Plains CO_2 Reduction (PCOR) Partnership – Phase III

U.S. Department of Energy Carbon Storage R&D Review

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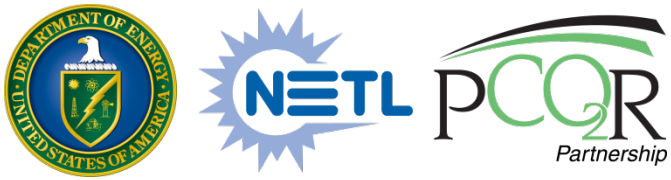
Energy & Environmental Research Center
August 12–14, 2014



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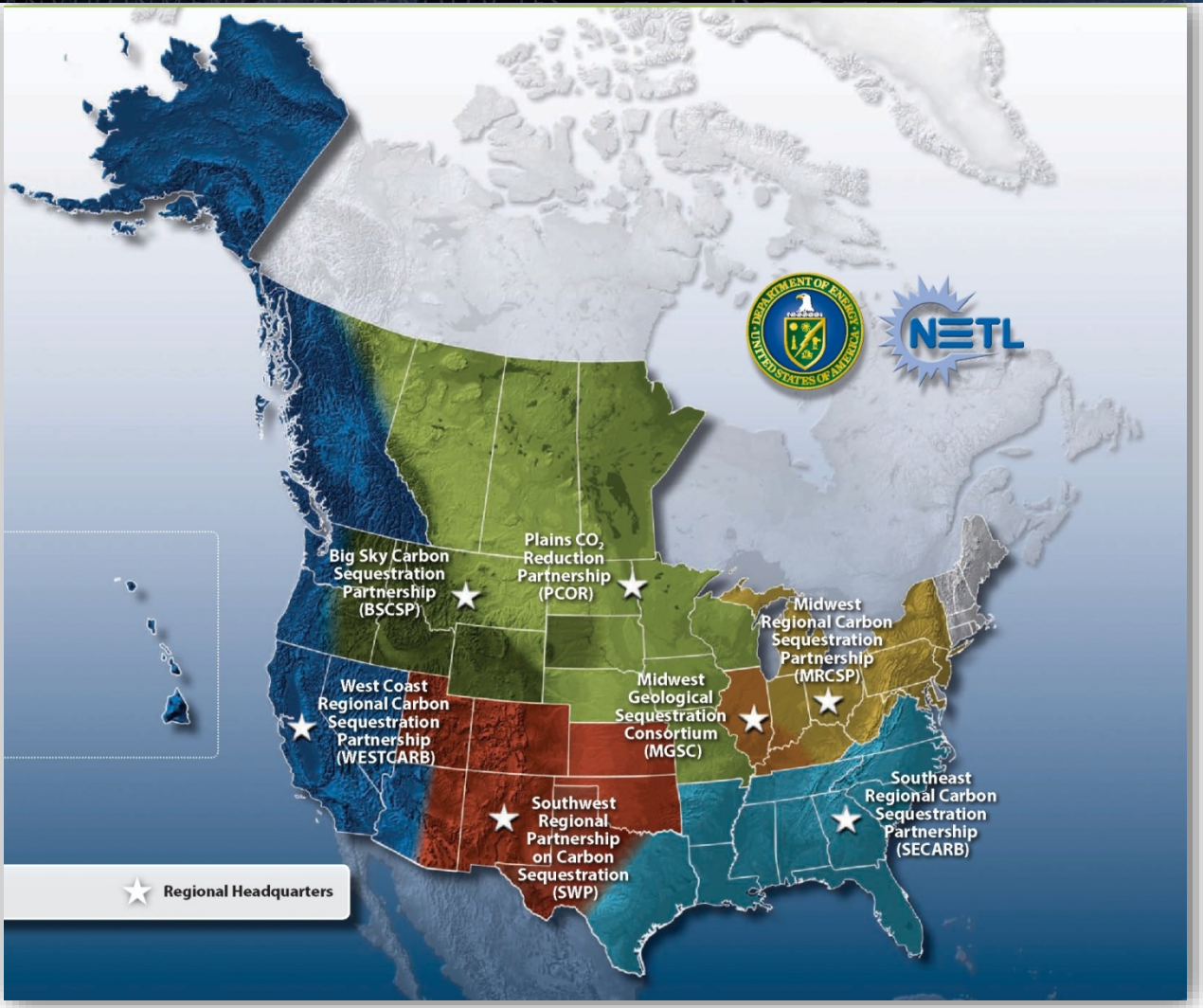
Presentation Outline

