Lessons Learned from Enhanced Oil Recovery Operations: The Plains CO_2 Reduction Partnership

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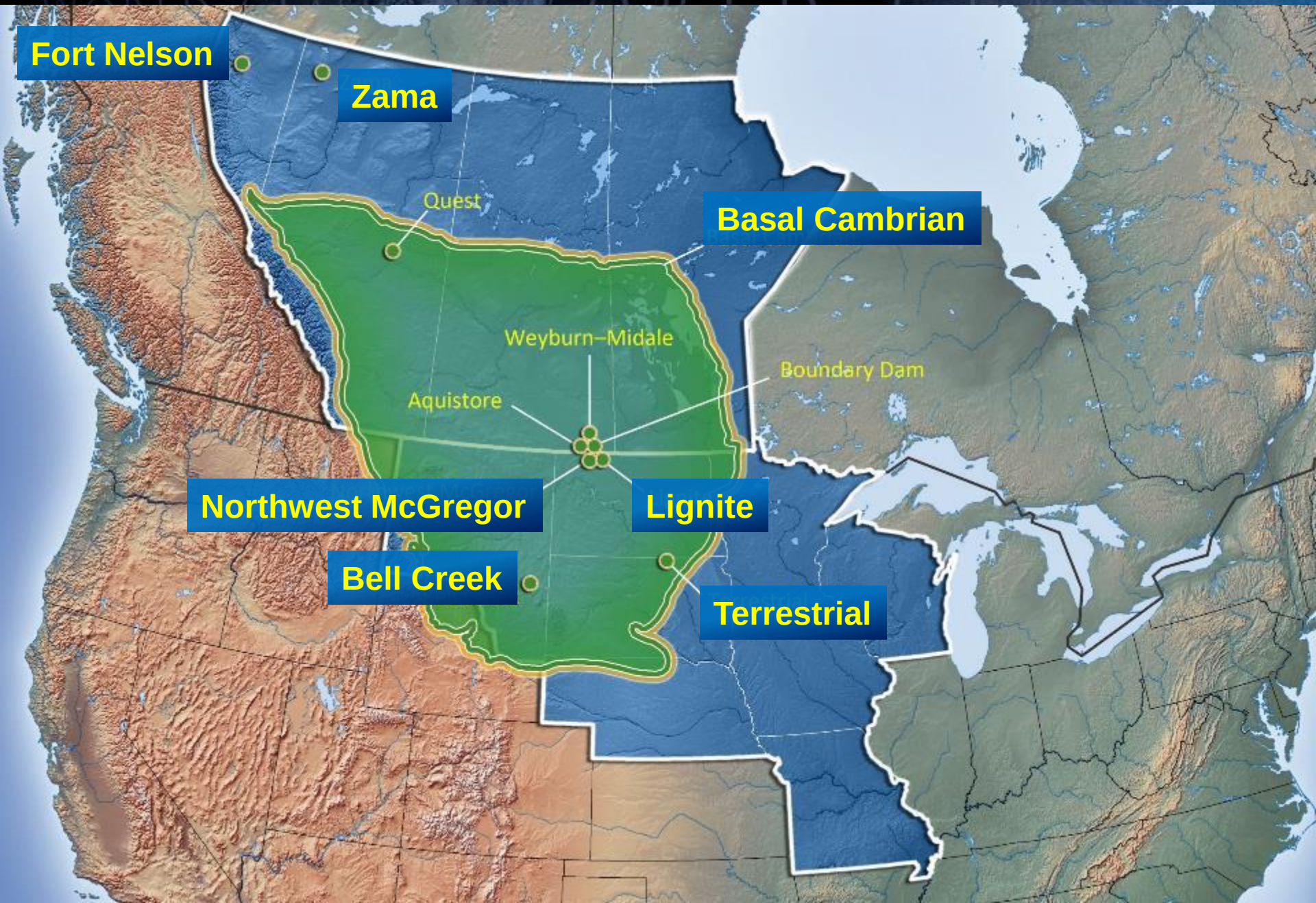
Plains CO_2 Reduction (PCOR) Partnership

- Nine states
- Four Canadian provinces
- 1,382,089 square miles
- More than 100 partners

