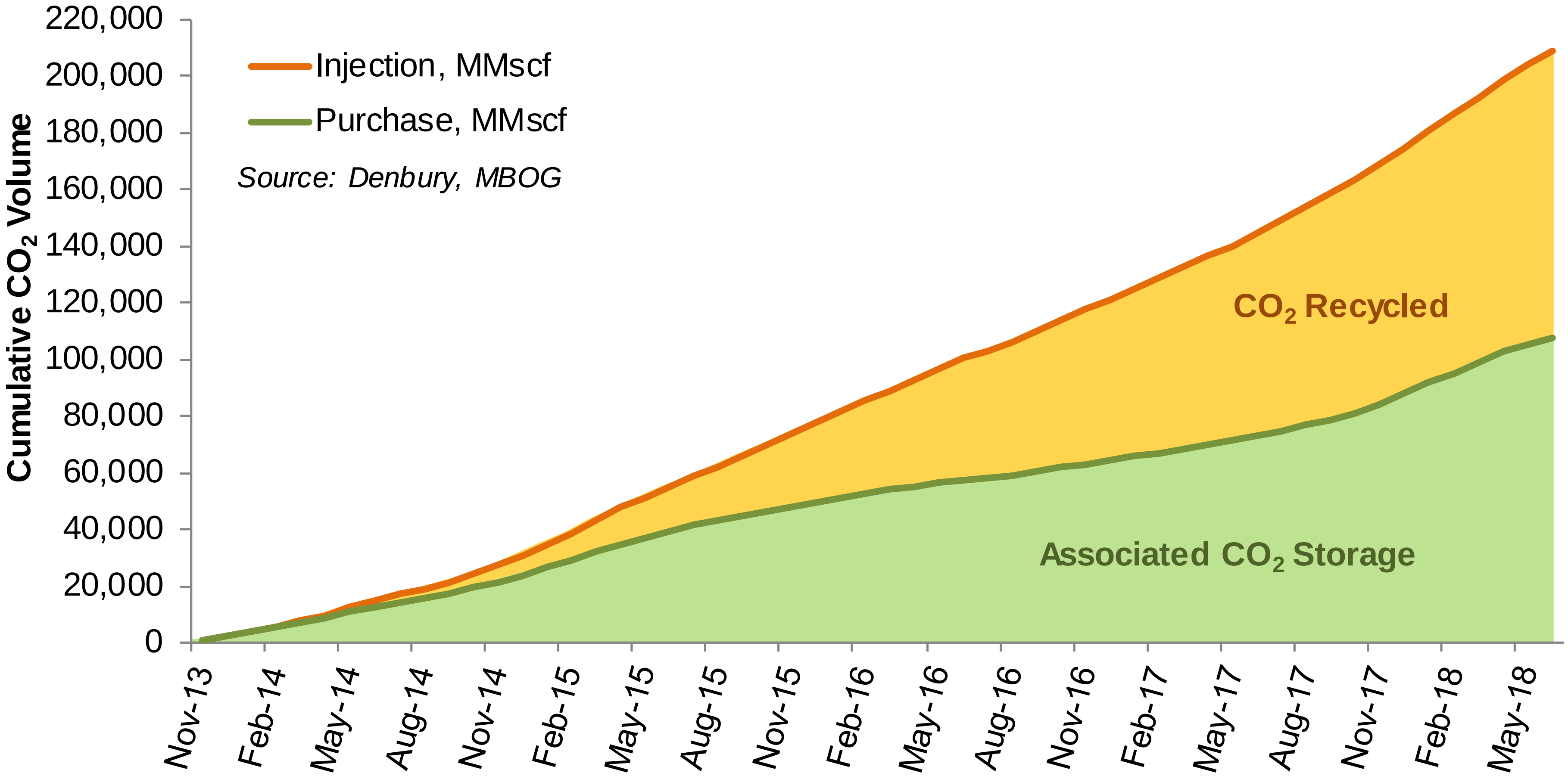


4. CCUS PROVIDES ECONOMIC AND ENVIRONMENTAL BENEFITS

Associated storage provides economic benefits:

- **Increased oil production**
- **Extended oilfield life**
- **Reduced emissions**
- **Jobs and revenue**

