The Plains CO_2 Reduction (PCOR) Partnership: Bell Creek Field Project

Carbon Storage R&D Project Review Meeting
August 18–20, 2015

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Energy & Environmental Research Center

PCOR Partnership Region

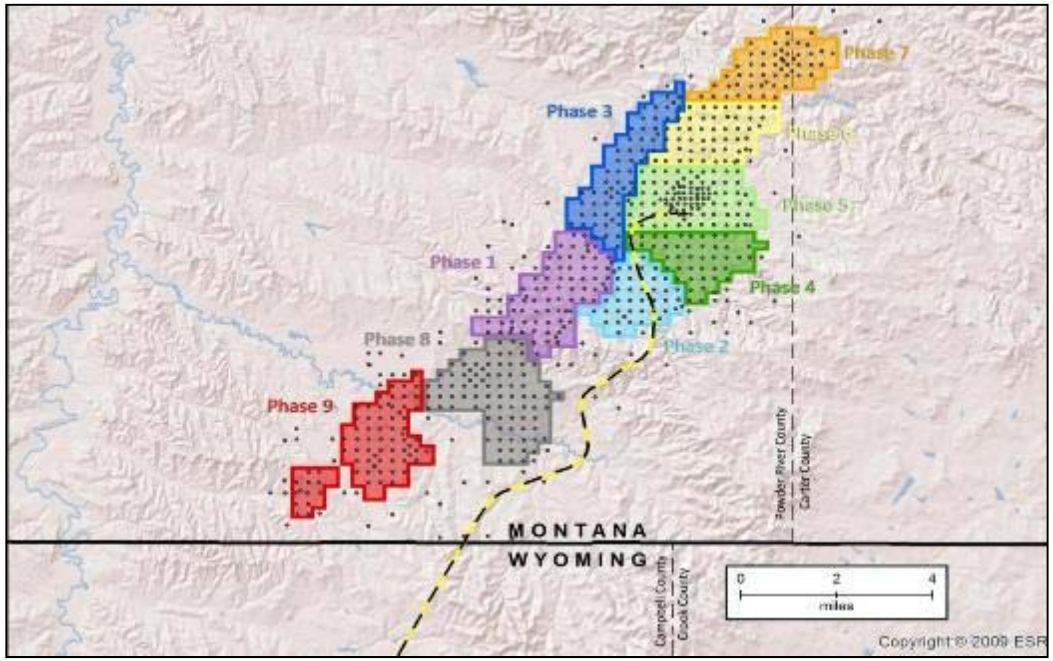
- Nine states
- Four Canadian provinces
- 3,579,594 km^2 (1,382,089 mi^2)
- More than 100 partners

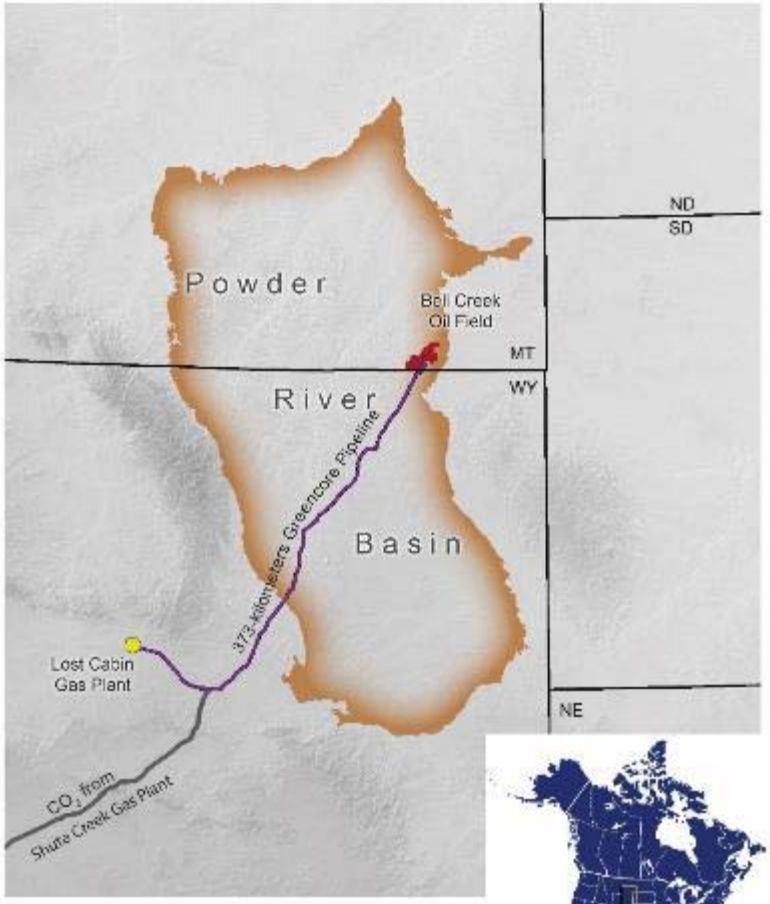
PCOR Partnership Objectives

- Safely and permanently demonstrate associated 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 the 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 EERC, through the PCOR Partnership, is studying associated CO_2 storage with regard to a commercial CO_2 EOR project.

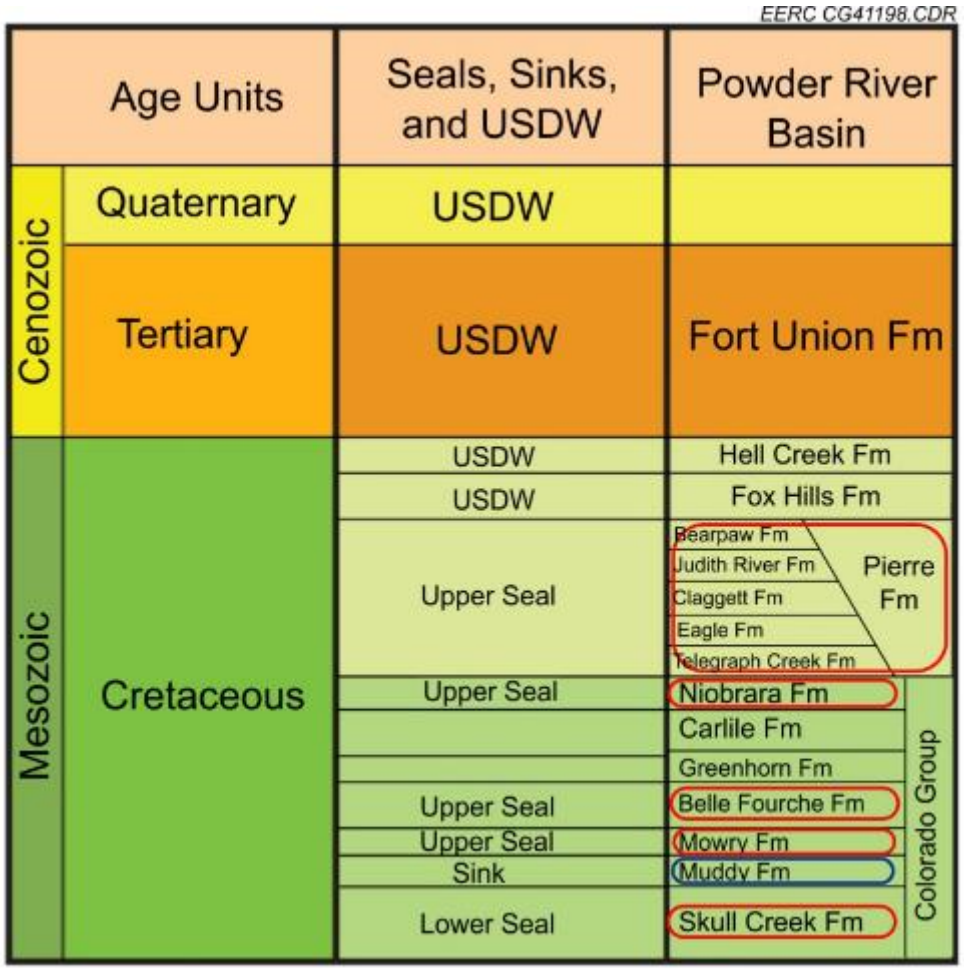




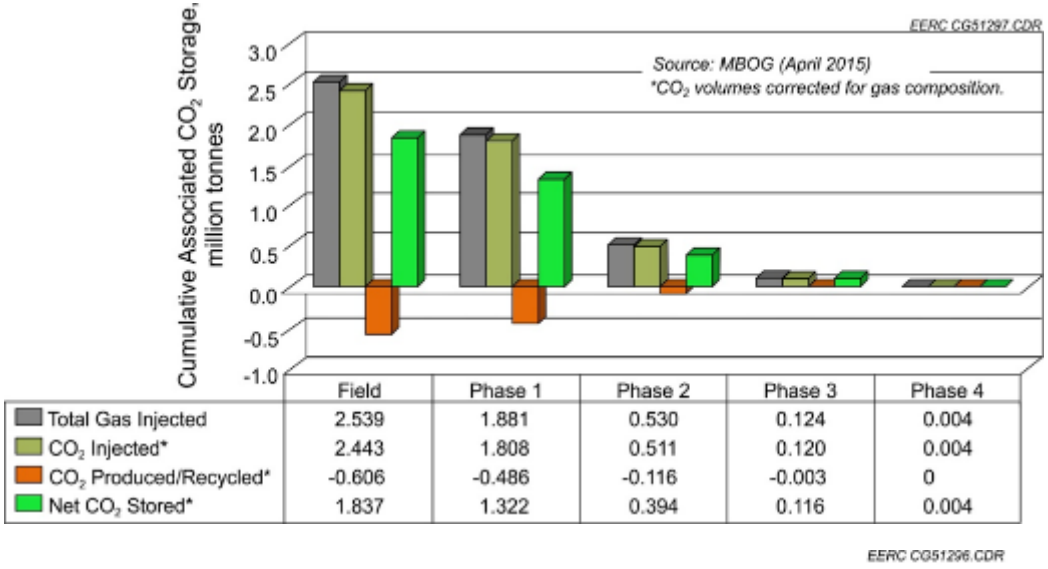
Site Characteristics

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



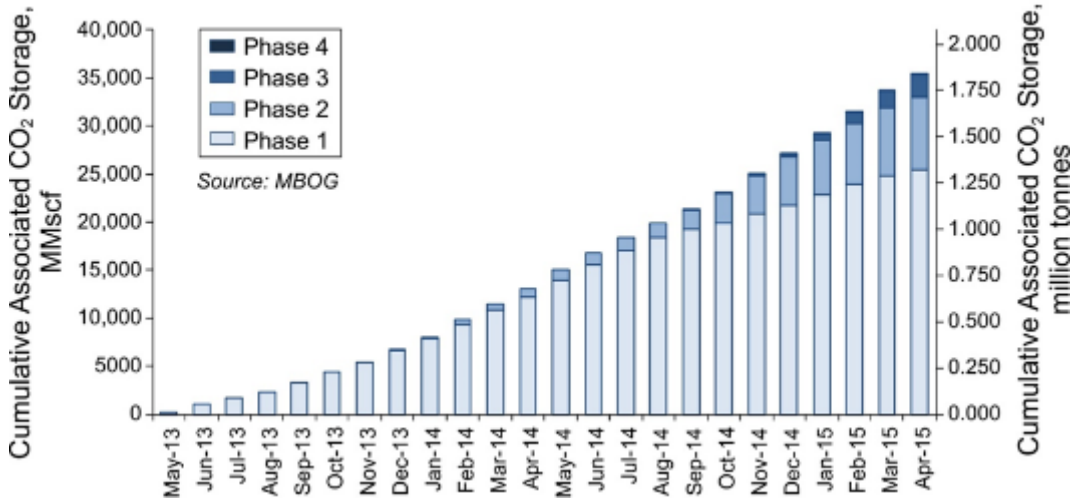
Total CO_2 Injected and Stored



	Field	Phase 1	Phase 2	Phase 3	Phase 4
Total Gas Injected	2.539	1.881	0.530	0.124	0.004
CO_2 Injected*	2.443	1.808	0.511	0.120	0.004
CO_2 Produced/Recycled*	-0.606	-0.486	-0.116	-0.003	0
Net CO_2 Stored*	1.837	1.322	0.394	0.116	0.004