PCOR Partnership Field-Based Projects

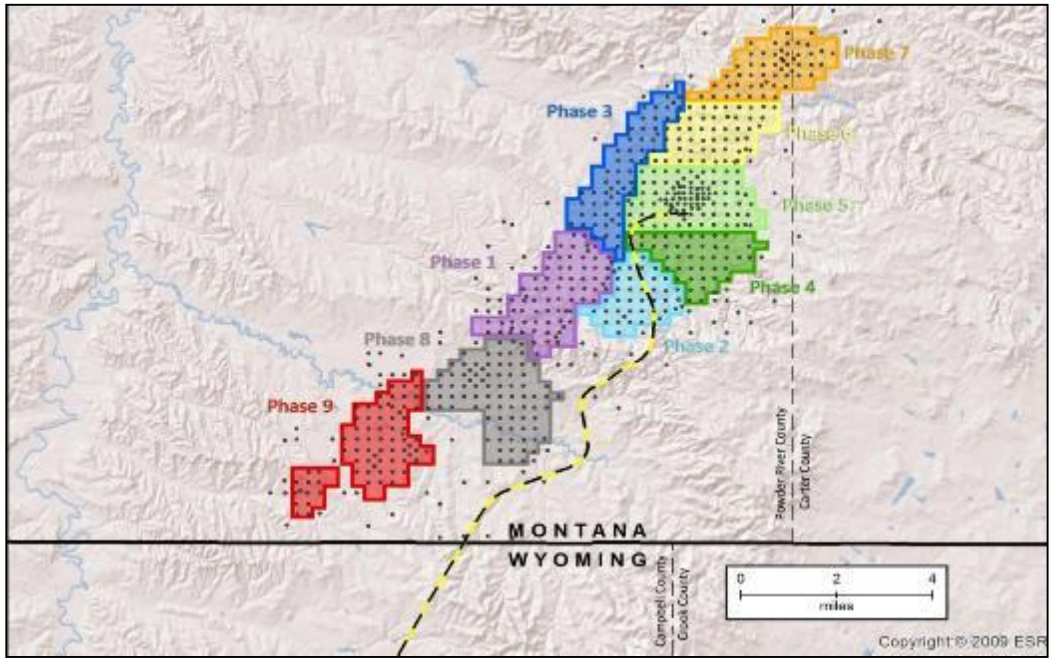


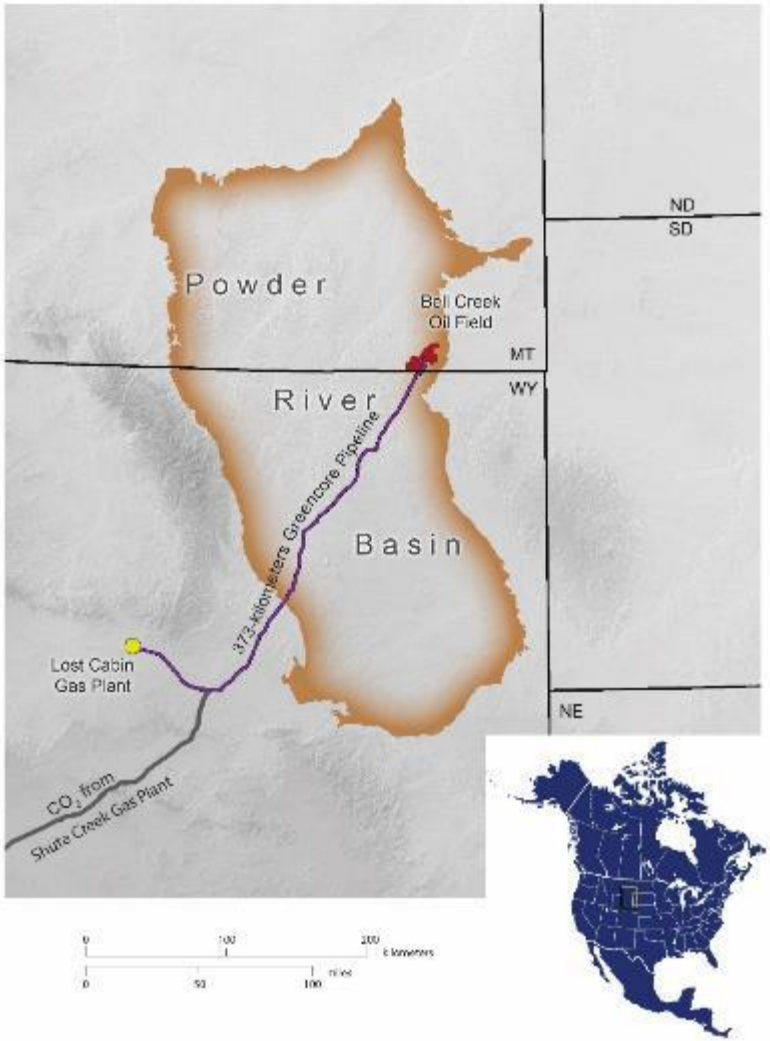
PCOR Partnership Objectives

- Safely and permanently demonstrate associated carbon dioxide (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 monitoring, verification, and accounting (MVA) methods to safely and effectively monitor and account for associated CO_2 storage in context of commercial-scale CO_2 EOR.
- 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.

Bell Creek Field

- The Bell Creek oil field is 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 Energy & Environmental Research Center, through the PCOR Partnership, is studying associated CO_2 storage with regards to a commercial CO_2 EOR project.



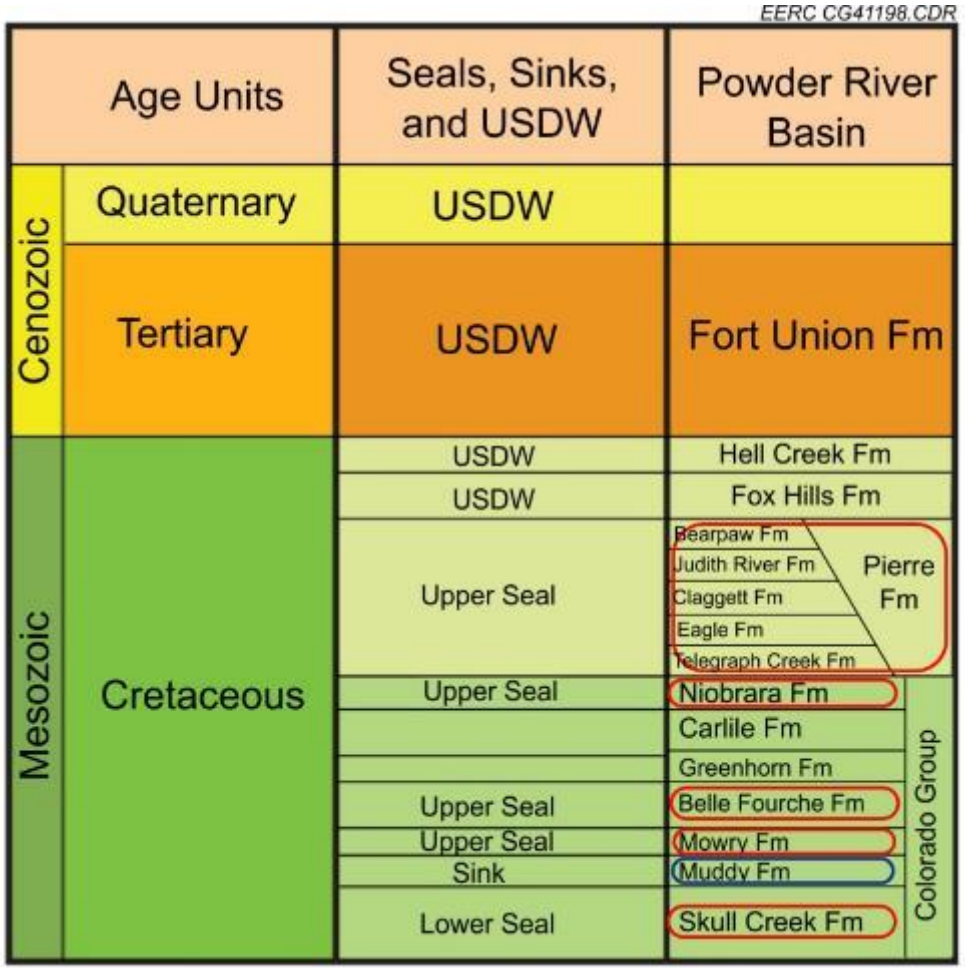


NETL PCOR Partnership

Site Characteristics

Bell Creek Properties

- Cretaceous Muddy Sandstone Formation
- Nearshore marine/strand plain (barrier bars)
- Approximately 4300–4500-ft depth
- Overlain by more than 3000 ft of siltstones and shales
- Average thickness 30–45 ft
- Average porosity range
  - 25%–35%
- Average permeability range
  - 150–1175 mD
- Low reservoir water salinity ~5000 ppm total dissolved solids (TDS)
- Oil gravity 32°–41° API



CO_2 Injection Is Ongoing!!!