ASSOCIATED CO_2 STORAGE, INCIDENTAL TO EOR



ECONOMIC BENEFITS OF CO_2 EOR

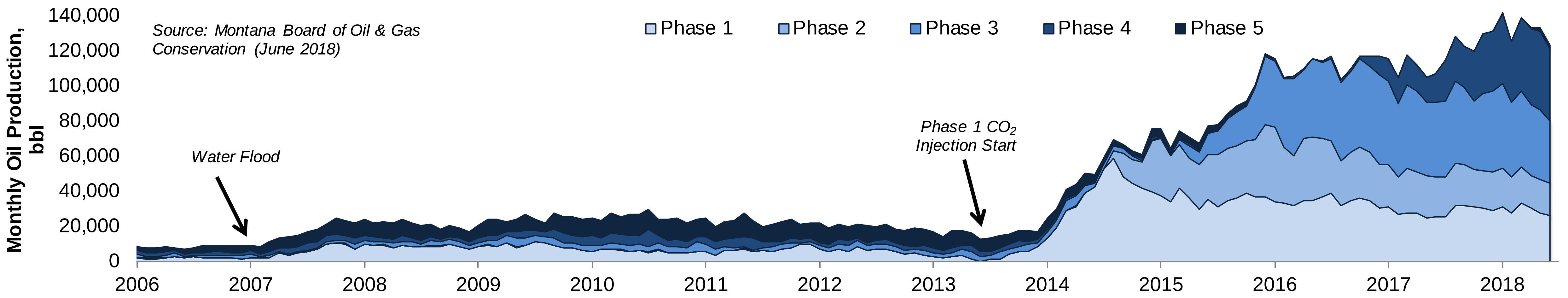


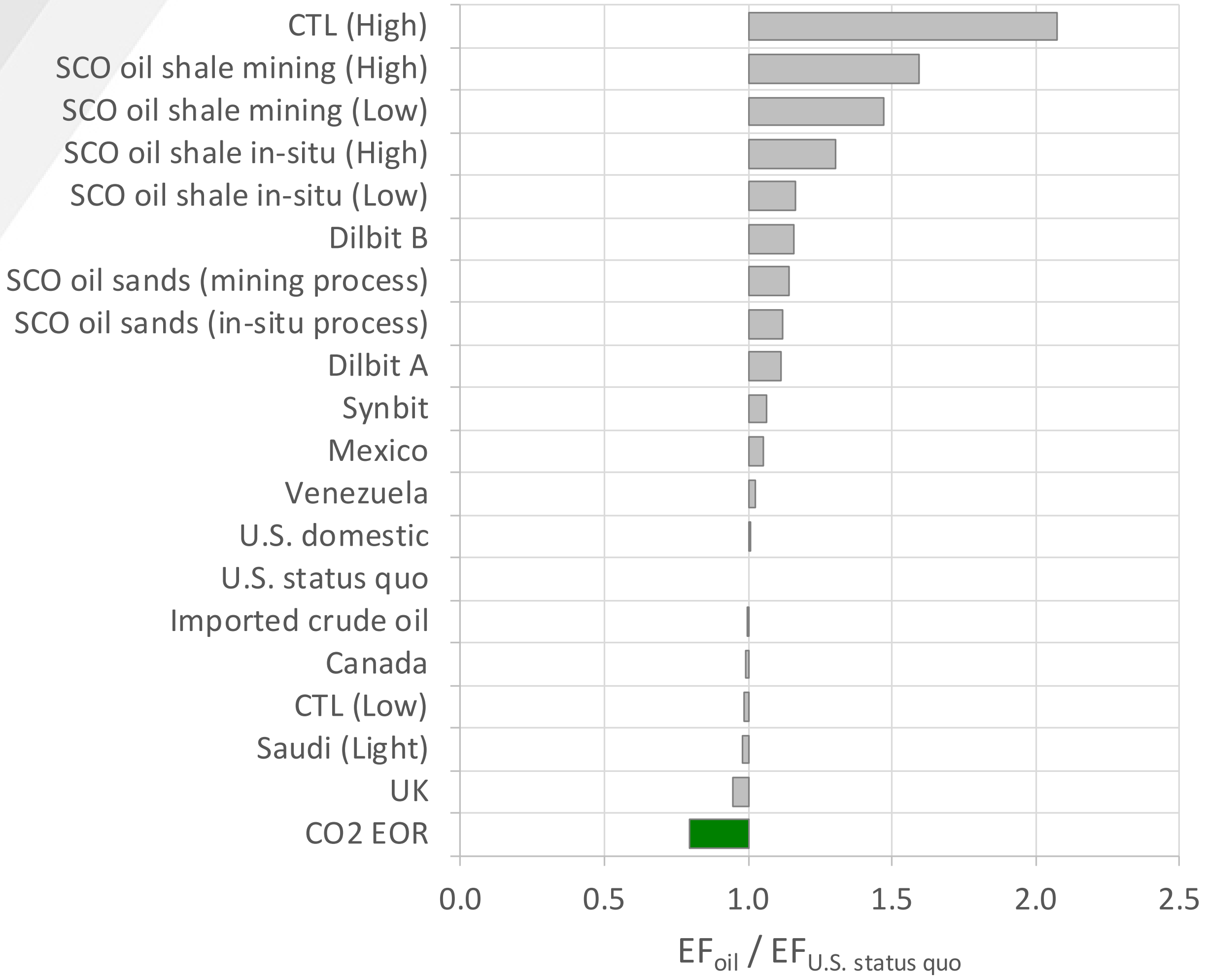
Image Credit – EERC

At Bell Creek:

- **Estimated 20–40 MMbbl of oil.** [1]
- **Nearly ~5.6 million bbl of oil has been produced since CO_2 enhanced oil recovery (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)

COMPARISON TO OTHER SOURCES OF CRUDE OIL



- Example of associated 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).**
- Spreadsheet model available on PCOR Partnership website.