- Plains CO_2 Reduction (PCOR) Partnership
- Bell Creek Project Overview
- Site Characterization
- Modeling and Simulation
- Risk Assessment
- Monitoring, Verification, and Accounting (MVA)
- Outreach

Regional Carbon Sequestration Partnerships



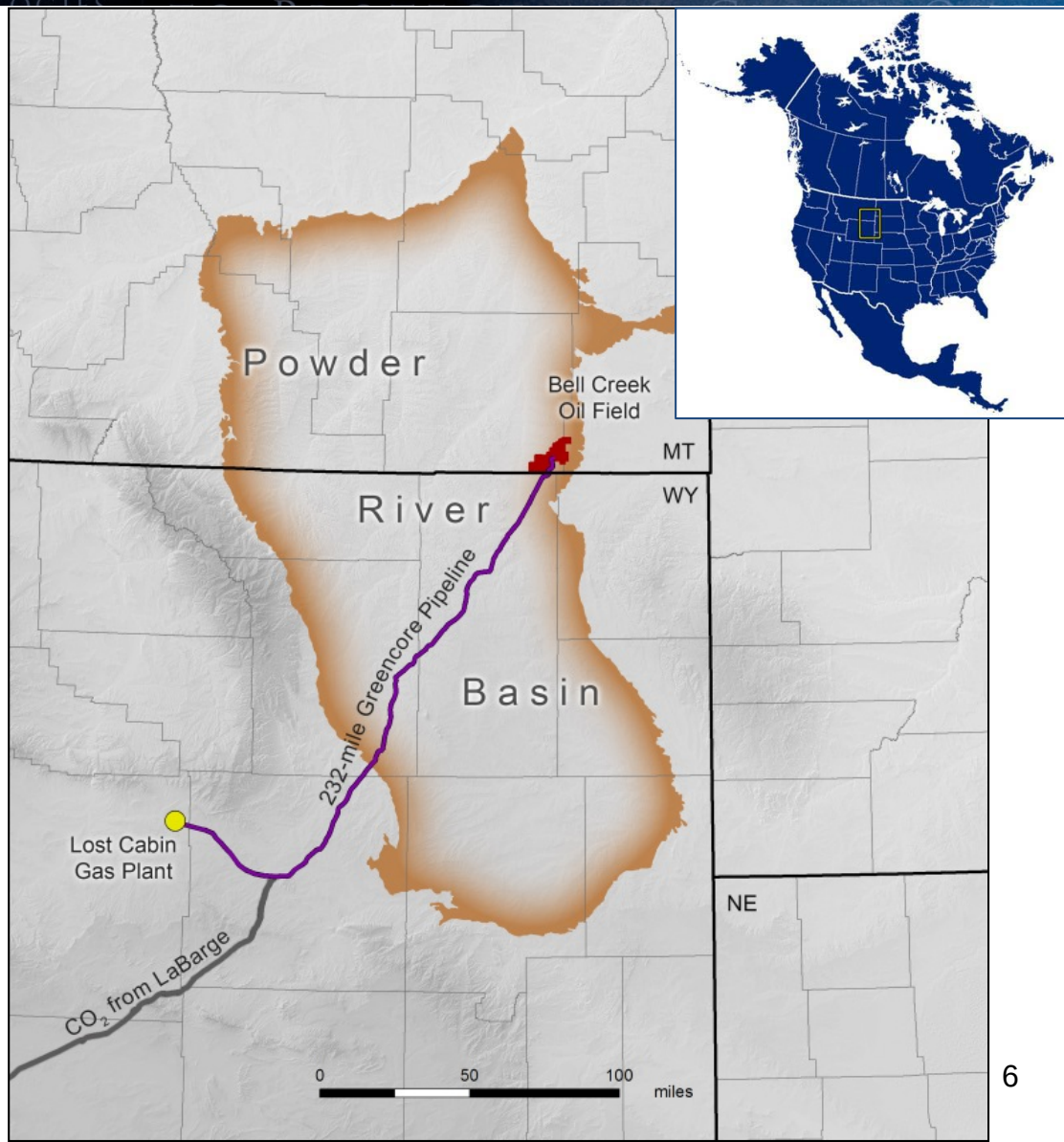
PCOR Partnership

PCOR Program Components

- **Bell Creek project**
- Fort Nelson project
- Aquistore project
- Zama project
- Basal Cambrian project
- Regional characterization
- Public outreach
- Regulatory involvement
- Water Working Group (WWG)

Bell Creek Project Overview

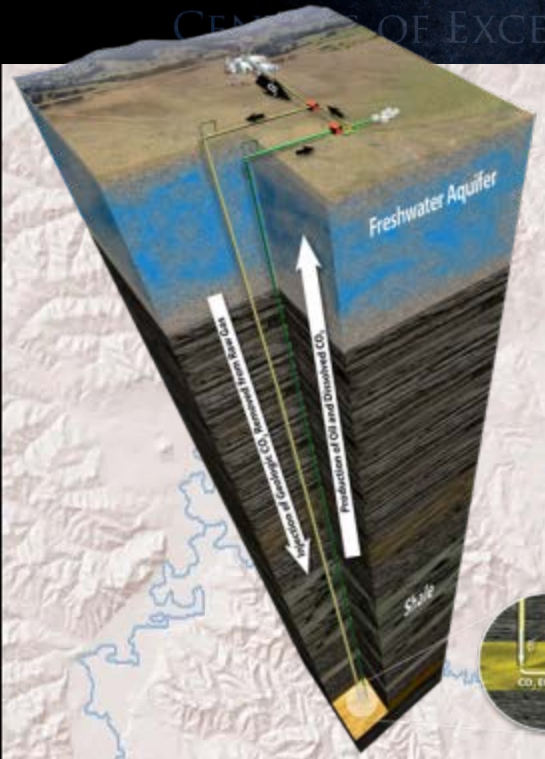
- The Bell Creek oil field is operated by Denbury, which is conducting a commercial EOR project.
- CO_2 is sourced from ConocoPhillips' Lost Cabin gas-processing plant and Exxon's Shute Creek gas-processing plant.
- The Energy & Environmental Research Center (EERC) is studying the interrelationship between EOR and incidental CO_2 storage at a commercial-scale project.



Bell Creek History

- **Discovered in 1967 (21,771 acres)**
- **Peak production 56,000 barrels of oil per day (August 1968)**
- **Stock tank original oil in place (STOOIP) 353 million barrels of oil (MMbo)**
- **Cumulative production 133 MMbo (~38% recovery)**