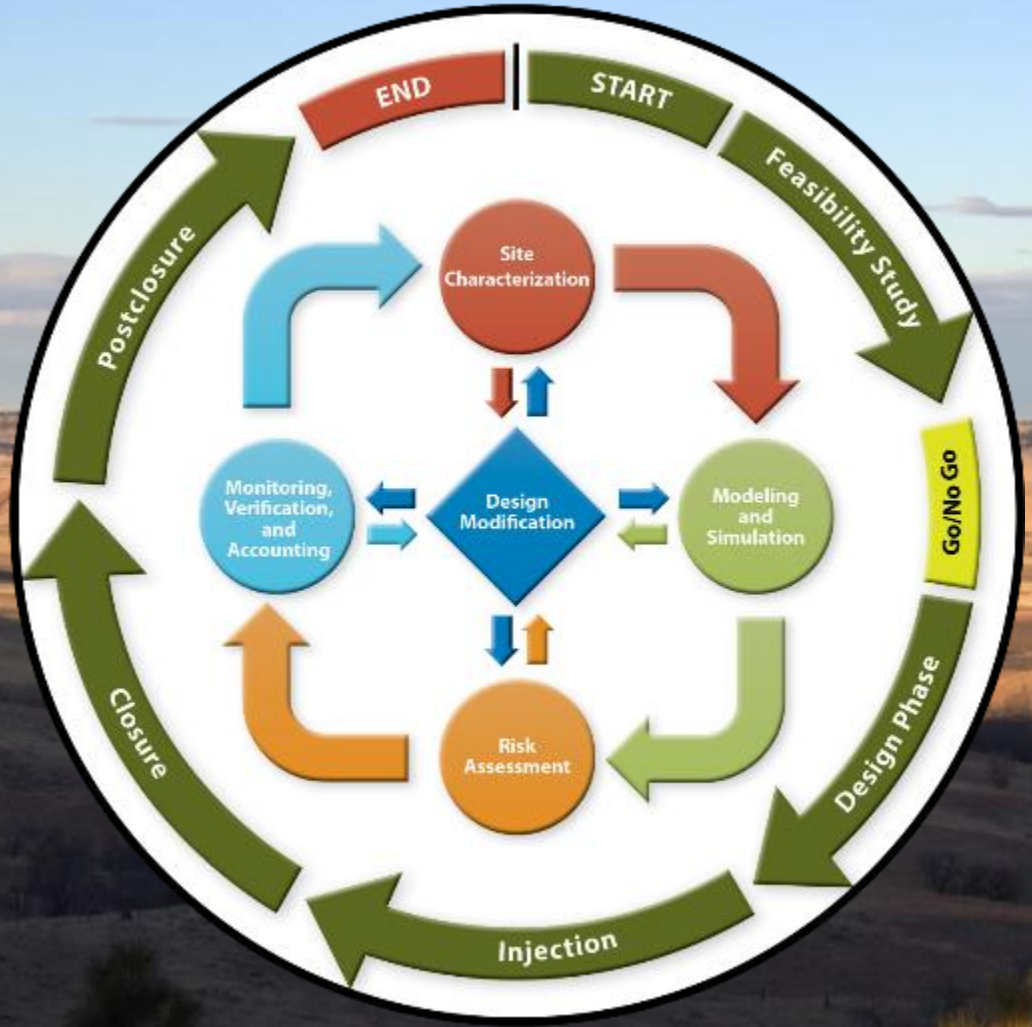
- Pipeline completed November 2012
- Pipeline filled February/March 2013
- First injection May 2013
- Facilities commissioned August 2013
- **1.60 million tonnes of CO_2 injected through November 2014**
- **1.51 million tonnes of CO_2 stored through November 2014**

(source: Montana Board of Oil and Gas Database)

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

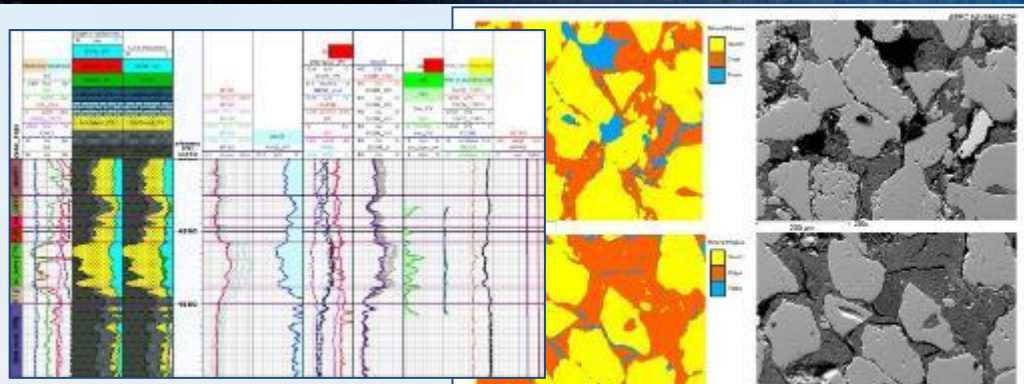
The PCOR Partnership's Integrated Approach to Program Development

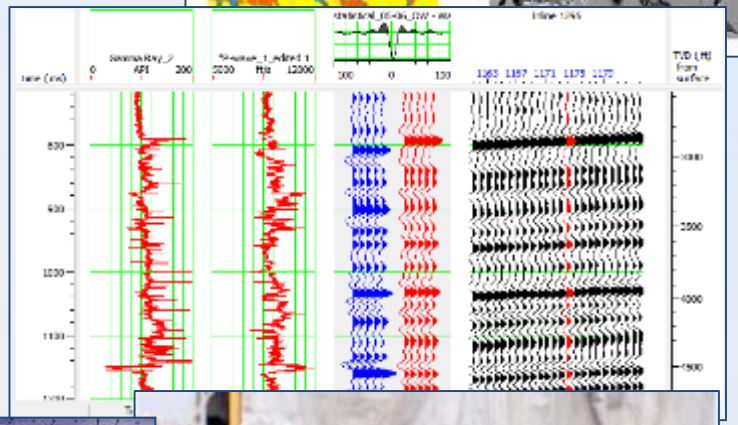
Focused on Site Characterization, Modeling and Simulation, and Risk Assessment to Guide MVA Strategy