EERC CG51296.CDR

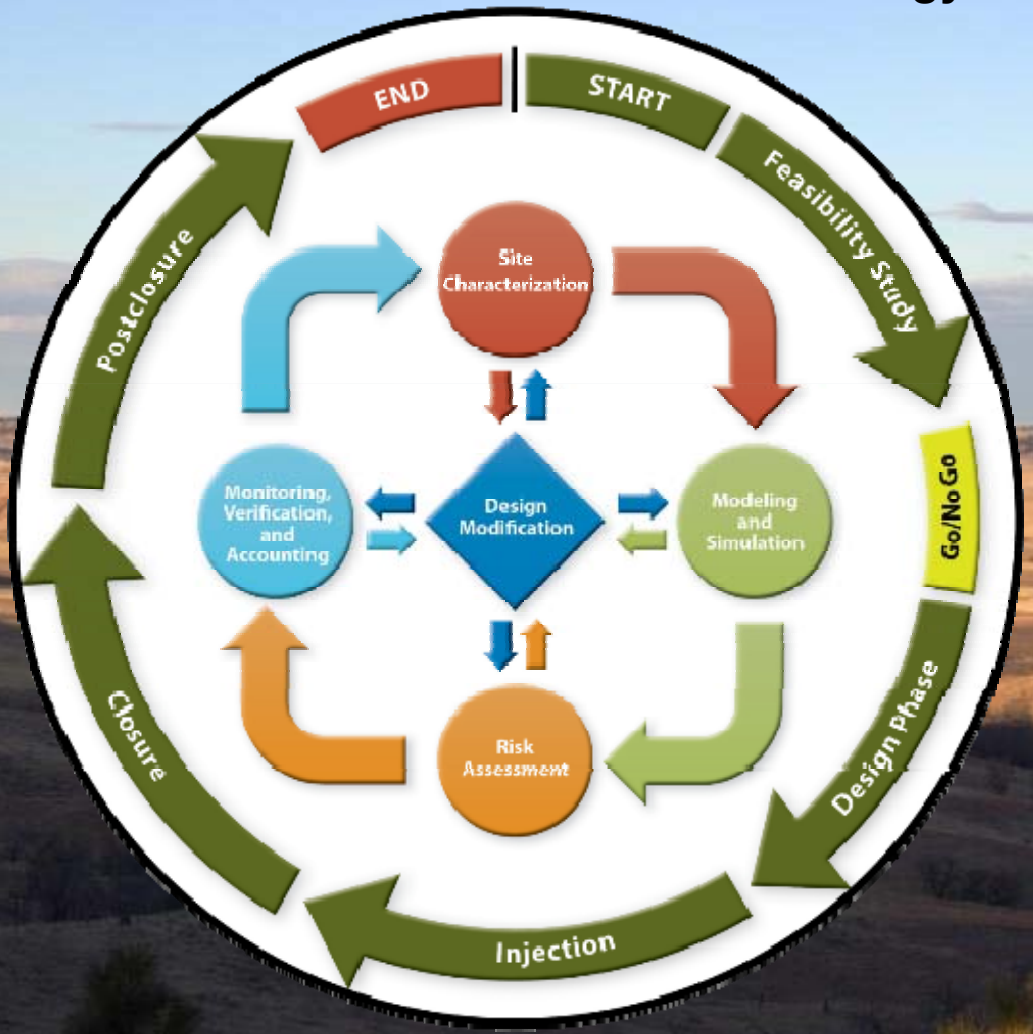
- **2.44 million tonnes of CO_2 injected through April 2015**
- **1.84 million tonnes of CO_2 stored through April 2014**



EERC

The PCOR Partnership's Integrated Approach to Program Development

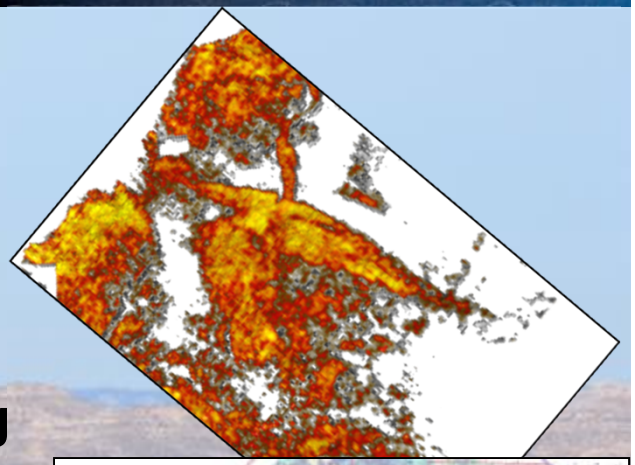
Focused on Site Characterization, Modeling and Simulation, and Risk Assessment to Guide MVA Strategy

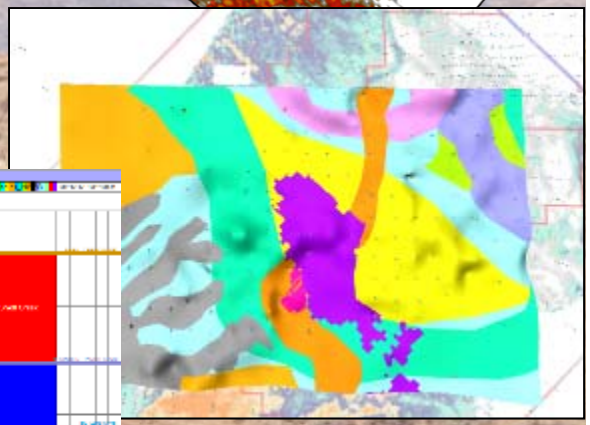


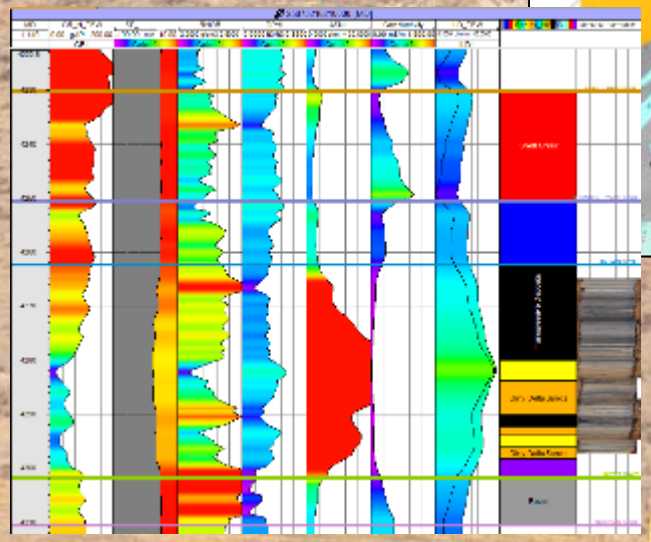
Site Characterization

Recent activities:

- **Comparing baseline pulsed-neutron log (PNL) saturations to simulation model.**
- **Calculating effective porosity using baseline PNLs.**
- **Reexamining depositional understanding based on baseline 3-D seismic survey.**

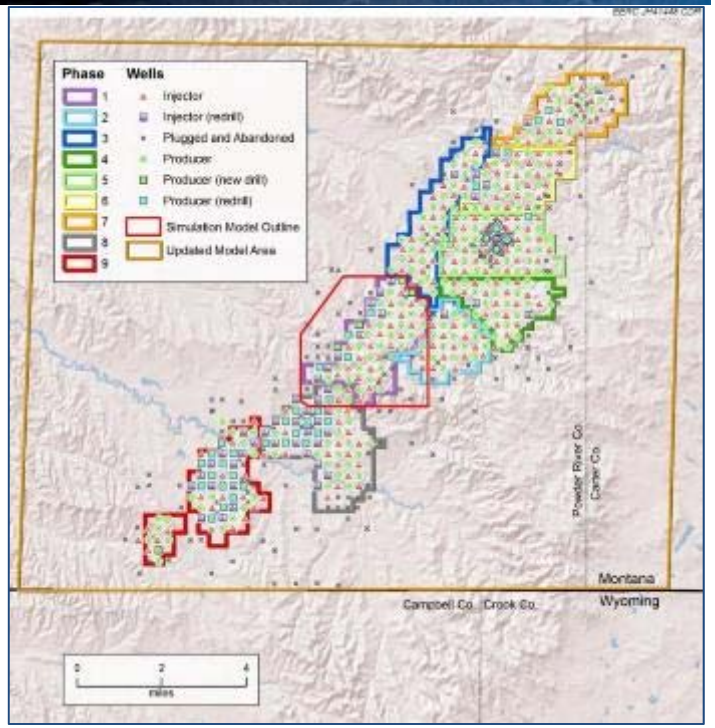


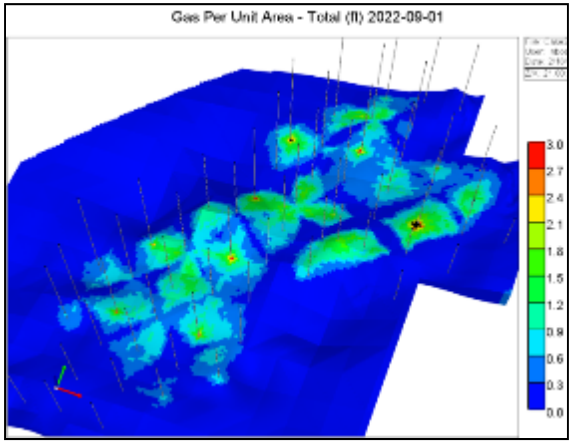




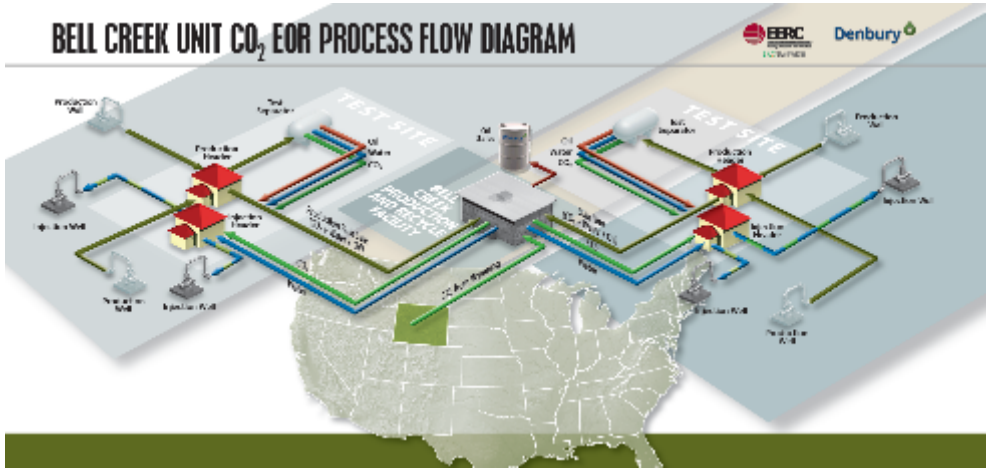
Modeling and Simulation Update

- Completed models:
  - Version 1 (Phase 1 area)
  - Version 2 (full field)
- Version 3 (development under way) includes:
  - 3-D seismic data.
  - Simulation results from Versions 1 and 2.
  - New interpretation of depositional environment.
  - Simulation/history matching to follow.
- Successfully history-matched Phases 1 and 2 of Version 2 geologic model.