Phased Development Approach

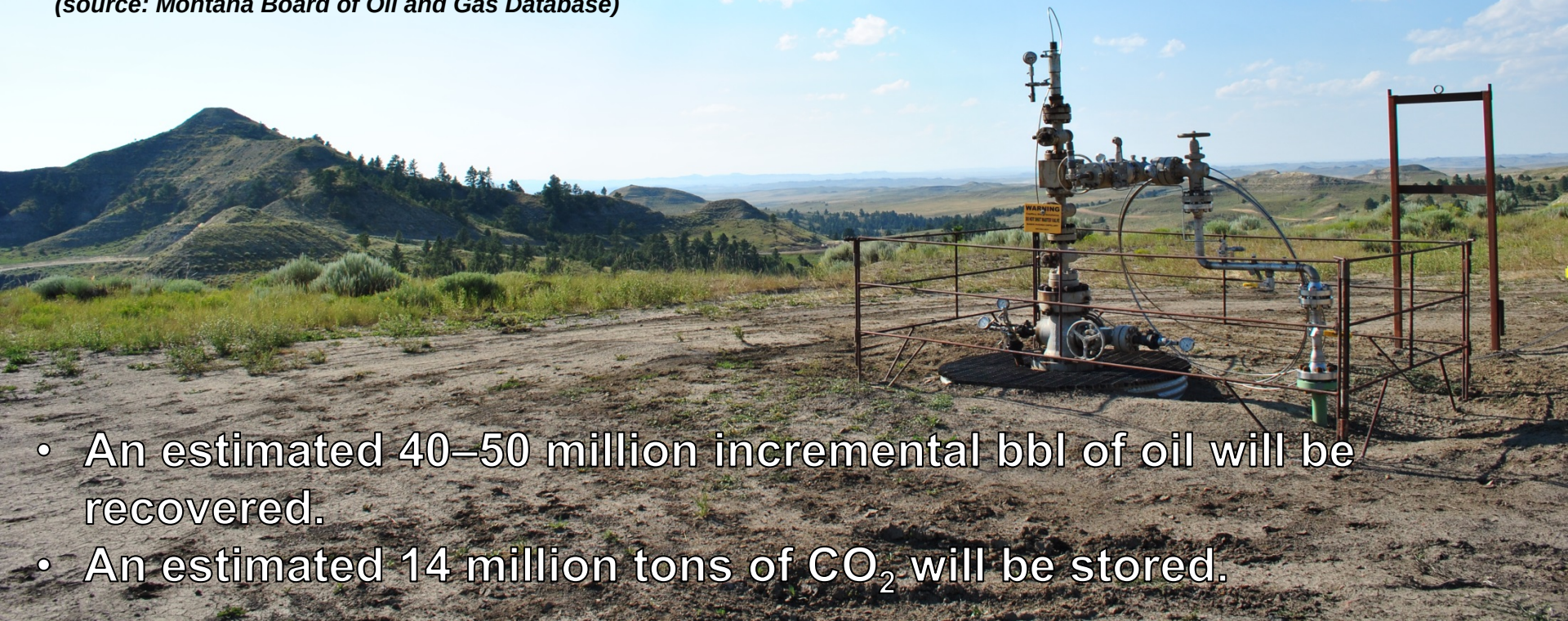


Phase 7
Phase 3
Phase 6
Phase 5
Phase 1
Phase 4
Phase 8
Phase 2
Phase 9
Powder River County
Carter County
MONTANA
WYOMING
Campbell County
Crook County
0 2 4
miles

CO_2 Injection Is Ongoing!!!

- Pipeline completed November 2012
- Pipeline filled February/March 2013
- First injection May 2013
- Facilities commissioned August 2013
- 997,392 tonnes injected through June 2014 (1,098,369 U.S. short tons)

(source: Montana Board of Oil and Gas Database)