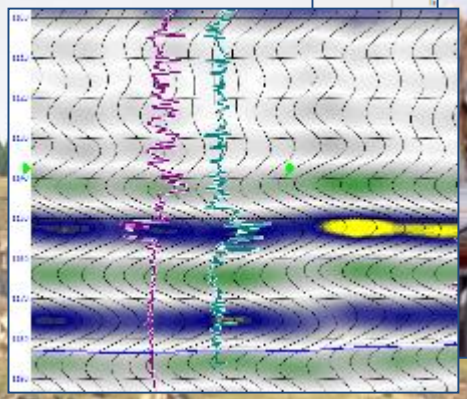


Site Characterization

- Well file integration
- Lidar (light detection and ranging) collection
- Outcrop investigations
- Drilling characterization wells
- New core collection and analysis
- SCAL (special core analysis) and pressure–volume–temperature (PVT) testing
- Existing core analysis
- 104-km^2 (40-mi^2) baseline 3-D seismic survey
- Baseline 3-D vertical seismic profiles (VSPs)
- Pulsed-neutron logs (PNLs)



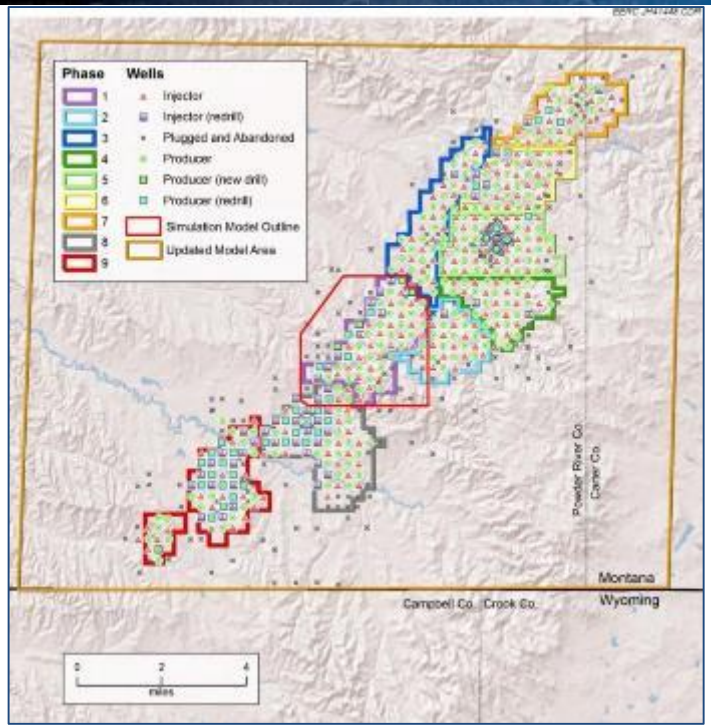




Modeling and Simulation

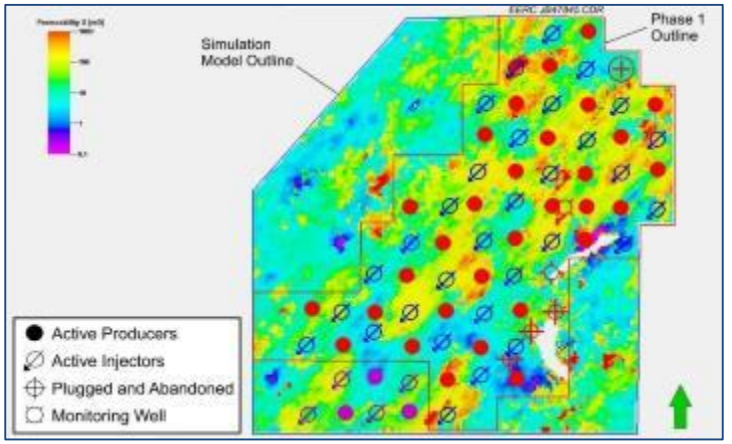
Models

- 518-km^2 (200-mi^2) domain models
- 20-km^2 (7.75-mi^2) multiphase flow numerical simulation models
- PVT and equation-of-state modeling
- 1-D and 3-D mechanical earth model
- Shallow-subsurface geochemical modeling
- Near-surface flow model

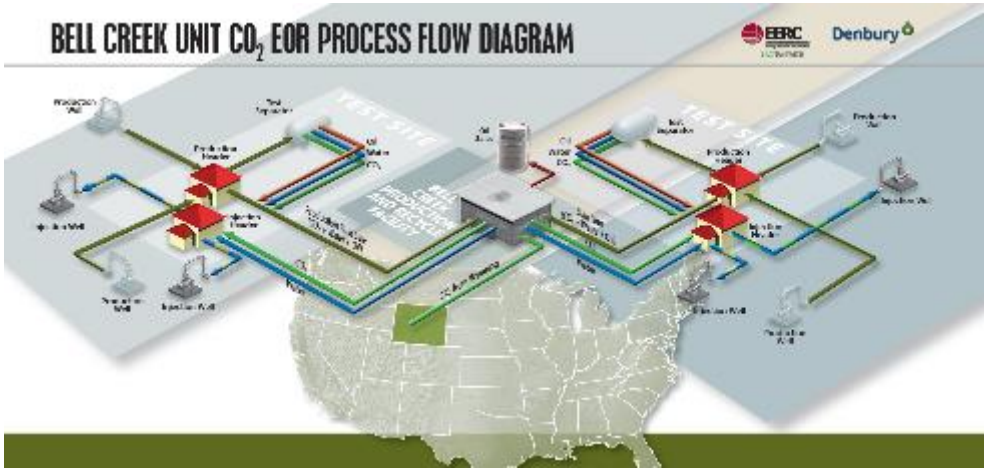


Simulation

- Phases 1 and 2 (separate) history matching and predictive simulation complete.
- Phases 1 and 2 combined history matching is under way.