Adapted from:

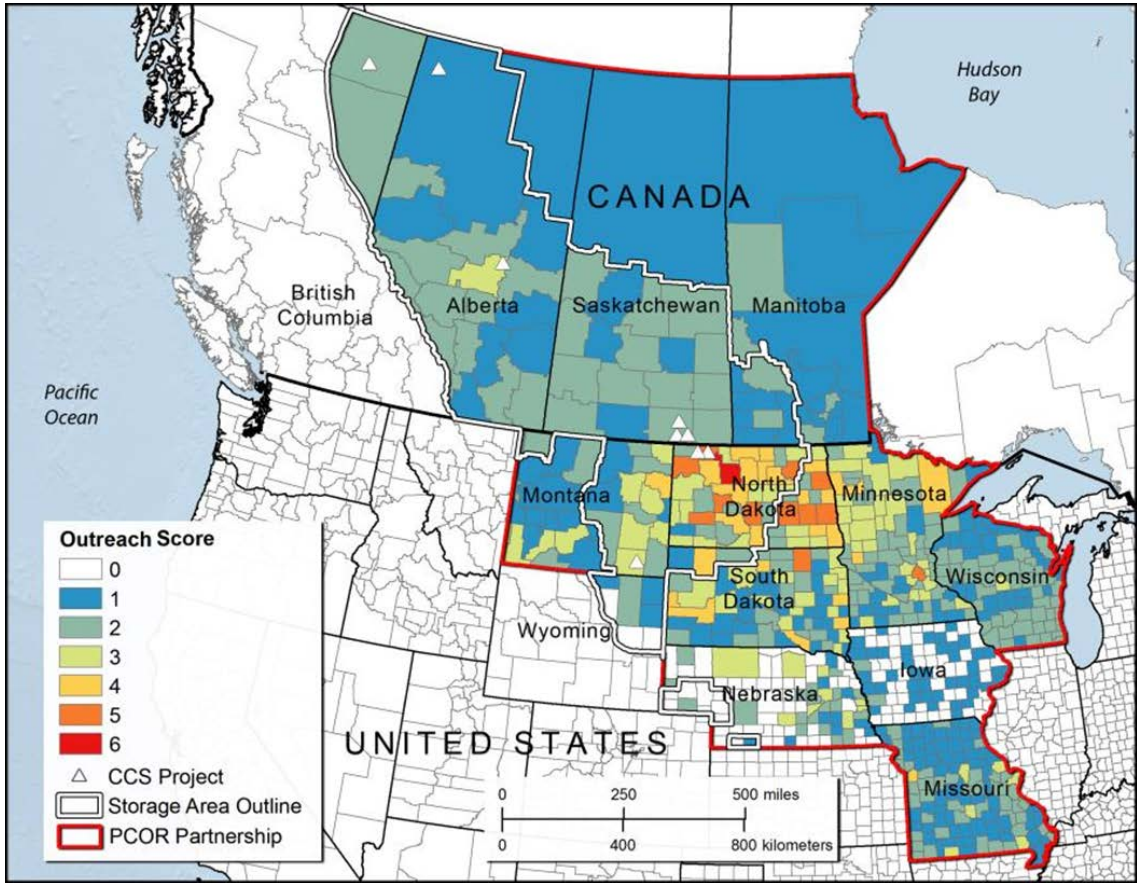
Mangmeechai, A., 2009. *Life Cycle Greenhouse Gas Emissions, Consumptive Water Use and Levelized Costs of Unconventional Oil in North America*. Dissertation. Carnegie Mellon University, Pittsburgh, PA.

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.

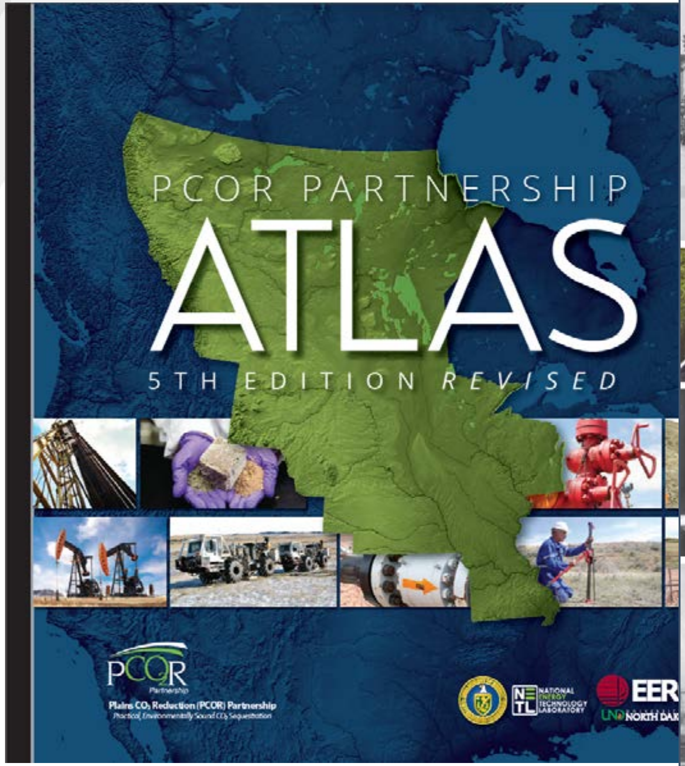
5. CCUS REQUIRES ACTIVE PUBLIC ENGAGEMENT