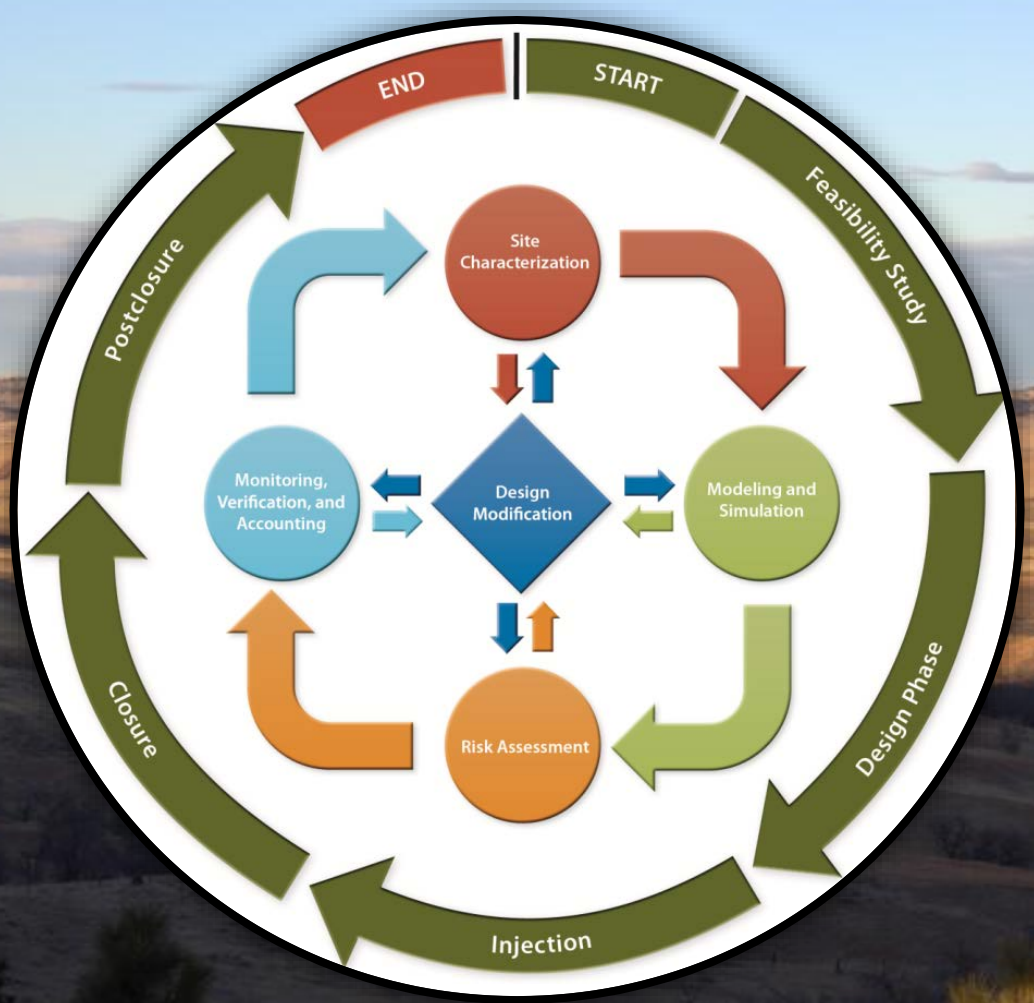


- An estimated 40–50 million incremental bbl of oil will be recovered.
- An estimated 14 million tons of CO_2 will be stored.

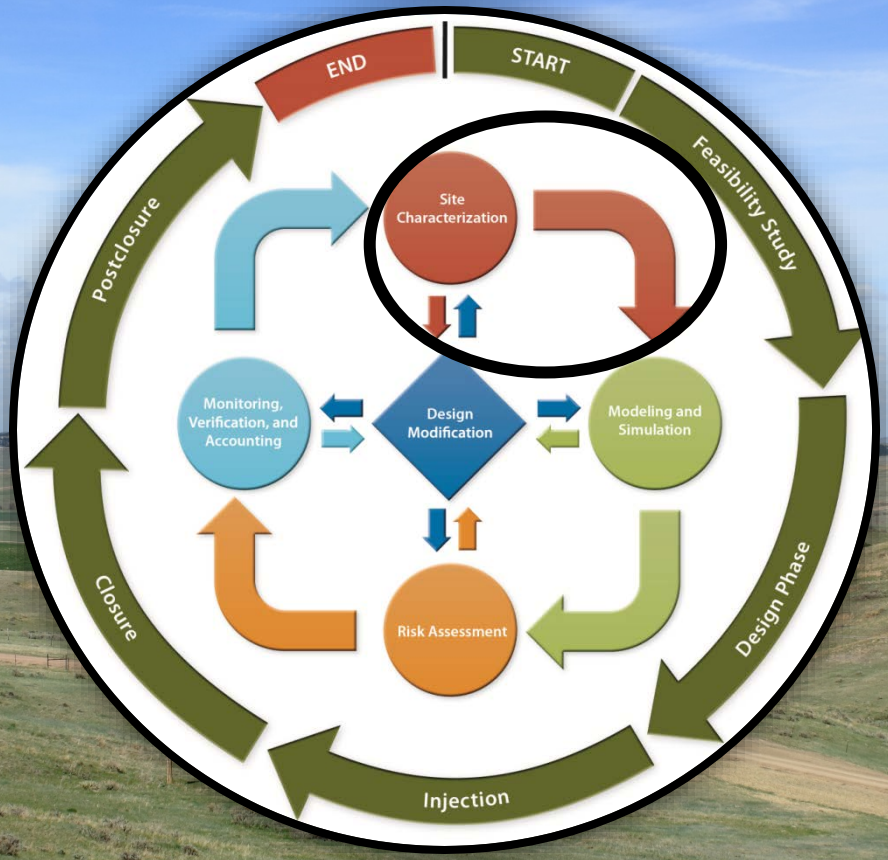
The PCOR Partnership

Integrated Approach to Program Development

Focused on site characterization, modeling and simulation, and risk assessment to guide MVA strategy