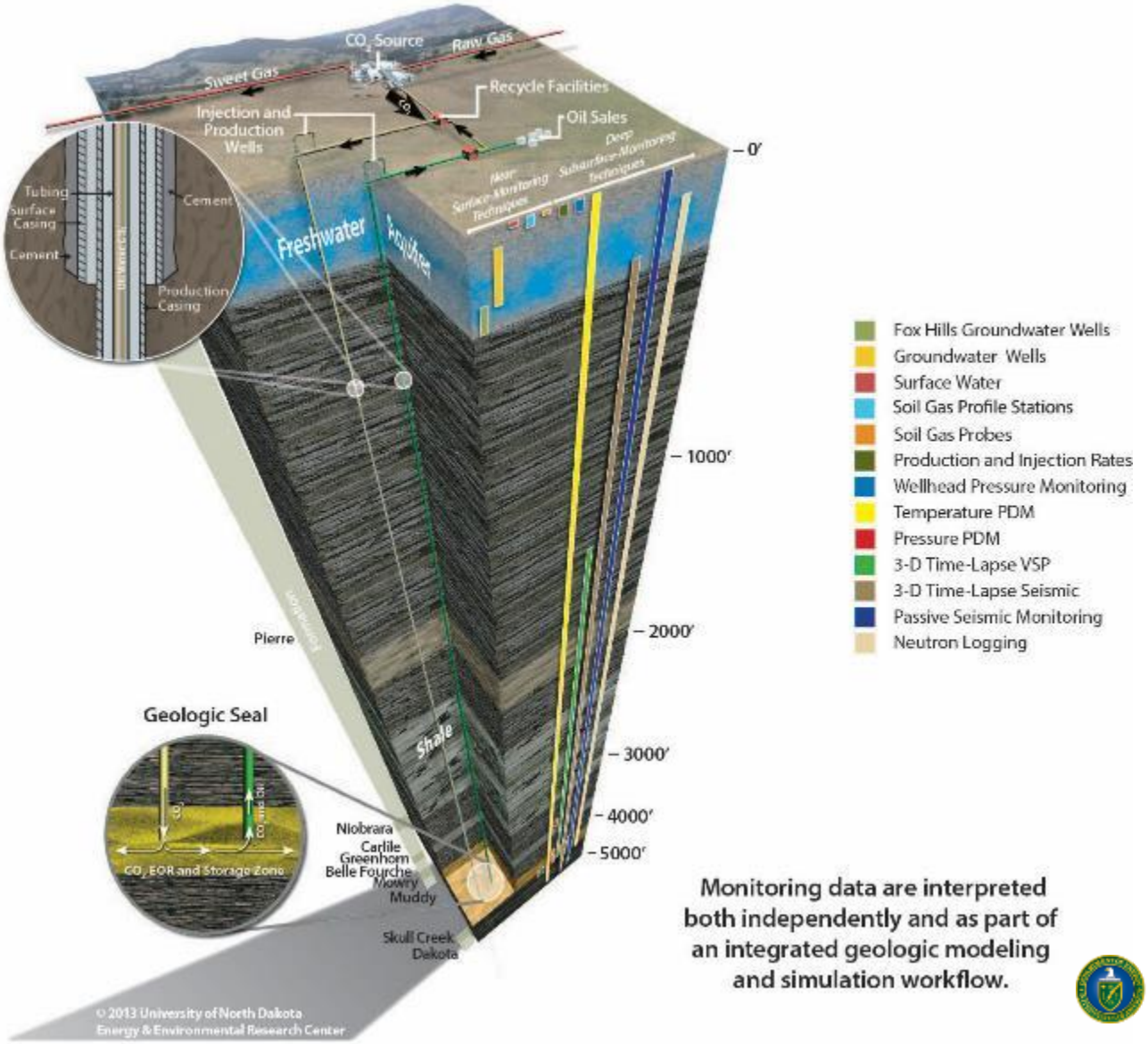
How do you develop MVA strategies that are practical and meaningful at a commercial scale?



Bell Creek (above), Permian Basin Examples (below)

Permian Basin oilfield, from Texas Oil Landscape of an Industry, CLUI photo

Research MVA and Surveillance Program Deployed at Bell Creek



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

Near-Surface MVA

Activity	Date
Prep and Planning	February-11
Baseline	November-11
Operational Monitoring 1	June-13
Operational Monitoring 2	June-14

Qtr 1, 2011 | Qtr 3, 2011 | Qtr 1, 2012 | Qtr 3, 2012 | Qtr 1, 2013 | Qtr 3, 2013 | Qtr 1, 2014 | Qtr 3, 2014 | Qtr 1, 2015 | Qtr 3, 2015

Prep and Planning

- Site access agreements
- Site reconnaissance
- Training and methods development
- Equipment procurement

Baseline

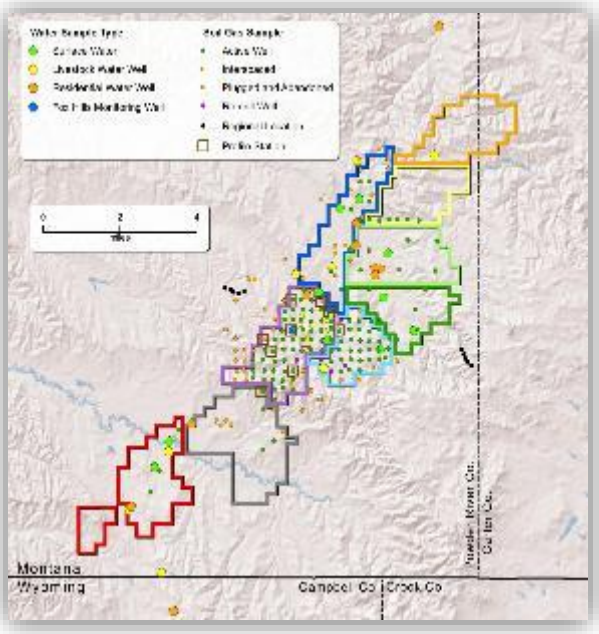
- Quarterly full-field water and soil gas sampling and analysis
- Transitioning to include monthly soil gas sampling and analysis at Phase 1 locations