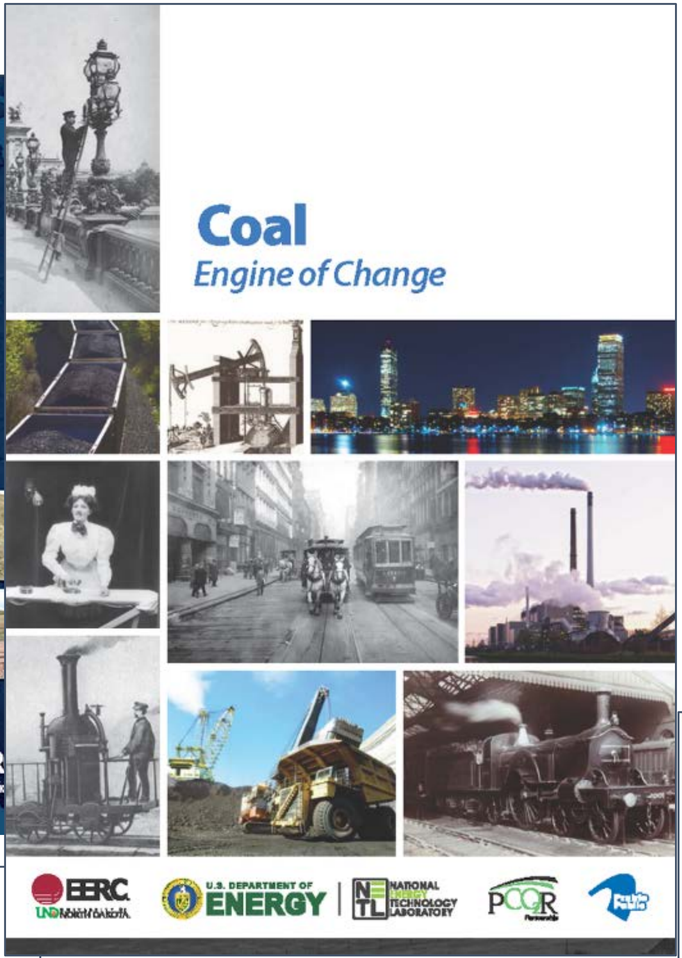
Increased public awareness of CCUS:

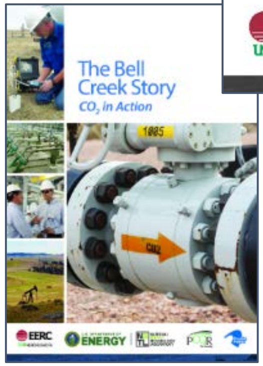
- **Active, multifaceted regional outreach**
- **Adoption of best practices**