Site Characterization Goals

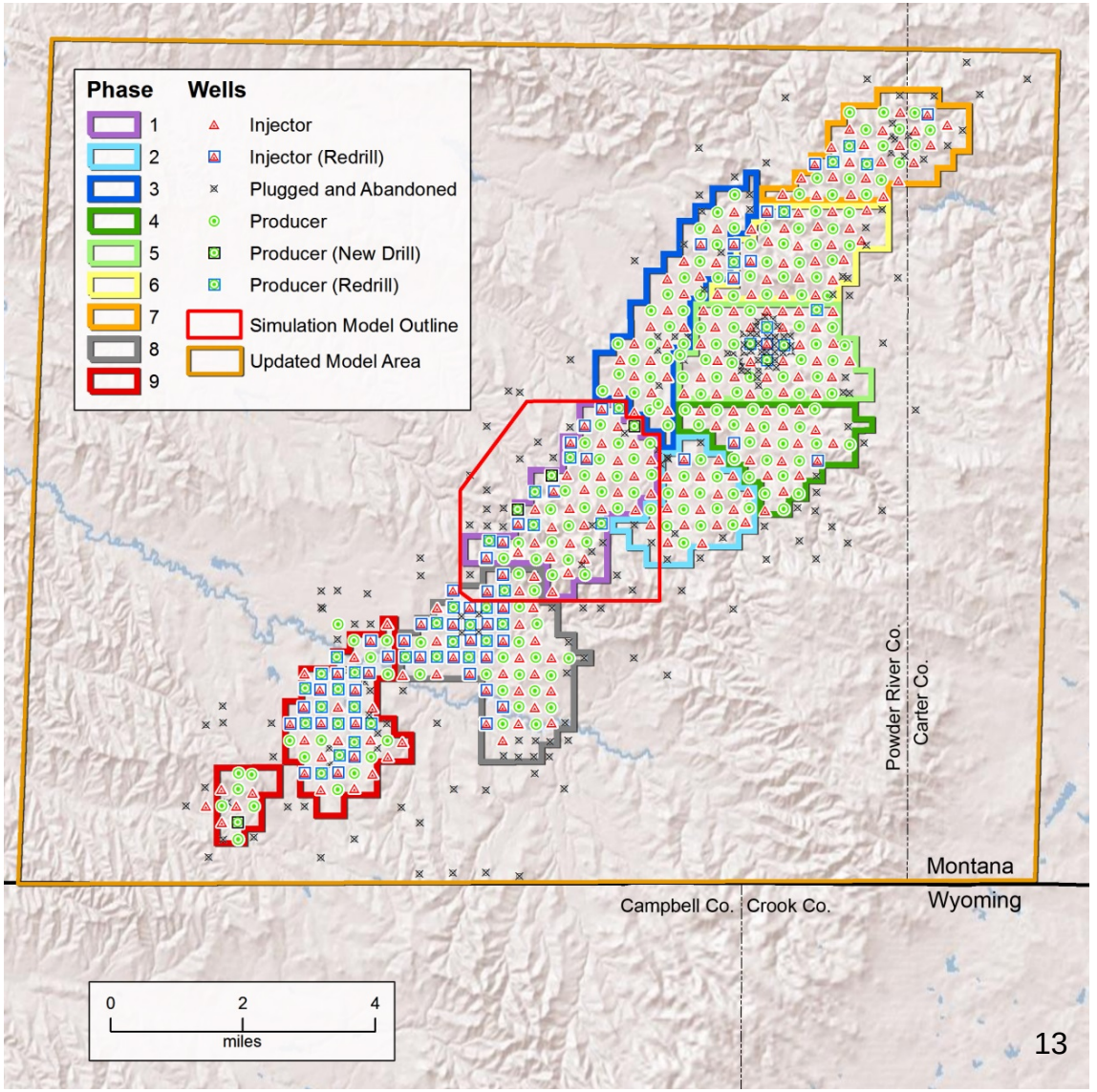


Completed Site Characterization Activities

- 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
- 40-mi^2 3-D seismic survey
- Baseline 3-D vertical seismic profiles (VSPs)
- Pulsed-neutron logs (PNLs)