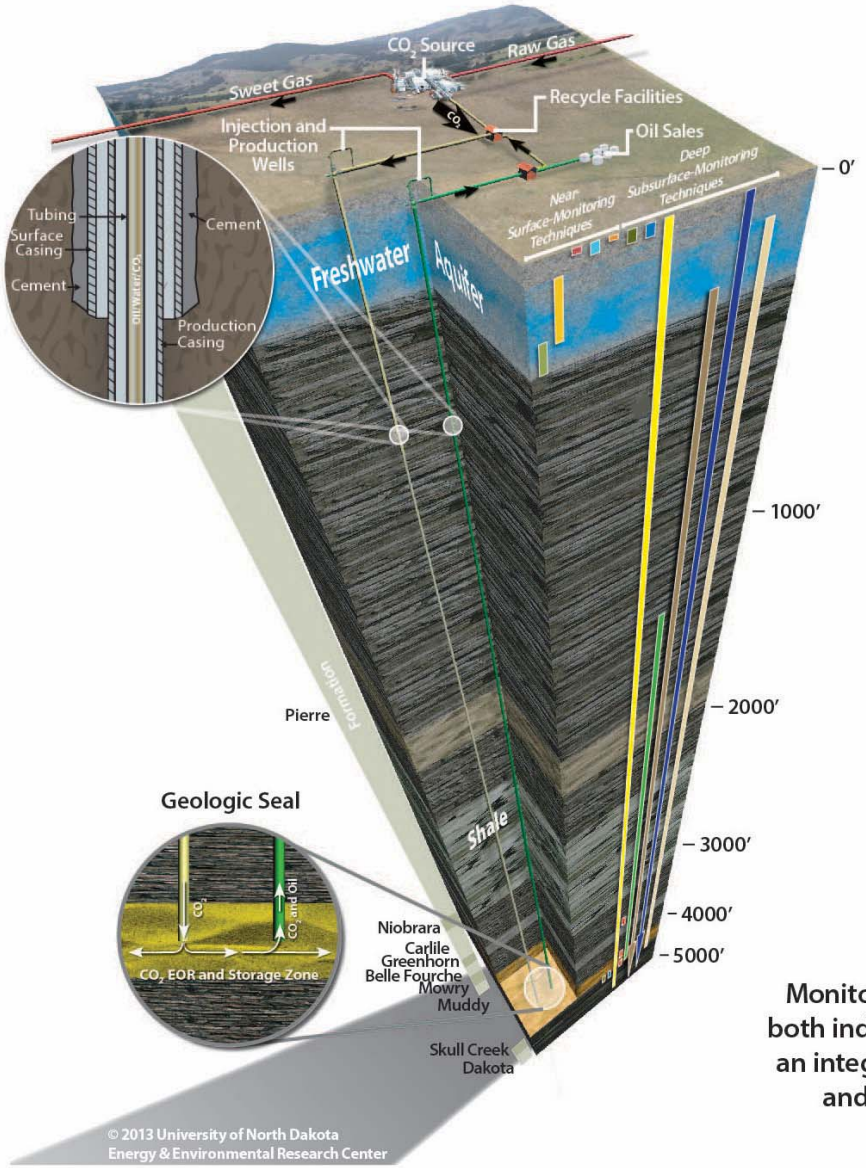
How do you develop MVA strategies that are practical and meaningful at a commercial scale?



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

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

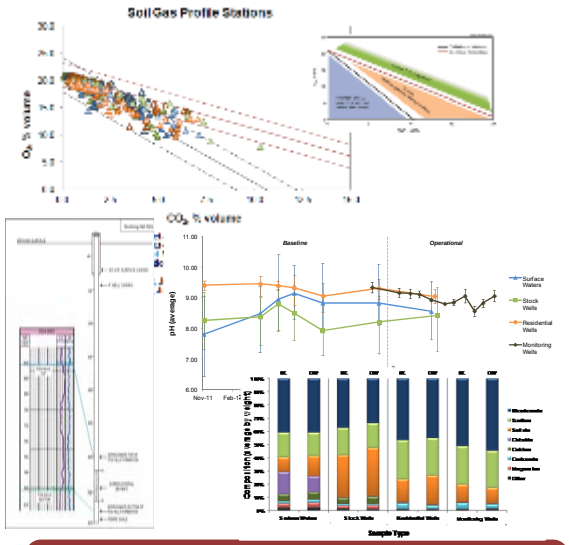
Research MVA and Surveillance Program Deployed at Bell Creek



- 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.

Near-Surface Monitoring
Soil Gas and Water Chemistry



Surveillance

- Naturally occurring variability of soil gas and water compositions in the near-surface environment
- Provide a scientifically defensible source of data capable of monitoring for and characterizing anomalies within these environments

Site Characterization

- Annual and interannual variability of soil gas and water chemistries
- Near-surface environments, chemistries, and mineralogy

Modeling and Simulation

- Geochemical modeling
- Hydrogeological modeling

Assurance Monitoring

- Demonstrate safe/effective associated storage
- Demonstrate no impact to near-surface environments

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

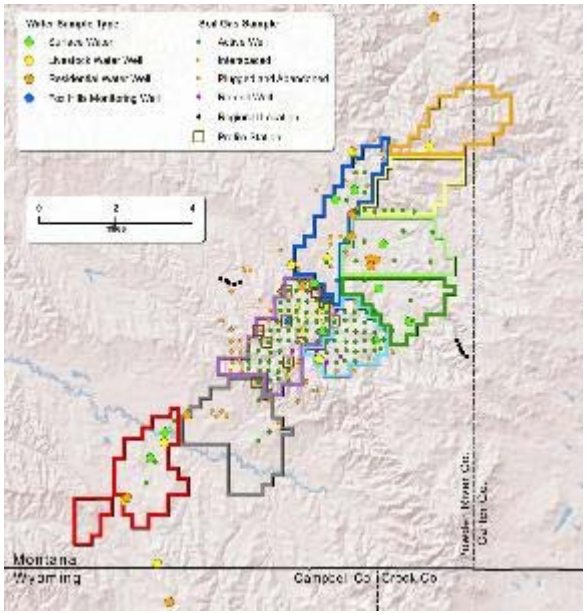
- Quarterly full-field water and soil gas sampling and analysis
- Transitioning to include monthly soil gas sampling and analysis at Phase 1 locations

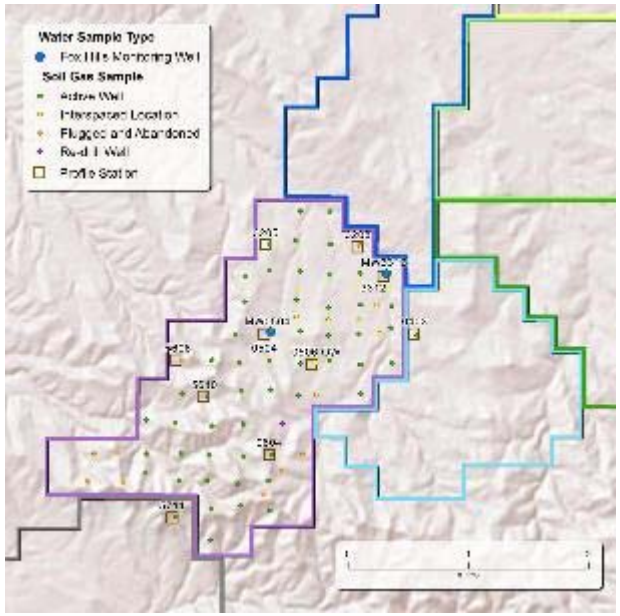
Operational Monitoring 1

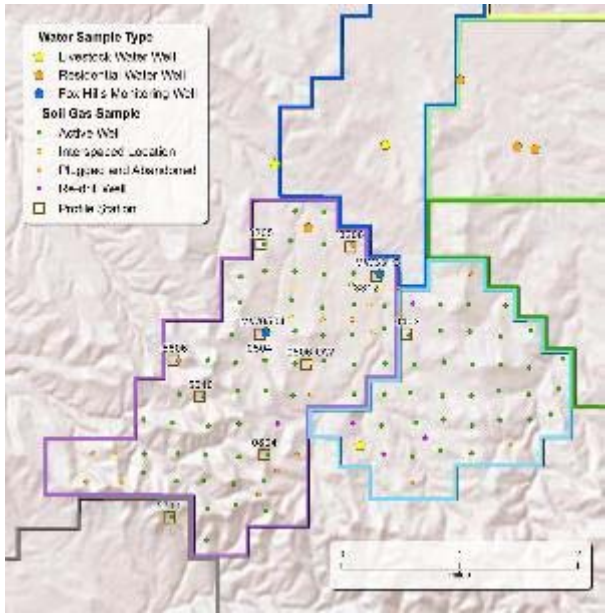
- Monthly water and soil gas sampling and analysis at Phase 1 locations
- Annual full-field water and soil gas sampling and analysis

Operational Monitoring 2

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

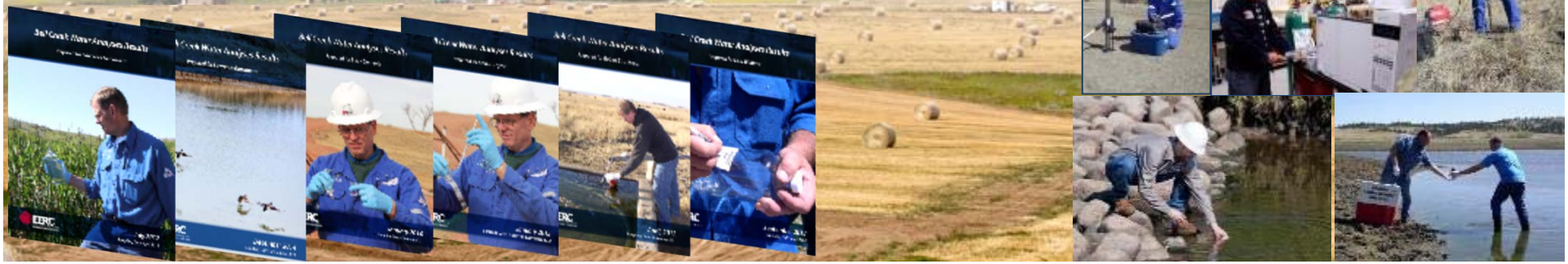






Near-Surface Monitoring Update

- NO evidence of out-of-zone migration has been detected (demonstrating site security).
- Baseline data set was acquired over 18-month period prior to injection.
- Monitoring program was sufficient to detect anomalies. Additional characterization showed they were NOT related to an out-of-zone migration event.
- First year of operational monitoring completed. Success has allowed a modified sampling program in a step toward a commercially viable, long-term strategy.
- Landowner relations key to **<u>success</u>.**



Seasonable Variability of Near-Surface Environments (aka “Spring”)