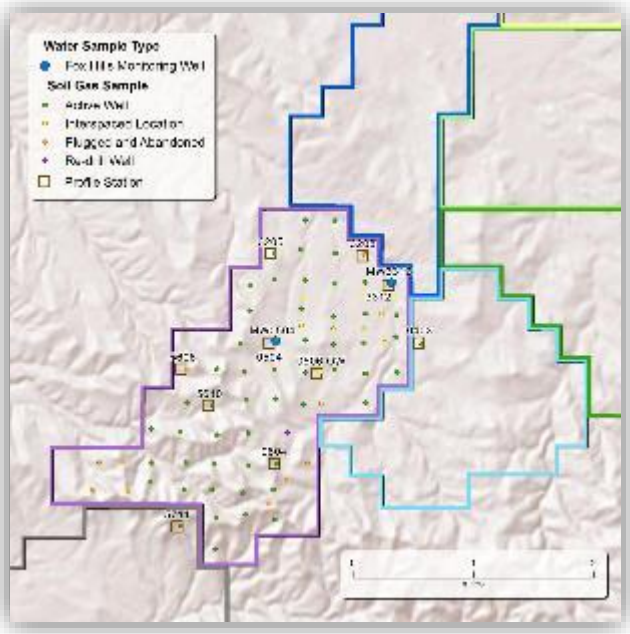
Operational Monitoring 1

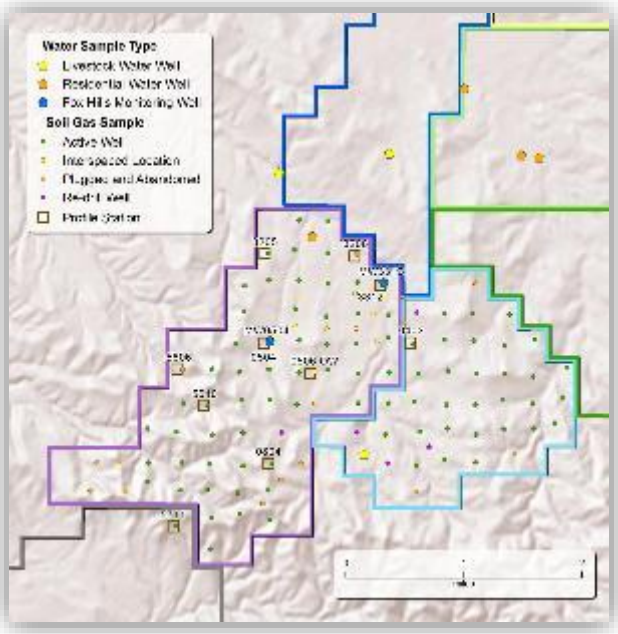
- Monthly water and soil gas sampling and analysis at Phase 1 locations
- Annual full-field water and soil gas sampling and analysis

Operational Monitoring 2

- Quarterly soil gas and water sampling and analysis alternating between select locations (Phase 1 and 2) and full-field events







Near-Surface Assurance Monitoring

- Successfully demonstrating **NO IMPACT** to near-surface environments.
- Chemical modeling and laboratory exposure testing indicate sufficient sensitivity to detect a hypothetical out-of-zone fluid migration, providing area of influence transects a monitoring point.
- Monitoring program was sufficient to detect, characterize, and attribute multiple anomalies to naturally occurring processes.
- Workflows were developed to semiautomate the analysis and characterization process that can be adapted into site-specific intelligent monitoring approaches.
- Baseline data set spanning 18-month period prior to injection providing a scientifically defensible data set of natural variability of near-surface environments supplemented by ~2 years of operational monitoring data.
- First years of operational monitoring have provided key insight regarding how the research monitoring program could be transitioned toward a more commercially viable long-term assurance-monitoring strategy.
- Landowner relations key to **<u>success</u>.**