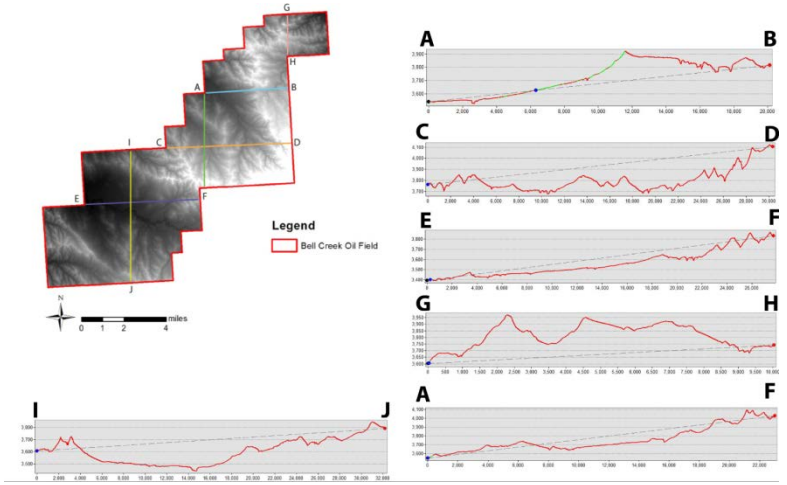
Well File Integration

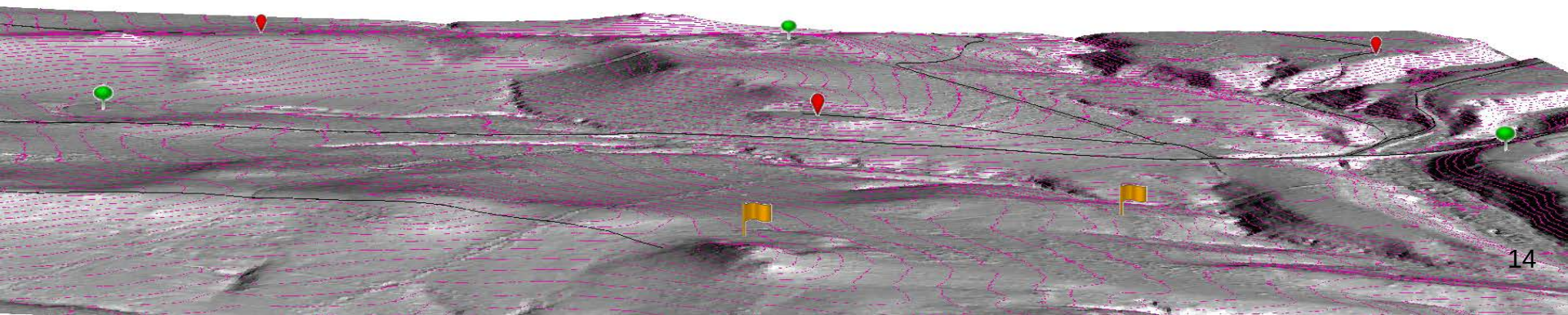
- Files from 674 wells electronically scanned from public and private sources.
  - Completions information and activity reports were statistically analyzed.
    - Guide risk assessment
    - Guide mitigation plans related to wells
    - Guide MVA
- Well files for geocellular modeling/simulation activities:
  - Quality assurance/quality control (QA/QC) of well logs from 748 wells.