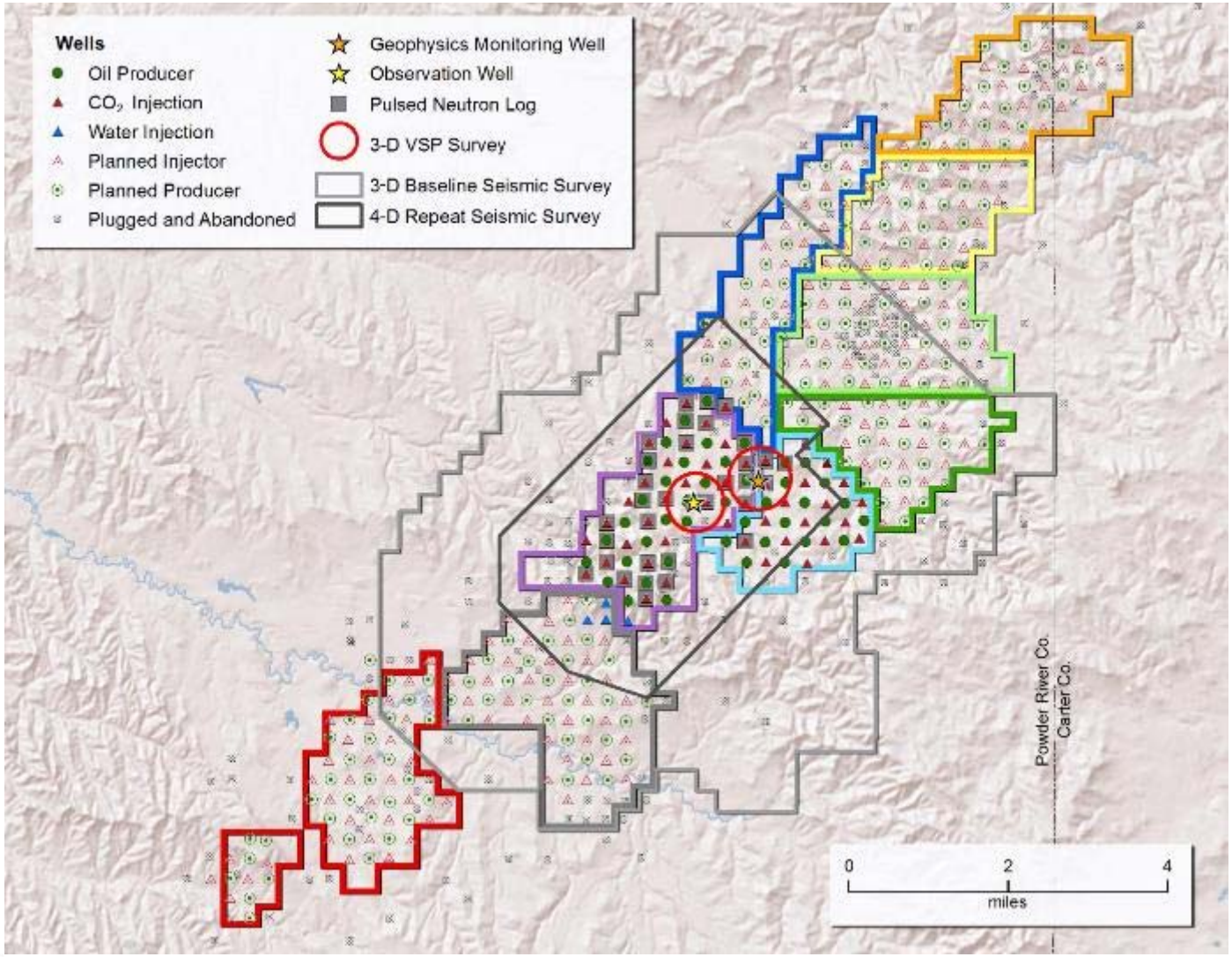




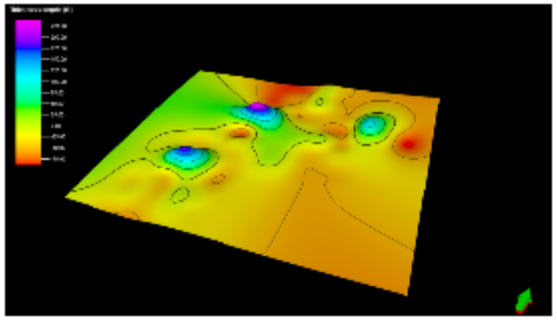




Subsurface MVA Program



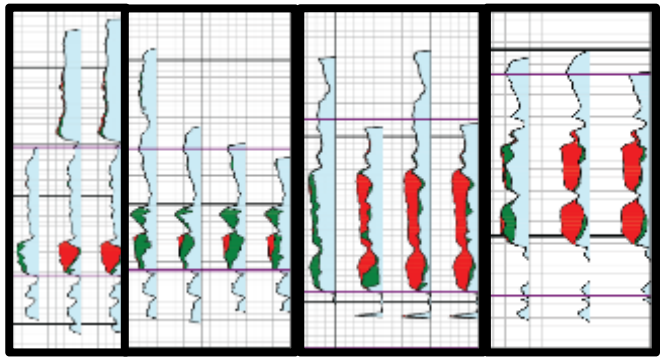
PNL Applications



Thickness Between Old Pierre Surface Tops and New Surface Tops
(in Petrel, 6x vertical exaggeration, 50 ft contours)

Surveillance

- Water/oil/gas saturation changes
- Residual water saturation
- Oil mobilization
- Conformance
- Storage/sweep efficiency
- Guide surveillance activities (go/no go)
- Vertical and lateral flow



Site Characterization

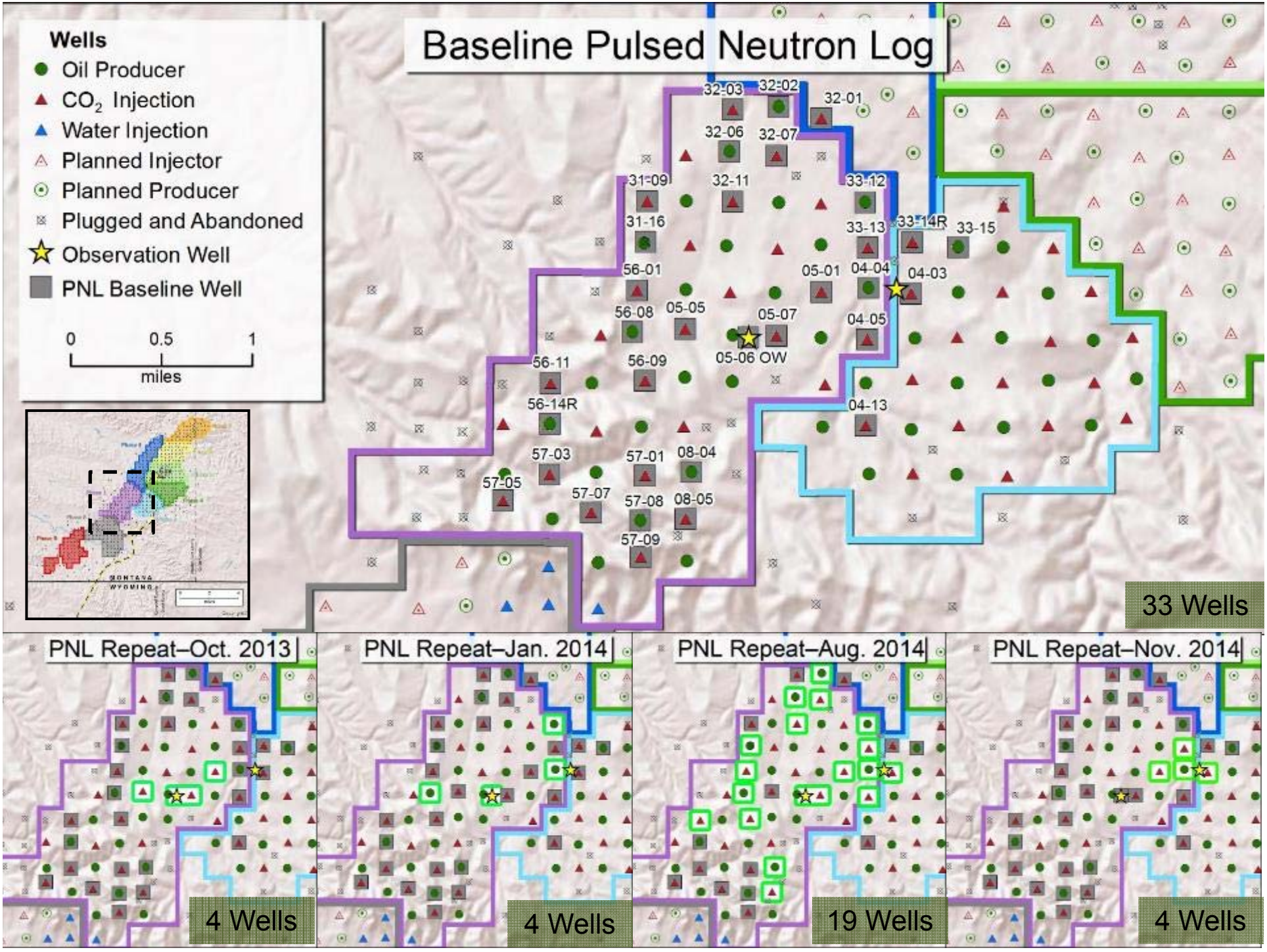
- Structural interpretation
- Reservoir and overlying strata properties
- Regional variability within reservoir and overlying zones

Modeling and Simulation

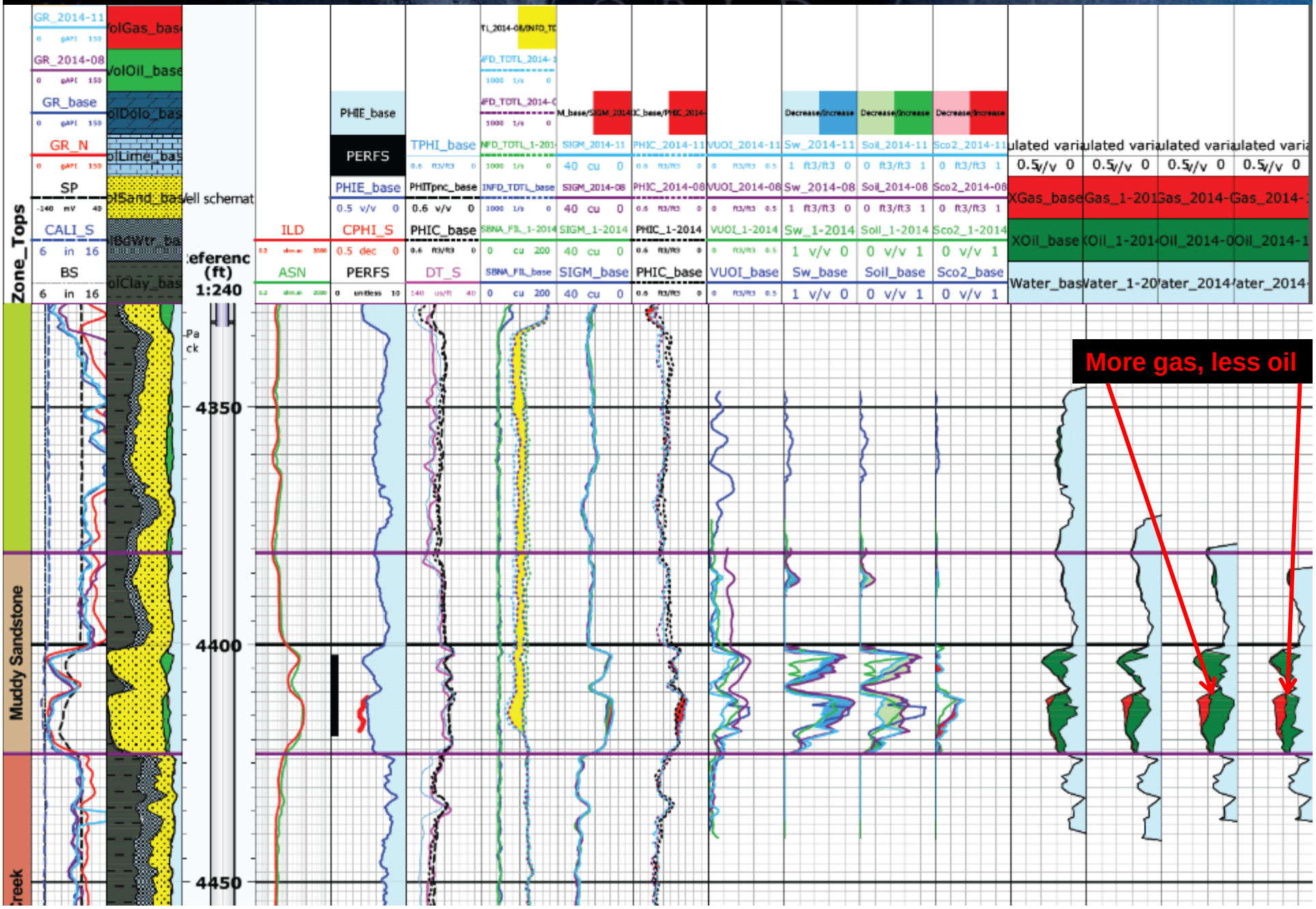
- History match
- Formation tops
- Porosity
- Tune and calibrate geomodel
- Synthetic logs
- Enhanced seismic interpretations