ONGOING OUTREACH







Premiered 2018, available online

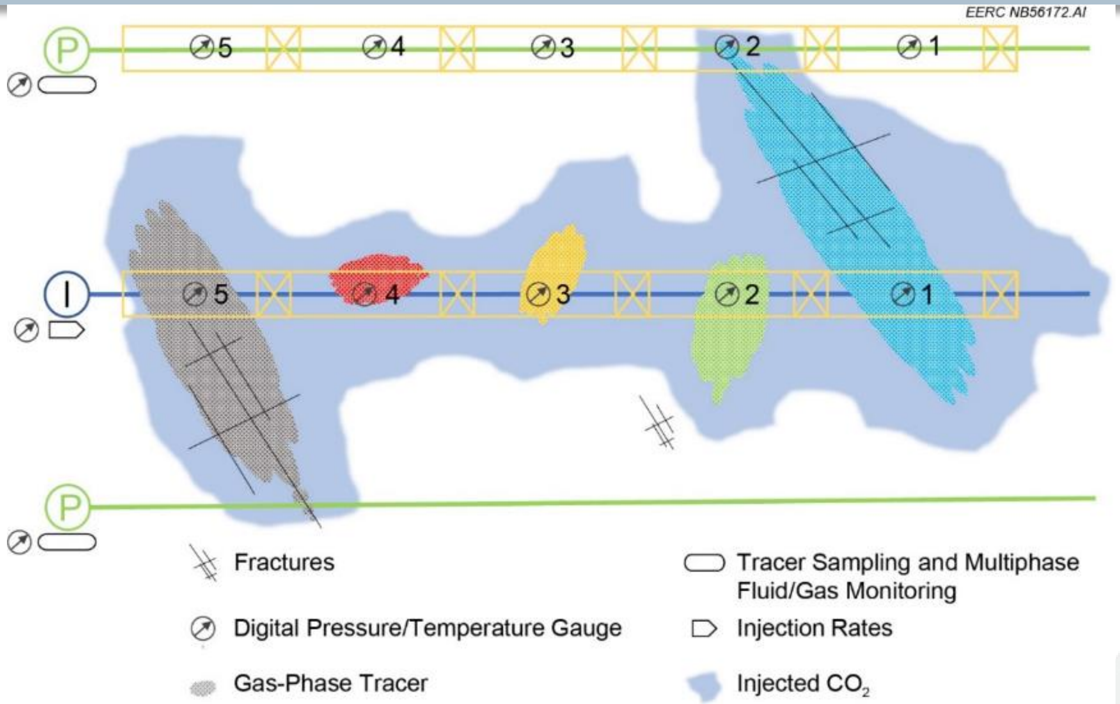
Images Credit – EERC

SYNERGY OPPORTUNITIES: CCUS PORTFOLIO AT EERC

Project	Focus					
	Capture	Transport	CO_2 Storage		Techno-Economic	Regulatory
			Dedicated	Associated		
PCOR Partnership, *PCOR Initiative*						
CarbonSAFE North Dakota Phase II						
CarbonSAFE Wyoming Phase I/II						
CarbonSAFE Nebraska Phase I						
Red Trail Energy						
Williston Basin Field Lab						
ND Techno-Economic						
BEST						
SASSA						
IMS						
Bakken CO_2 Storage and EOR						
Advanced Characterization						
Tight Oil CO_2 Project						
Rich Gas for Conventional EOR						
EOR Controllable Completions						

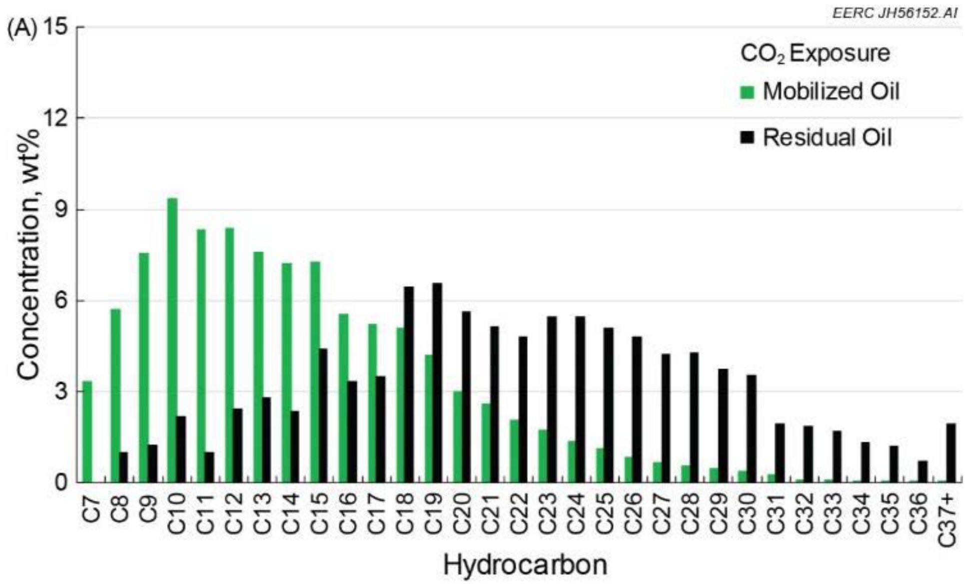
NEXT-GENERATION CONTROLLABLE COMPLETIONS

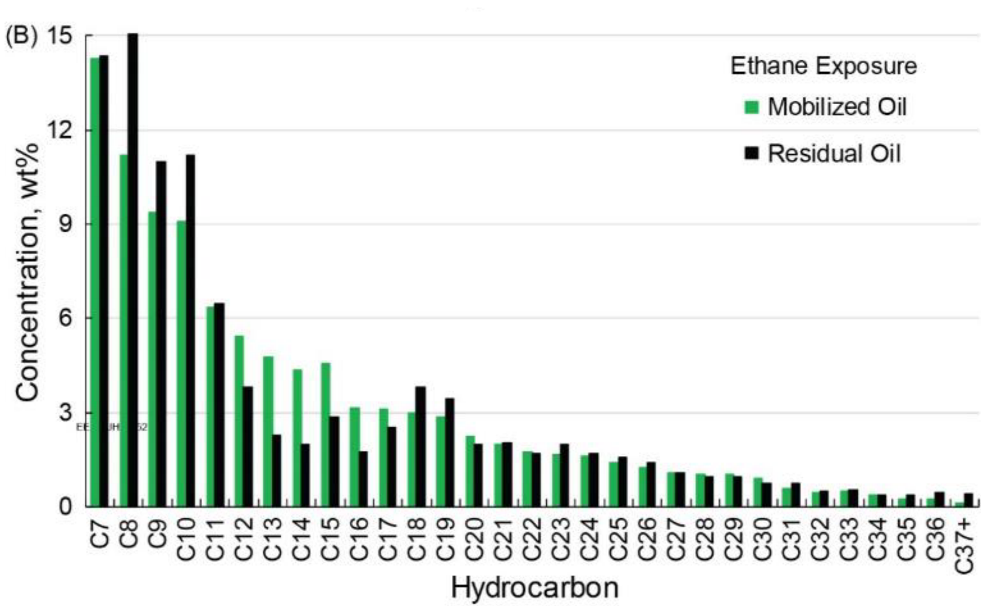
Research Hypothesis: *Deploying controllable completions in horizontal wells and integrating real-time downhole measurements into a machine learning approach will enable the development of a semiautonomous control system to help EOR operators manage injection conformance and optimize EOR operations.*