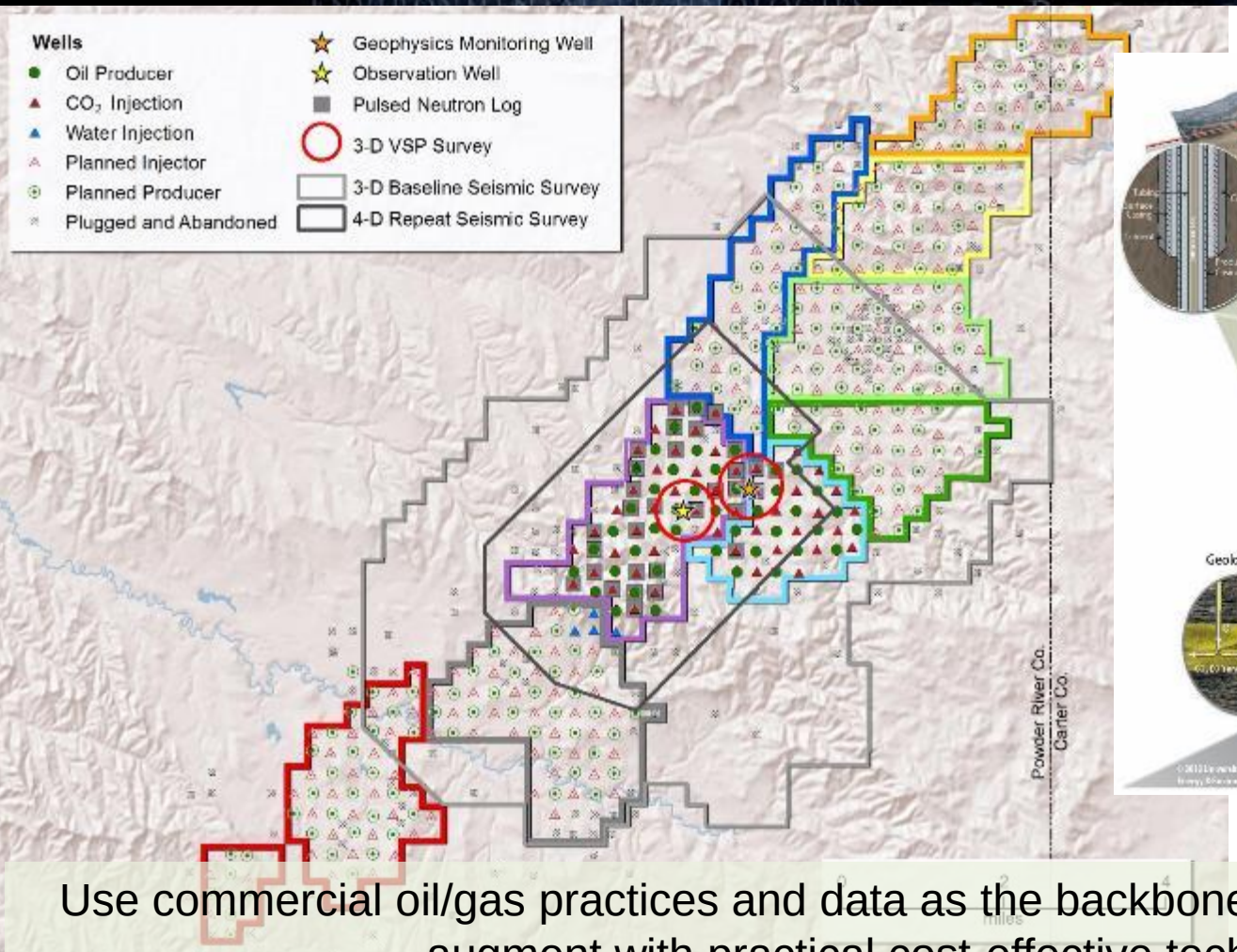


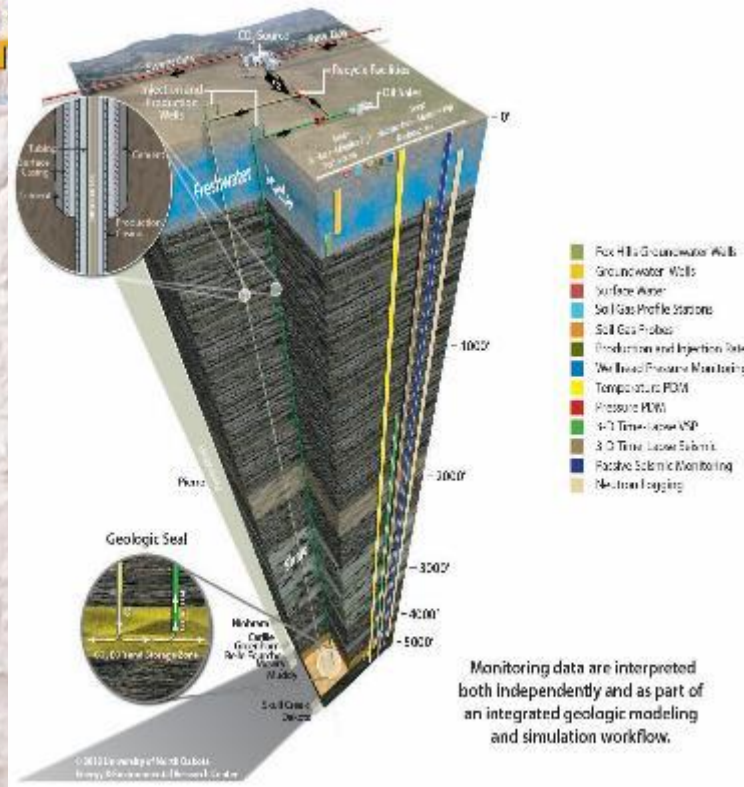







Subsurface MVA Program

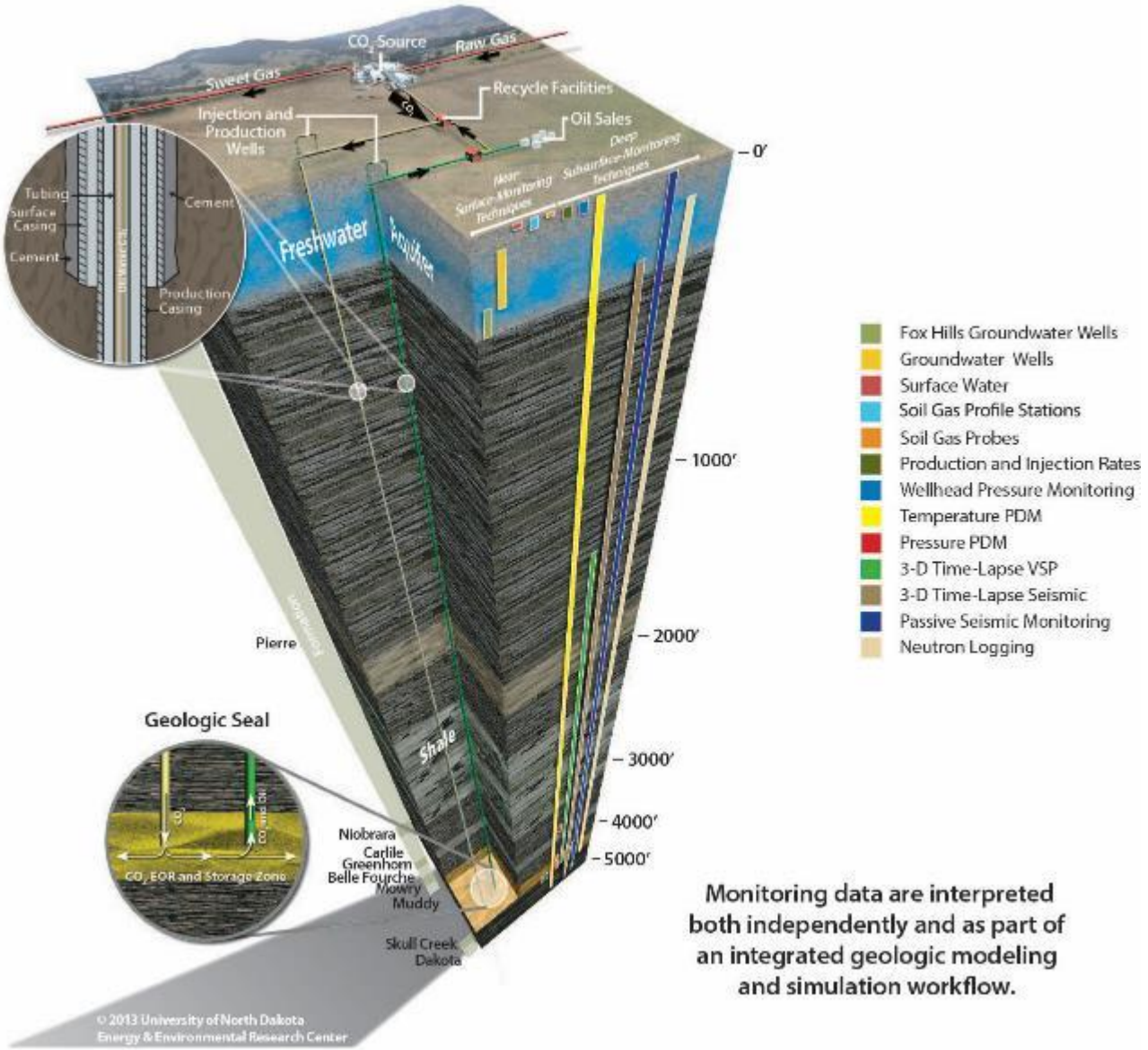




Use commercial oil/gas practices and data as the backbone of the MVA strategy, then augment with practical cost-effective techniques.