Assurance Monitoring

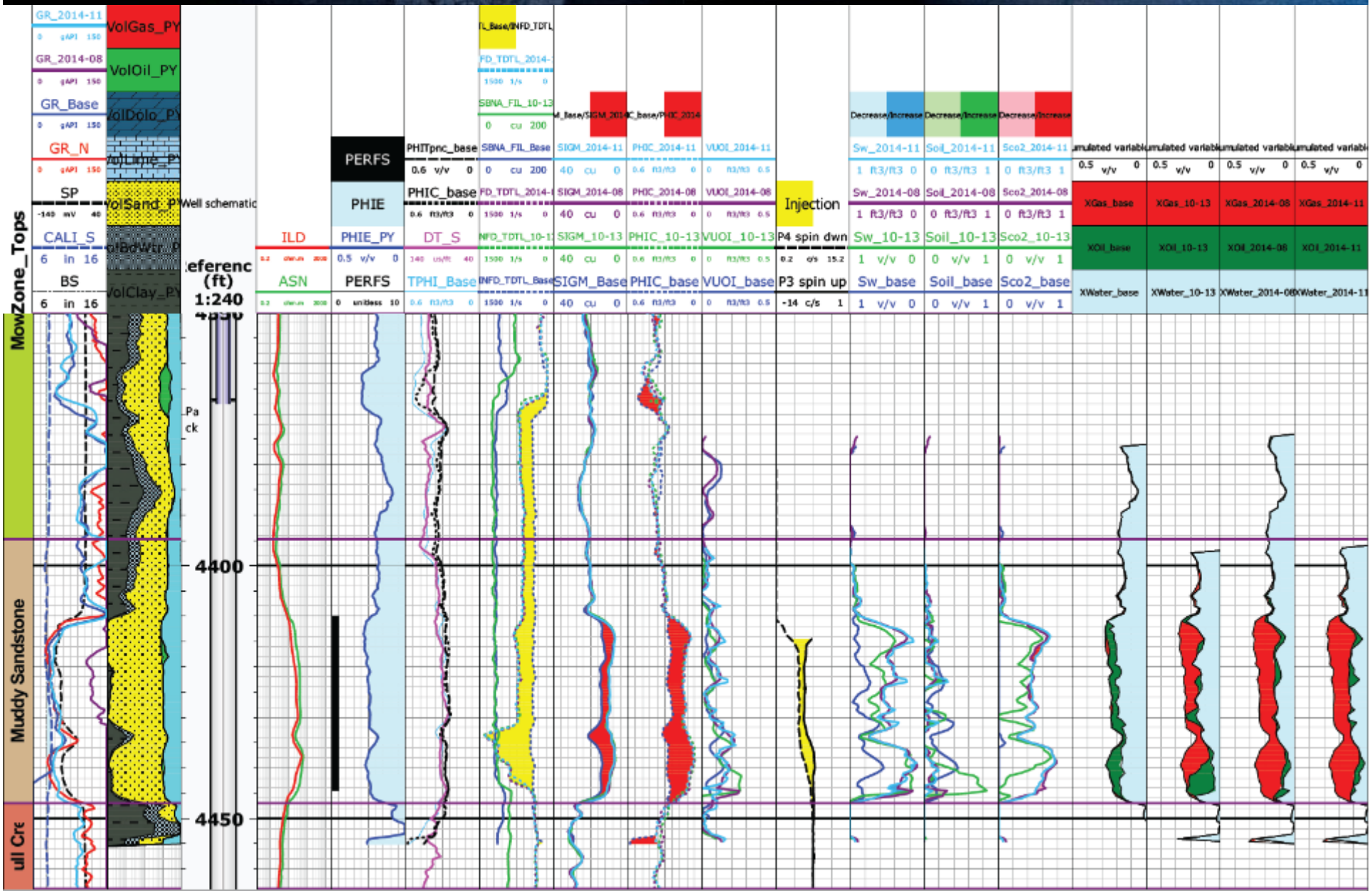
- Monitor for out-of-zone vertical migration (accumulation zones)
- Wellbore integrity monitoring
- Demonstrate safe/effective associated CO_2 storage


Wells
Oil Producer
CO_2 Injection
Water Injection
Planned Injector
Planned Producer
Plugged and Abandoned
Observation Well
PNL Baseline Well
0
0.5
1
miles
Baseline Pulsed Neutron Log
32-03
32-02
32-01
32-06
32-07
31-09
32-11
33-12
31-16
33-13
33-14R
33-15
56-01
05-01
04-04
04-03
56-08
05-05
05-07
04-05
05-06 OW
56-11
56-09
56-14R
04-13
57-03
57-01
08-04
57-05
57-07
57-08
08-05
57-09
33 Wells
PNL Repeat–Oct. 2013
4 Wells
PNL Repeat–Jan. 2014
4 Wells
PNL Repeat–Aug. 2014
19 Wells
PNL Repeat–Nov. 2014
4 Wells

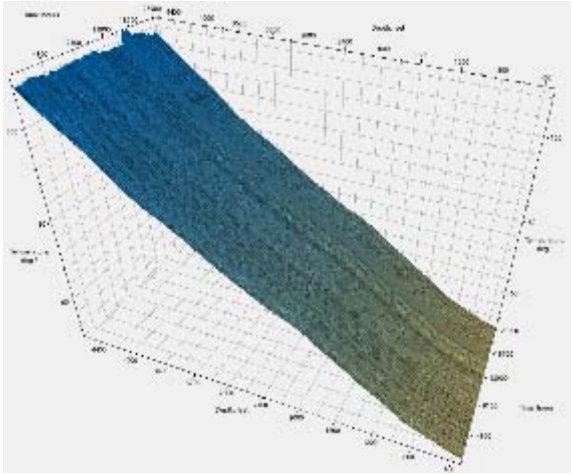
Producer Time-Lapse PNL



Injector Time-Lapse PNL

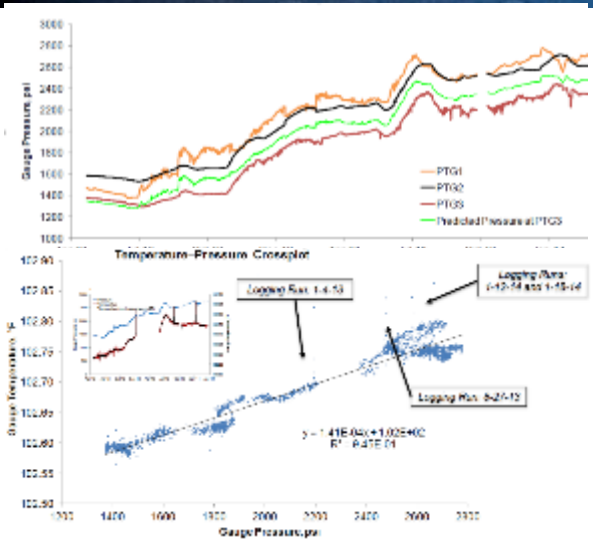


Pressure/Temperature



Surveillance

- Reservoir pressure/temperature
- Fluid phase behavior conditions
- Aquifer support
- Well testing/pressure communication
- Reservoir behavior vs. injection/production rates



Site Characterization

- Lateral and vertical zonal pressure isolation

Modeling and Simulation

- History match
- Phase behavior and equation of state (EOS)

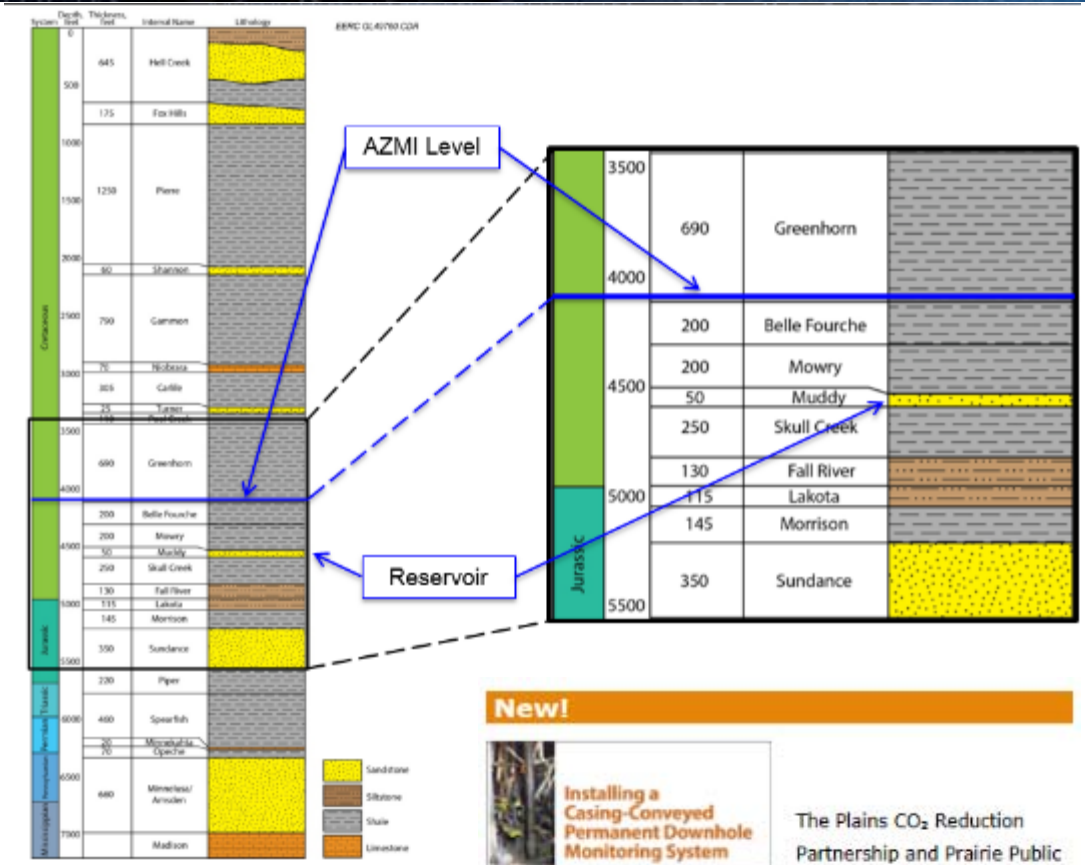
Assurance Monitoring

- Monitor for vertical pressure communication
- Demonstrate safe/effective associated CO_2 storage

Permanent Downhole Monitoring (PDM)

- Three casing-conveyed pressure–temperature gauges (PTGs)
  - Three monitoring zones record data at 5-min intervals:
- Casing-conveyed fiber optic distributed-temperature system (DTS) records temperature traces at 4-hr intervals:
  - DTS anchor at 4750 ft MD
  - Temperature data every 1 m (3.3 ft)
- Installed January 2012; continuous operation since April 20, 2012.

For more information and a detailed overview of the PDM system, a videographic documentary can be viewed at www2.undeerc.org/website/PCORP/.



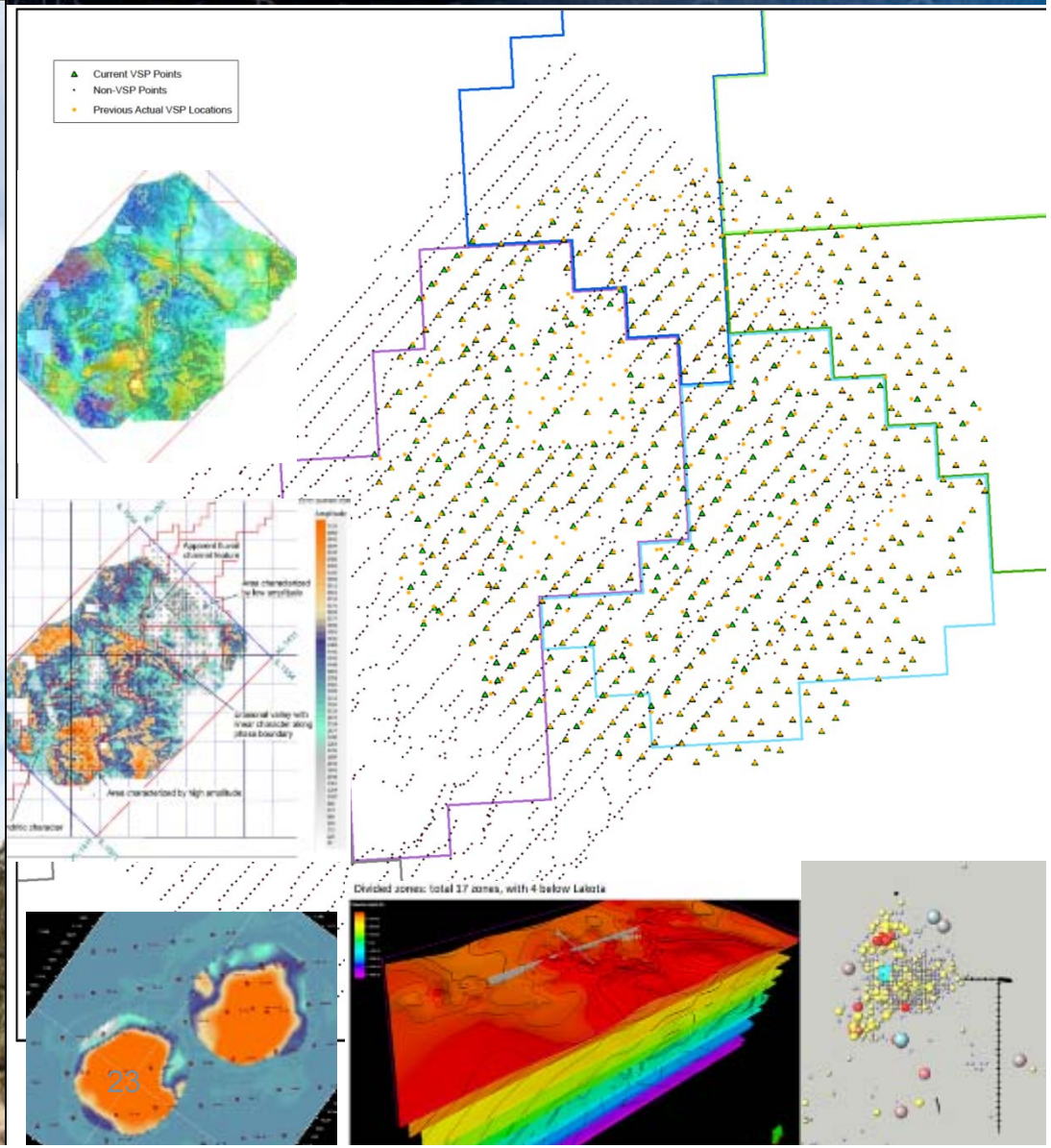
New!