CO_2 BLENDED WITH RICH GAS

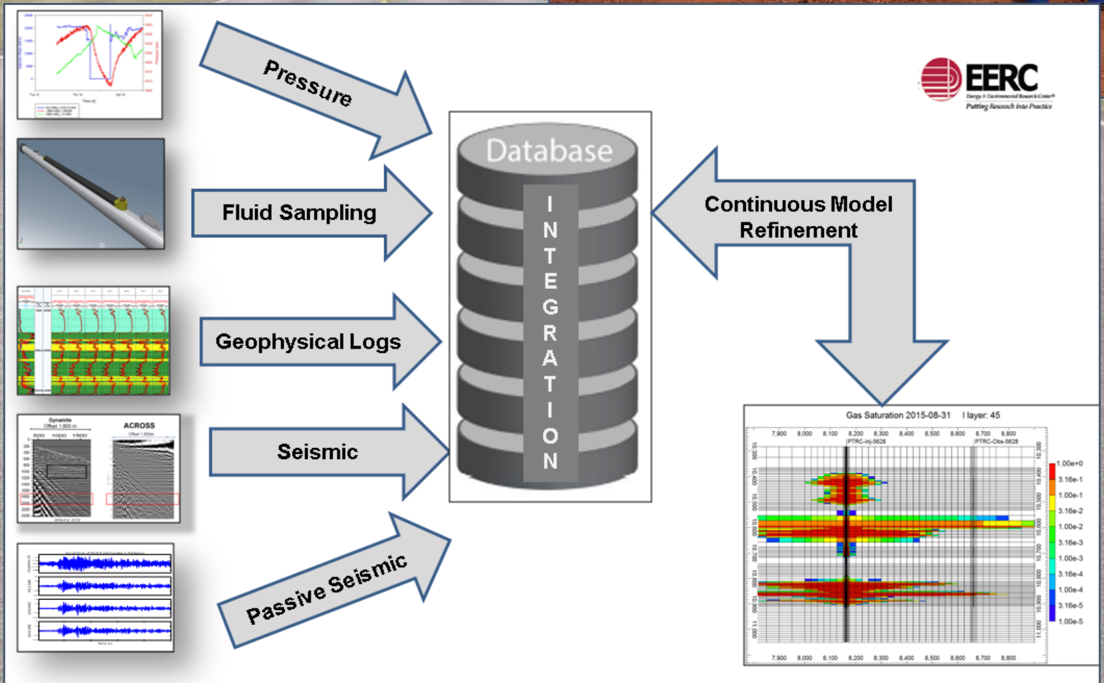
Research Hypothesis: *The injection of a blend of rich hydrocarbon gas and CO_2 into an oil reservoir will reduce molecular weight selectivity, lower minimum miscibility pressure and viscosity of the oil, and improve gas solubility, resulting in an overall improvement in EOR performance.*





SYNERGY OPPORTUNITIES: MVA EVOLUTION

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



PROJECT SUMMARY: PCOR PARTNERSHIP KEY MESSAGES

Five key messages from the PCOR Partnership:

1. Engaged membership and collaboration to deploy CCUS.
2. The PCOR Partnership region has outstanding CCUS potential.
3. CCUS works; through applied research we have demonstrated:
   a) Low risks associated with storage.
   b) Successful MVA to track injected CO_2.
4. CCUS provides economic and environmental benefits.
5. CCUS requires active public engagement and outreach.

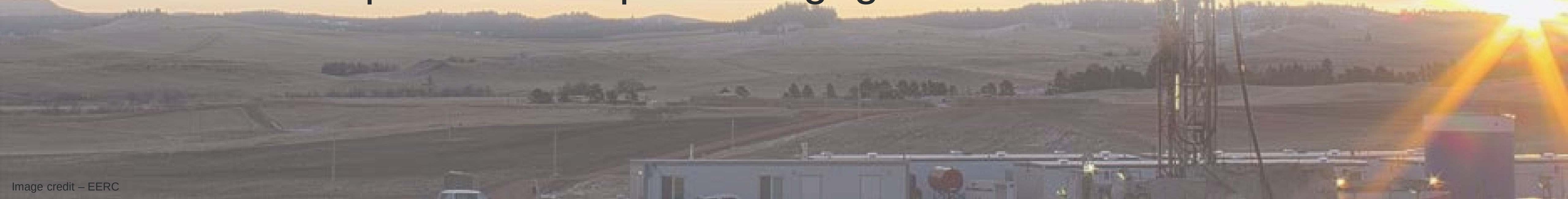


Image credit – EERC

EERC | UND UNIVERSITY OF NORTH DAKOTA

Charles Gorecki
CEO
cgorecki@undeerc.org
701.777.5355 (phone)

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

www.undeerc.org

701.777.5000 (phone)
701.777.5181 (fax)