Path Forward – Operational Monitoring

- Update risk analysis with monitoring data.
- Time-lapse seismic surveys.
- PNL.
- Reduced sampling interval for soil gas and groundwater.



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EERC

Developing Successful Monitoring Strategies

- **Clear objectives/purpose that lead to actionable decisions.**
- Site-specific strategies and site-compatible technologies.
- Talk to your service providers about objectives, not tools. Use due diligence in selection (good data are a win/win).
- Have sufficient expertise and resources to process, interpret, and analyze acquired data.
- Deploy cost-effective monitoring strategies with clear and robust interpretation techniques that can enhance project.
- Minimize impact to operations and manage risk/liability of deployment.
- Use commercial oil/gas data as a backbone to build enhanced monitoring programs and interpretations and to validate technologies.
- Interpret data in context of overall project.

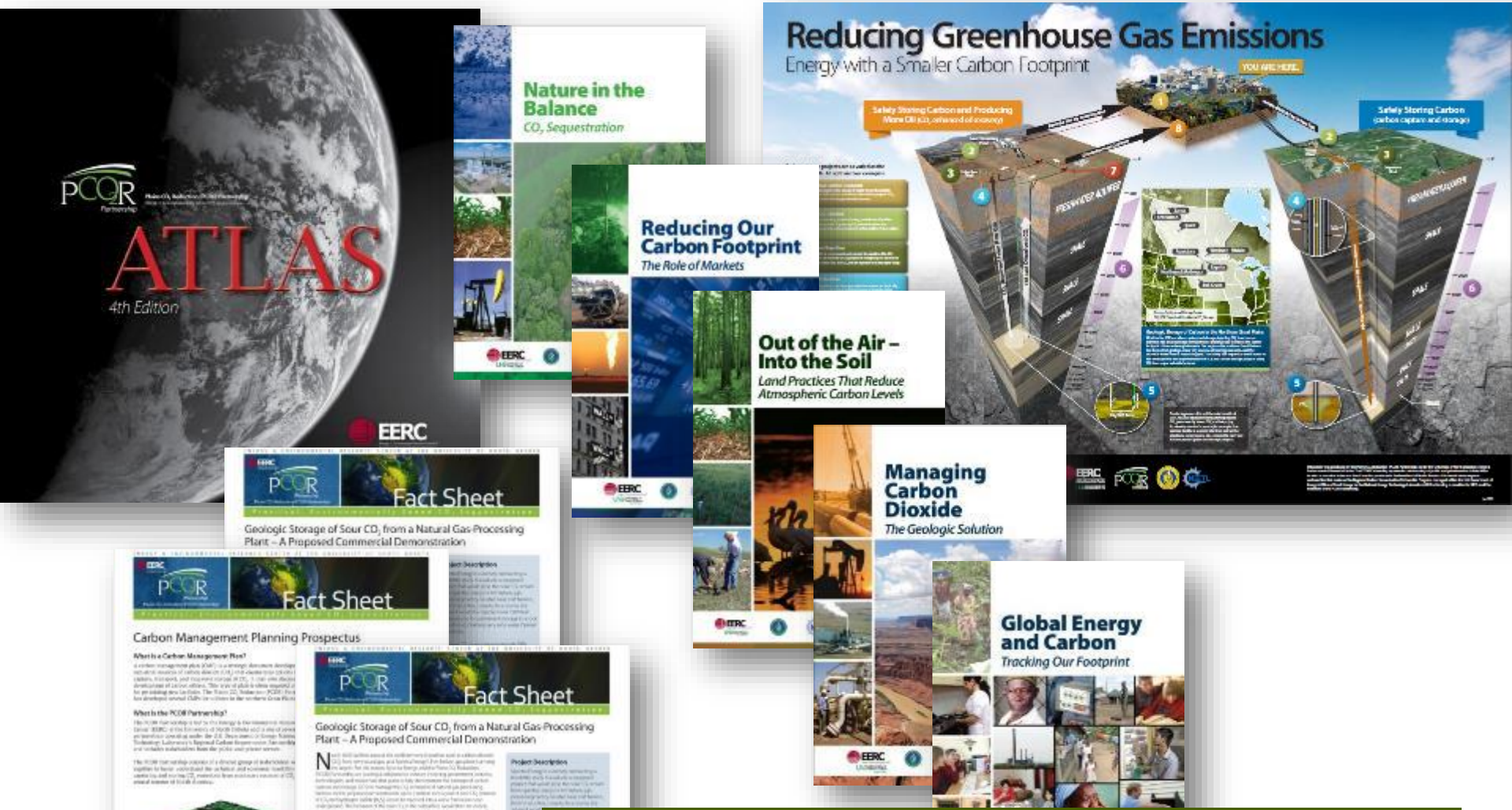
Enhanced value through an integrated project approach to MVA, technical risk assessment, characterization, modeling, and predictive simulation.

Challenge of Seasonable Variability in Near-Surface Environments

Lessons Learned

- Over 1.5 million tonnes of CO_2 stored since May 2013.
- Practical value of research activities coupled with partner and landowner relations have been a continuing key to success.
- Successfully demonstrating site security.
- Adaptive management approach has provided a key mechanism for cost-effective, commercially viable, and practical approaches to meeting program objectives.
- Lessons learned from baseline and first years of operational monitoring coupled with an adaptive management approach are allowing for transition to a more commercially viable long-term MVA approach.
- With a focus on long-term, positive implications for commercially viable EOR with associated CO_2 storage, the PCOR Partnership is developing approaches/workflows for site characterization, simulation, risk assessment, reservoir surveillance, CO_2 accounting, and data interpretation and vetting new technologies and their applications.

Knowledge Sharing



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