The Plains CO_2 Reduction Partnership and Prairie Public Broadcasting have coproduced a video describing the basics of casing-conveyed permanent downhole monitoring.

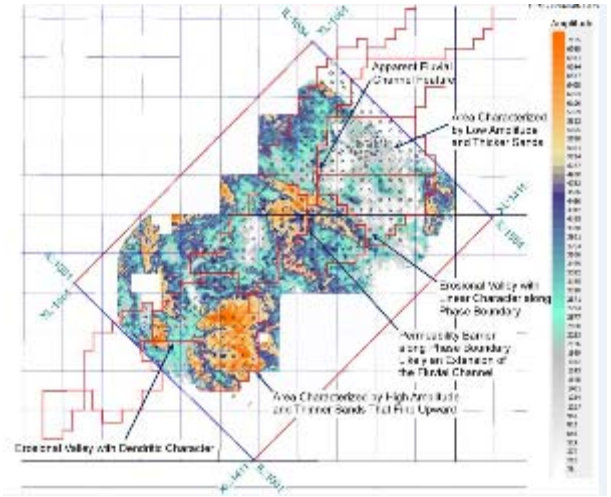
Click here to view the video.

Geophysics Portfolio

- 3-D and 4-D surface seismic
  - Baseline survey (May 2013, 45 mi^2)
  - Monitor survey (October 2014, 11.5 mi^2)
  - 4-D analysis
- 3-D and 4-D vertical seismic profile (VSP)
  - Baseline survey (May 2013, 05-06 OW and 04-03 OW)
  - Monitor survey (October 2014, 04-03 OW only)
  - 4-D analysis
- Passive seismic monitoring
  - Approaching 2 years of data collection
  - First year of data processed; interpretation ongoing

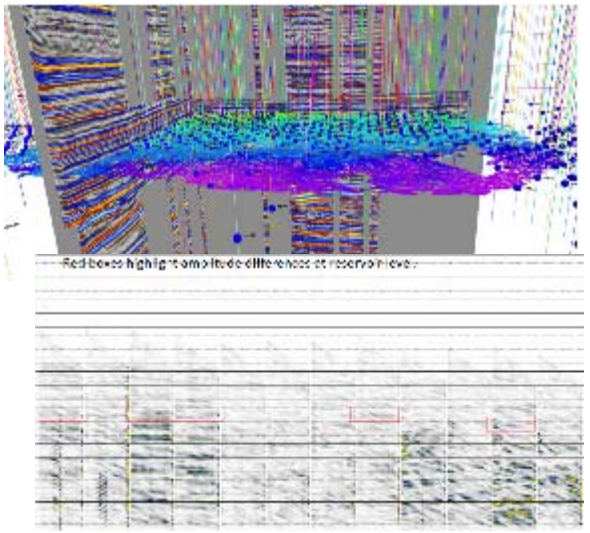


3-D Seismic



Surveillance

- Gas saturation changes
- Conformance
- Areal extent of gas plume
- Surveillance boundaries



Site Characterization

- Structural interpretation
- Sequence stratigraphy and depositional environment
- Permeability barrier locations
- Fault and fracture identification
- Geomechanical properties from seismic inversion

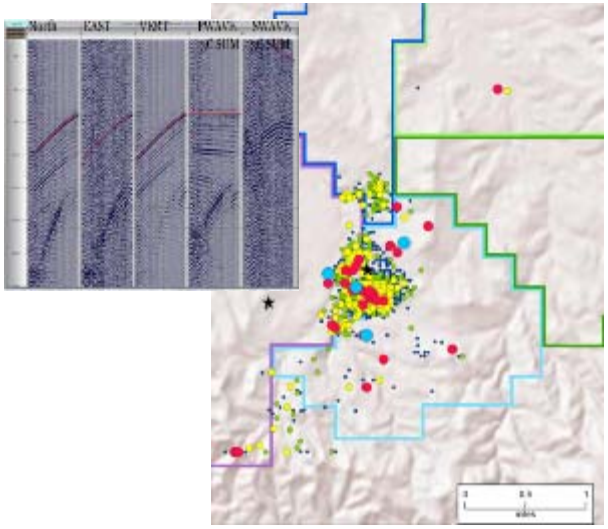
Modeling and Simulation

- Refined history matching
- Tune and calibrate the geologic model
- Geomechanical modeling and simulation

Assurance Monitoring

- Show that out-of-zone migration, vertically or laterally, is not occurring
- Demonstrate safe/effective associated CO_2 storage

Passive Seismic



Surveillance

- Source and depth of seismic emissions
- Lateral or vertical out-of-zone pressure communication

Site Characterization

- Variability within reservoir and overlying zones
- Fault identification
- Pressure communication
- Correlation of events with geomechanical models

Modeling and Simulation

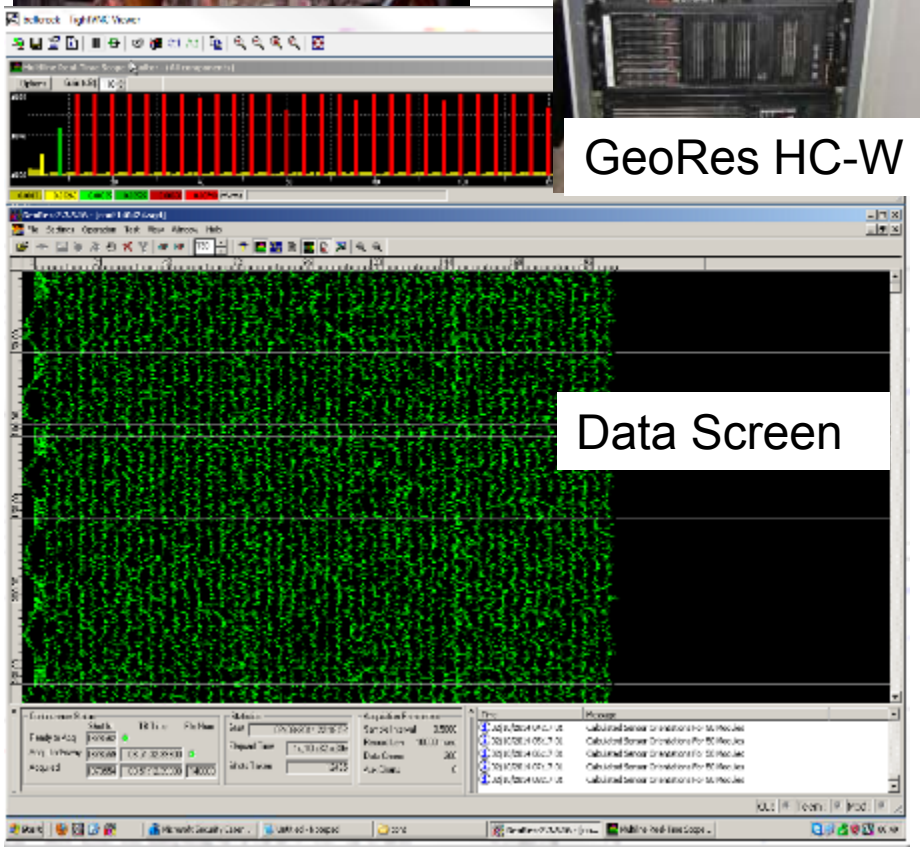
- History match
- Geomechanical models
  - Understand stress
  - Calibrate
  - Fine-tune

Assurance Monitoring

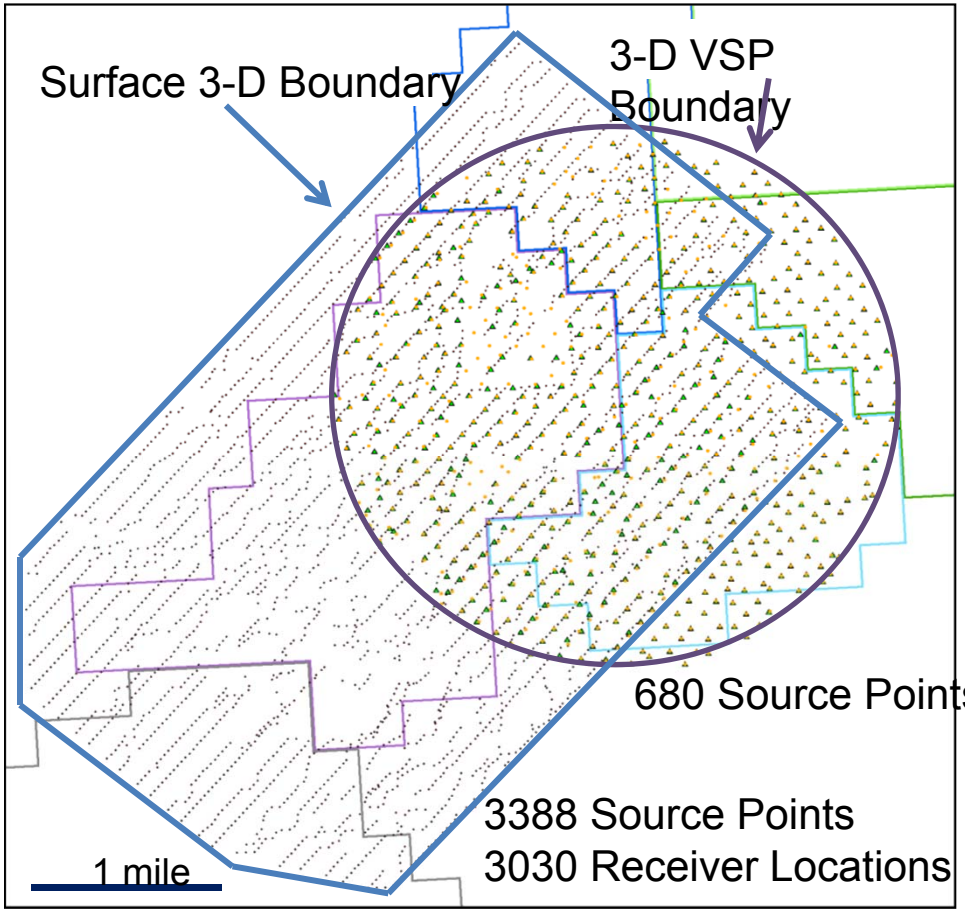
- Monitor, identify, and locate induced seismic emissions vs. natural seismic events
- Monitor for vertical migration to overlying accumulation zones
- Monitor for fault activation
- Demonstrate safe/effective associated CO_2 storage