BENEFIT TO THE PROGRAM: ADDRESSING RCSP PROGRAM GOALS

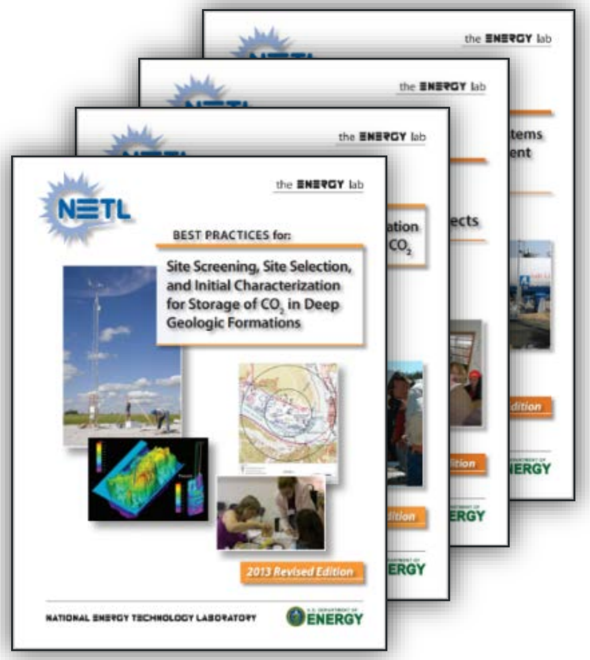
- Develop technologies that will support the industry’s ability to predict CO_2 storage capacity in geologic formations to within ±30%:
  - *Conducting pilot tests and demonstration projects in hydrocarbon reservoirs, saline formations, and coal seams to improve understanding of sweep and storage efficiency.*
  - *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.”



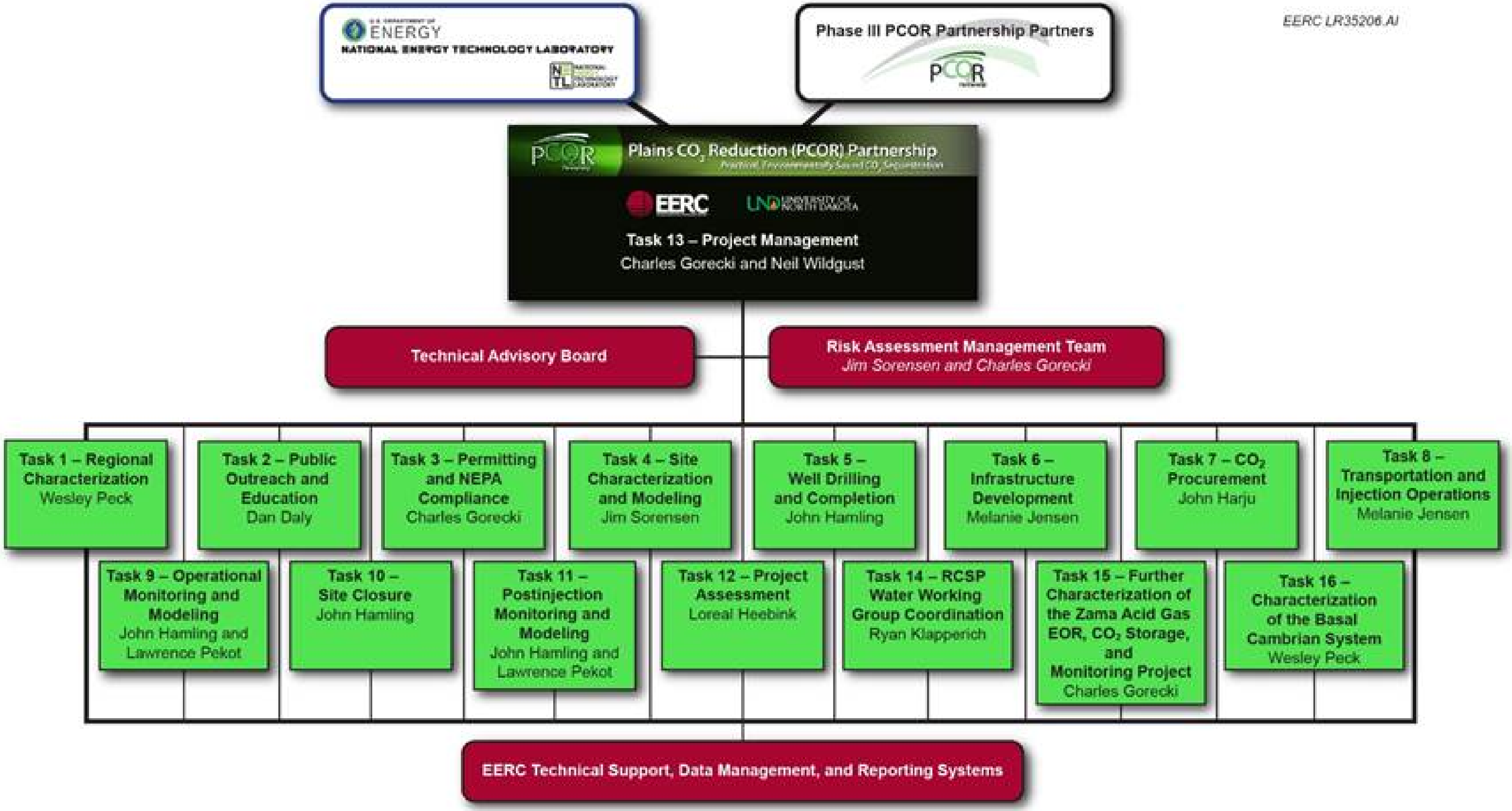
PCOR PARTNERSHIP BELL CREEK OBJECTIVES

- 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.