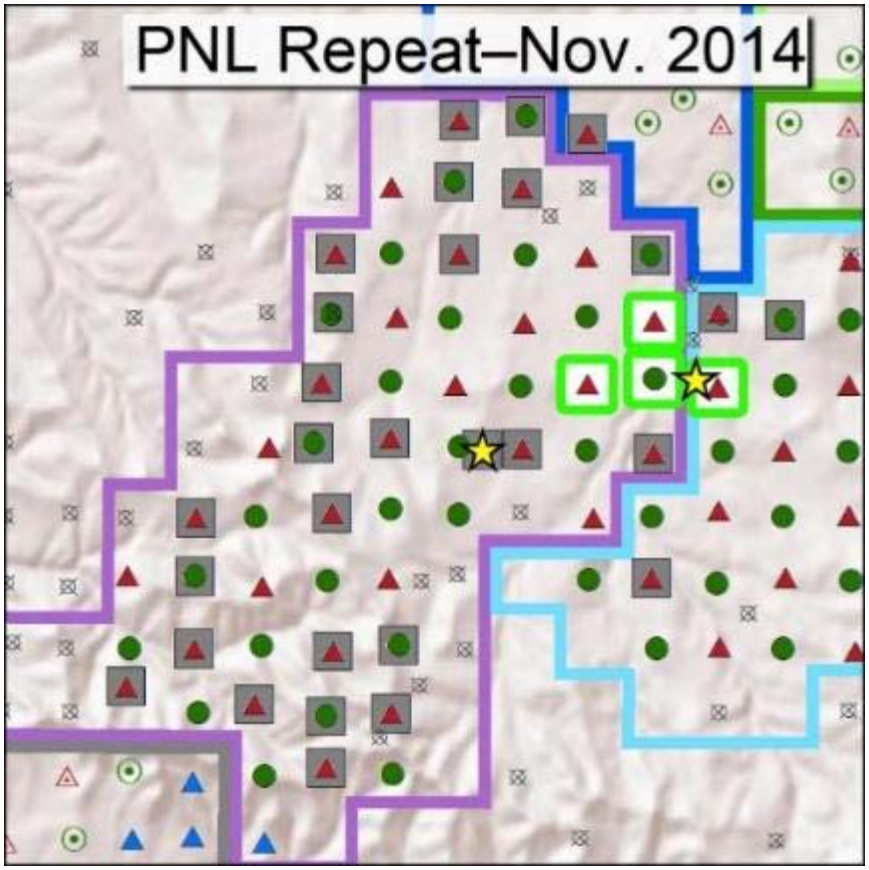
Passive Monitoring

- Monitoring Well 04-03 OW
  - 50 three-component geophones + hydrophone cemented in the wellbore
  - Total depth: 2471 ft
  - 15-m sensor pod spacing (49.2 ft)
    - First level at 60-ft depth
  - System status e-mail every 4 hours
  - Data collected from May 2013 to present
    - First year of data processed

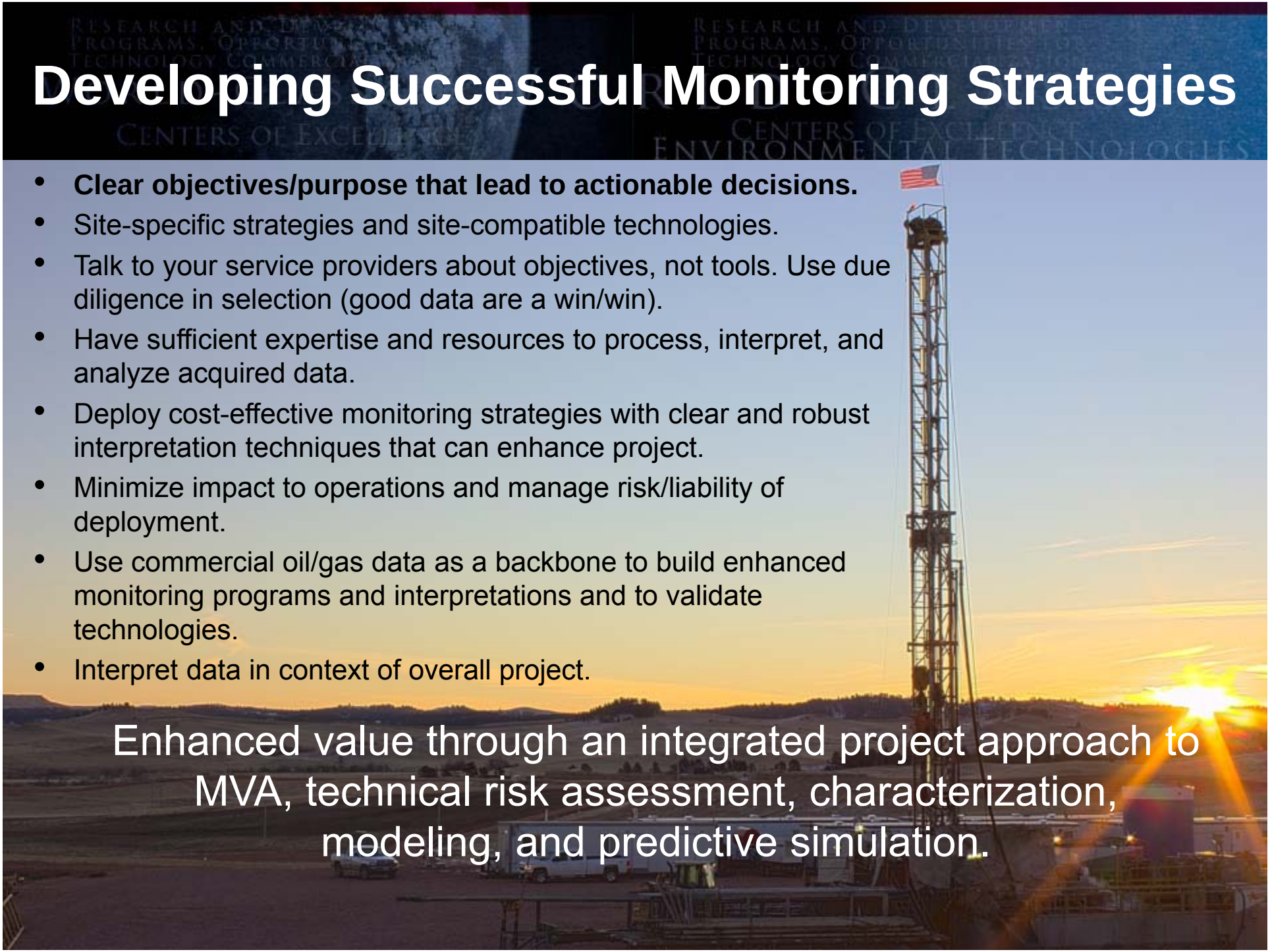


Integrating MVA Techniques





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.

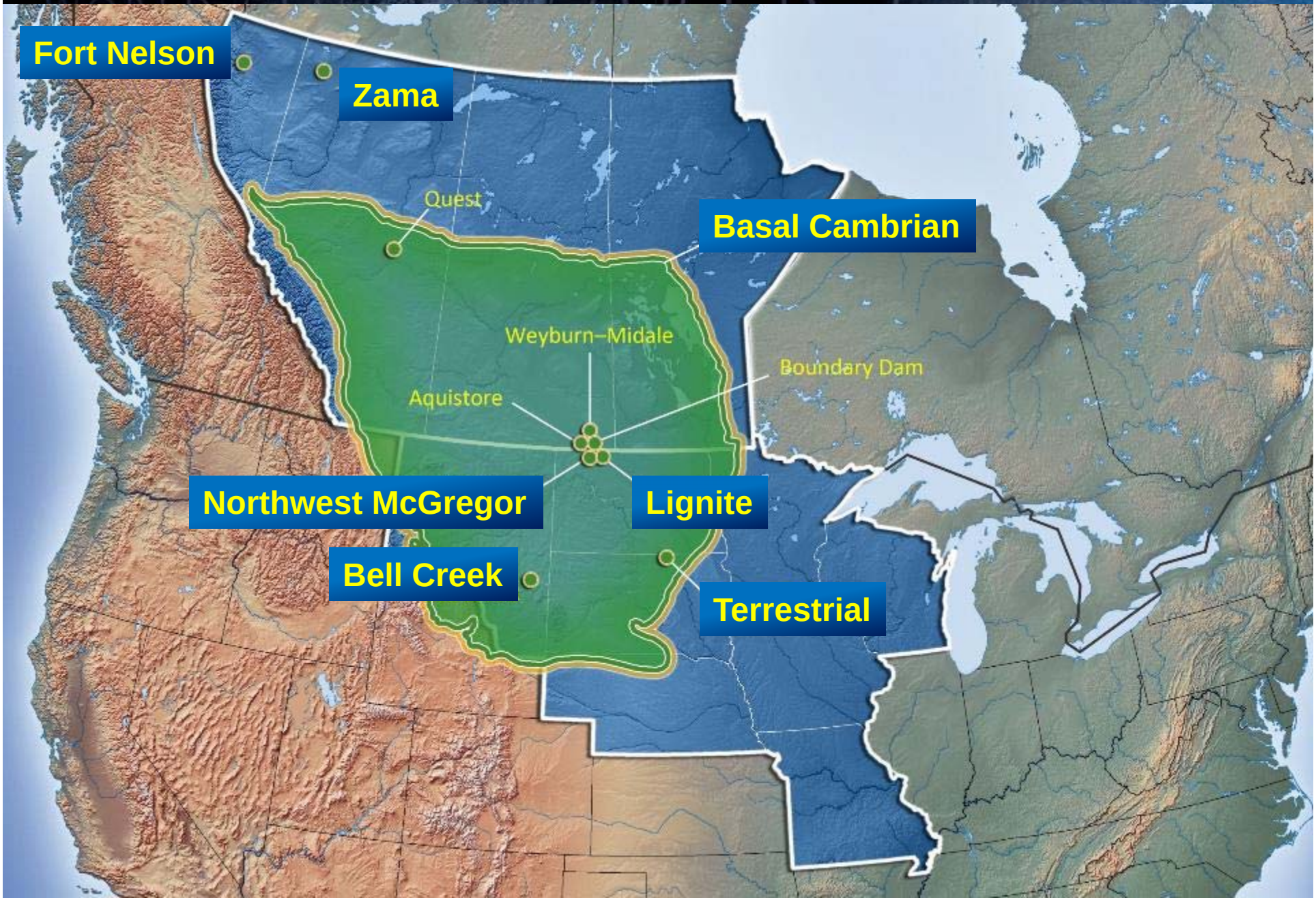
EOR at the Bell Creek Oil Field

Minimal Visual Impact

EOR at the Bell Creek Oil Field

Minimal Visual Impact – Over 25 Wells in this View

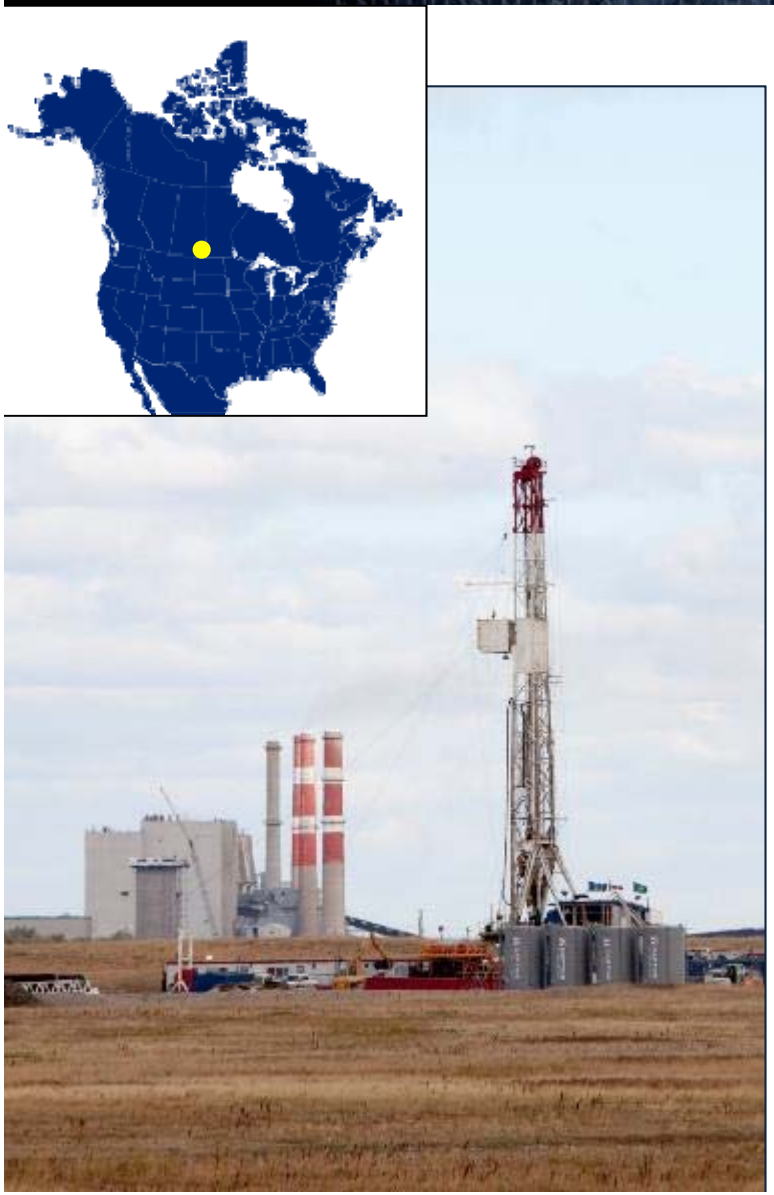
PCOR Partnership Field-Based Projects



Fort Nelson Carbon Capture and Storage in a Deep Saline Formation

- Developed MVA plan based on site characterization and modeling and simulation activities.
- Completed best practices manual (BPM).

Aquistore Project



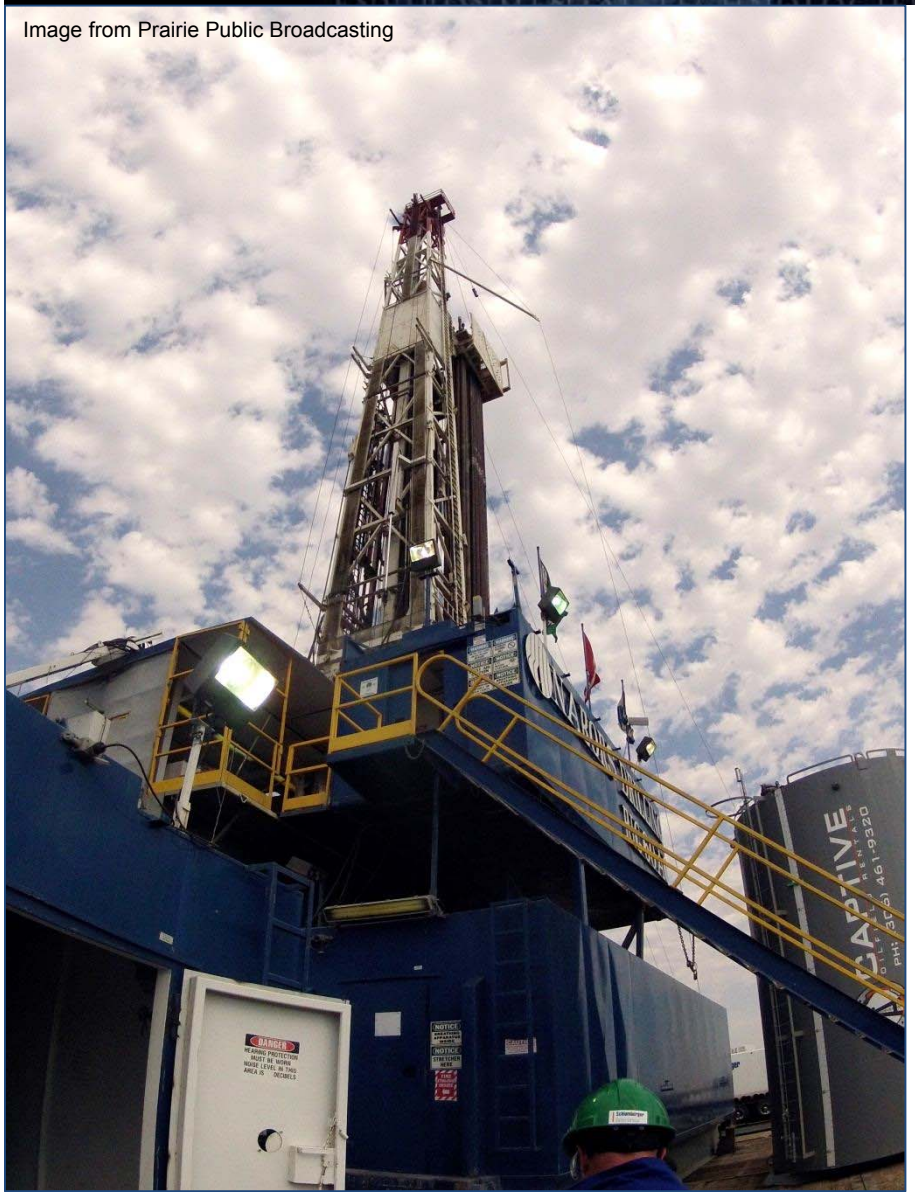
- CO_2 sourced from the Boundary Dam power plant in southeastern Saskatchewan for injection into a saline formation.
  - Target zone is Deadwood Formation, 3200 m (10,500 ft) deep, >50 m (>150 ft) thick.
  - PCOR Partnership activities include:
    - Core analysis.
    - Static and dynamic modeling.
    - Public outreach.
    - Participation in Aquistore Science and Engineering Research Council (SERC).

ptrc Petroleum Technology Research Centre

Aquistore

NETL PCOR

CO_2 Injection Is Under Way!

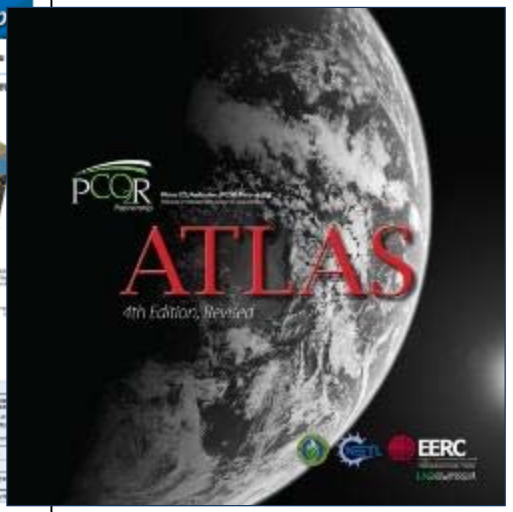


- Injection of CO_2 began April 2015.
- Downhole monitoring data are being collected from multiple zones.

Ongoing Work

- Update predictive simulations with injection data in an iterative fashion (near-real-time history matching).
- Expand fine-scale model.
- Optimize simulations to maximize storage efficiency.

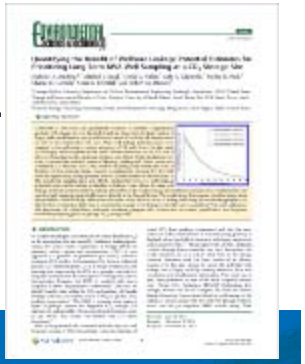
PCOR Partnership Outreach Activities Occur at Local and Regional Levels



Other PCOR Activities

Regional Characterization

- Four value-add reports completed in the last year. Three in development.
- Paper submitted and accepted to a journal (*Environmental Science and Technology*).



RCSP Regional Carbon Sequestration Partnerships

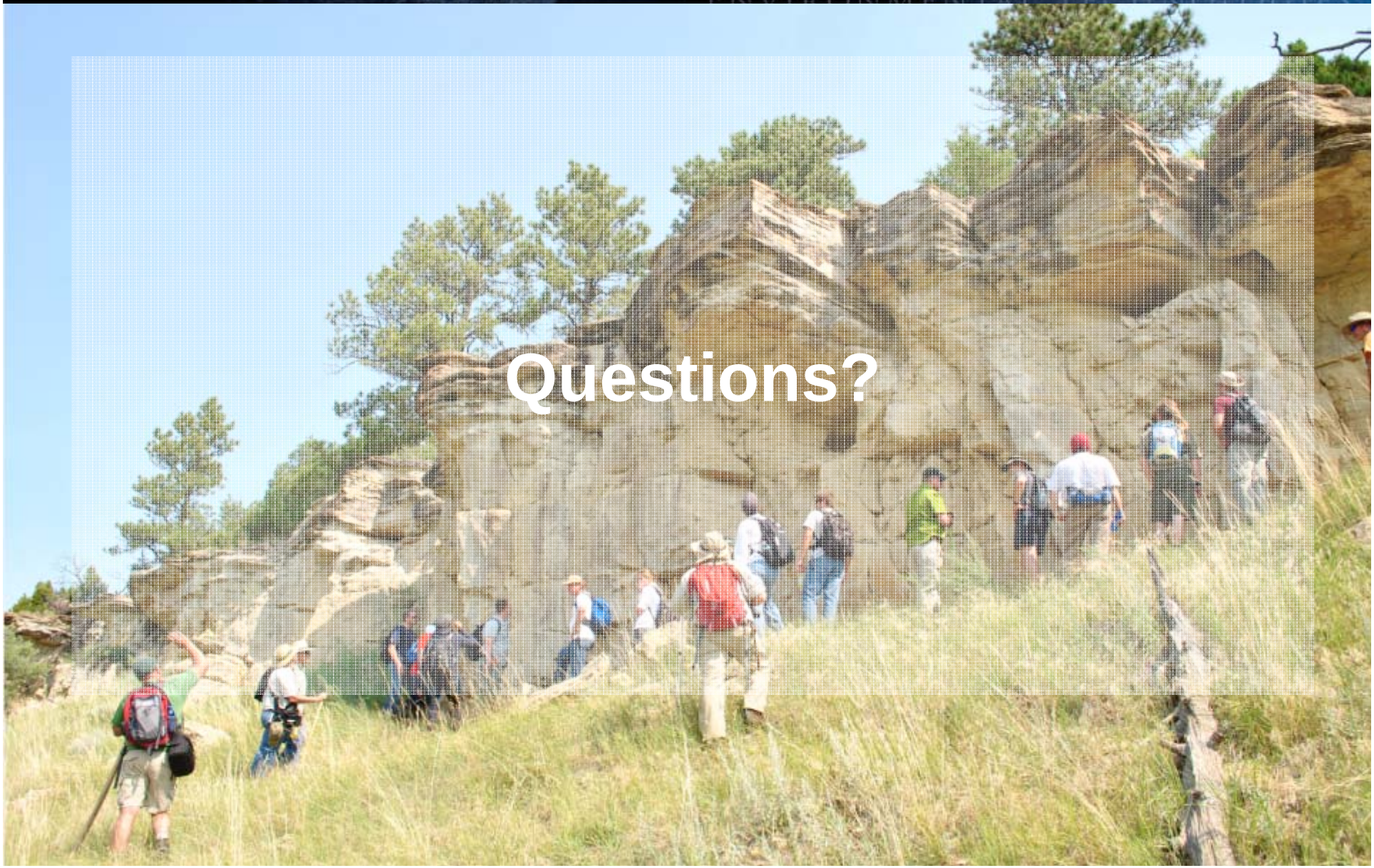
Water Working Group

- Developing a project capstone report (due November 2016).
- Publishing special edition of the *International Journal of Greenhouse Gas Control* (target mid-2016).
  - Special edition focused on “The Nexus of Water and CCS.”
  - Solicitation for papers is being prepared and will be released soon.

Regulatory

- Participation in Interstate Oil and Gas Compact Commission activities.
- 7th Annual PCOR Partnership Regulatory Roundup held in July 2015.
- Preparing document on permitting for CO_2 storage in the PCOR Partnership region.

Thank You!



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Acknowledgment

This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. DE-FC26-05NT42592.

Disclaimer

Supplemental Slides

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 study sweep and storage efficiency in each project.*
  - *Evaluating multiple oil fields, saline formations, and coal seams in the 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 RCSP Storage Capacity working group.*
  - *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 (completed 2014)

RCSP Program Goals (continued)

- 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 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.

RCSP Program Goals (continued)

- Develop 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.

RCSP Program Goals (continued)

- The PCOR Partnership will develop several BPMs throughout the course of the program, including the following:
  - Bell Creek Test Site – Site Characterization
  - Bell Creek Test Site – Simulation
  - Bell Creek Test Site – Monitoring for CO_2 Storage and CO_2 EOR
  - Fort Nelson Test Site – Feasibility Study
  - The Nexus of Water and Carbon Sequestration Activities
  - Permitting
- Developed a videographic BPM entitled *"Installing a Casing-Conveyed Permanent Downhole Monitoring (PDM) System" (*draft under review).