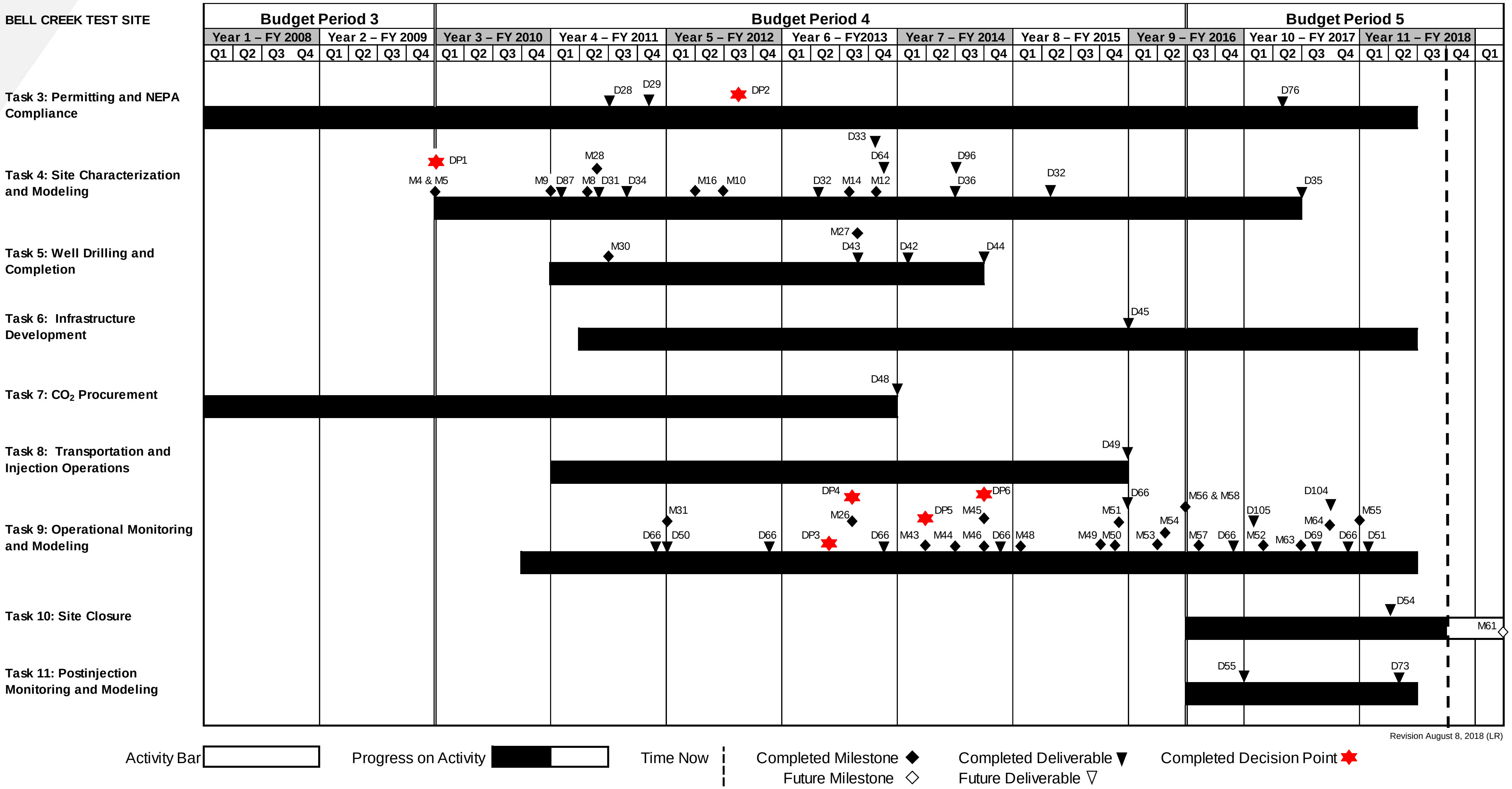
LESSONS LEARNED

- 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 (note: project extended to end 2019 for reporting purposes)



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 CO_2 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 CO_2 storage efficiency factors in hydrocarbon reservoirs—a detailed look at CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 hysteresis effects during multiple floods of a conventional clastic oil reservoir: International Journal of Greenhouse Gas Control, v. 78, p. 1–6.

EERC | UND UNIVERSITY OF NORTH DAKOTA

Critical Challenges. Practical Solutions.