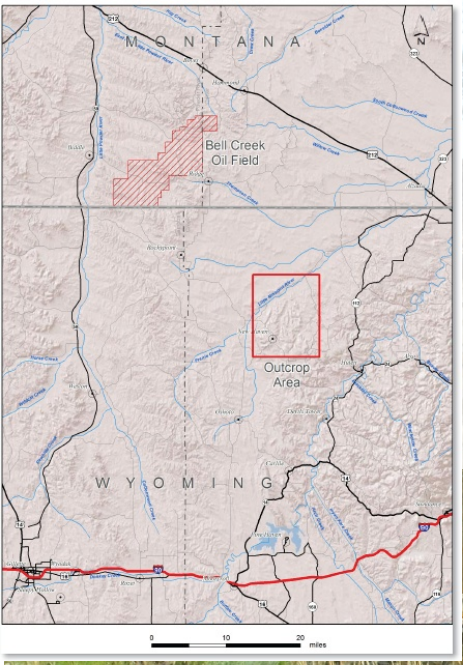
Lidar

- 75-square-mile lidar survey (July 14, 2011) including high-resolution aerial imagery
  - Lidar 3-foot horizontal spatial resolution and 6-inch vertical accuracy
- **Applications**
  - Precisely placed well locations and elevations.
  - Locate plugged and abandoned (P&A) wells.





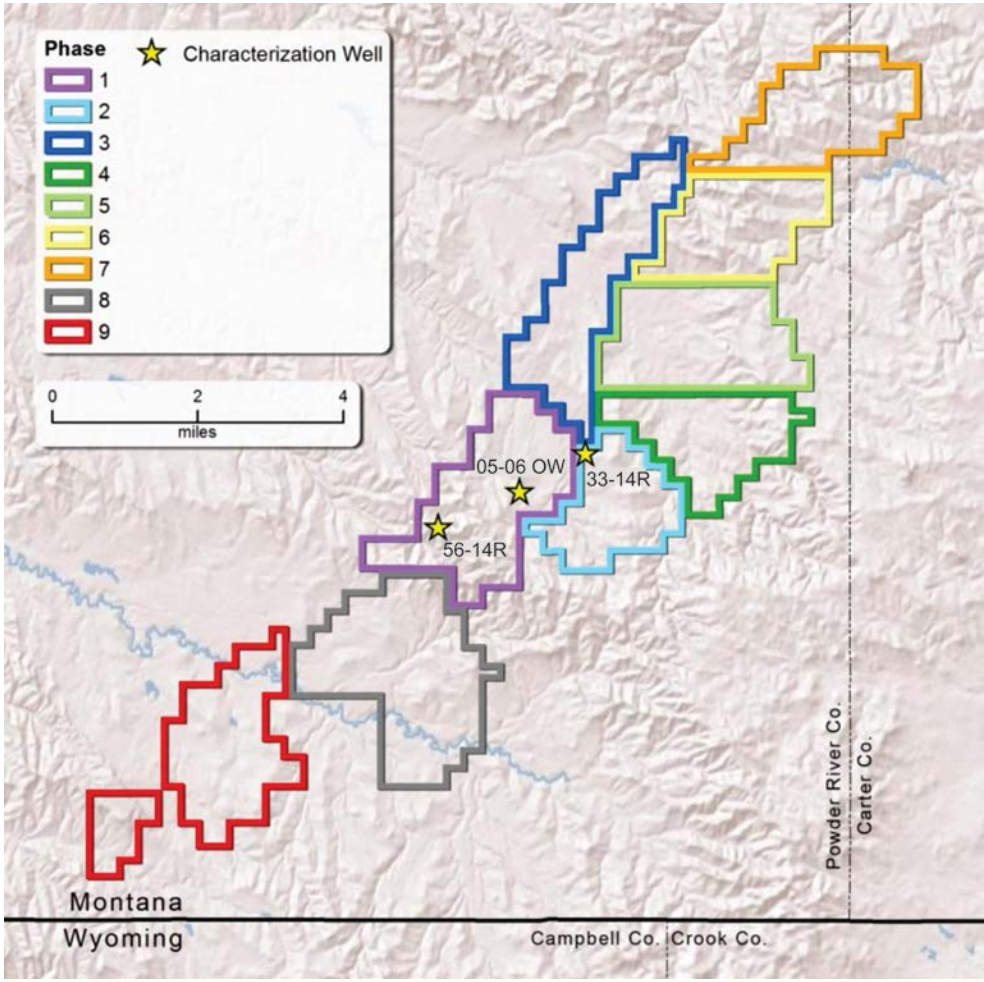
Outcrop Characterization



- Joint Denbury–EERC field trip
  - July 2011 and August 2013
- **Application**
  - Understand heterogeneities in the reservoir.
  - Understand regional structure and facies.
  - Gain insight into major properties, flow zones, and flow barriers in the reservoir.

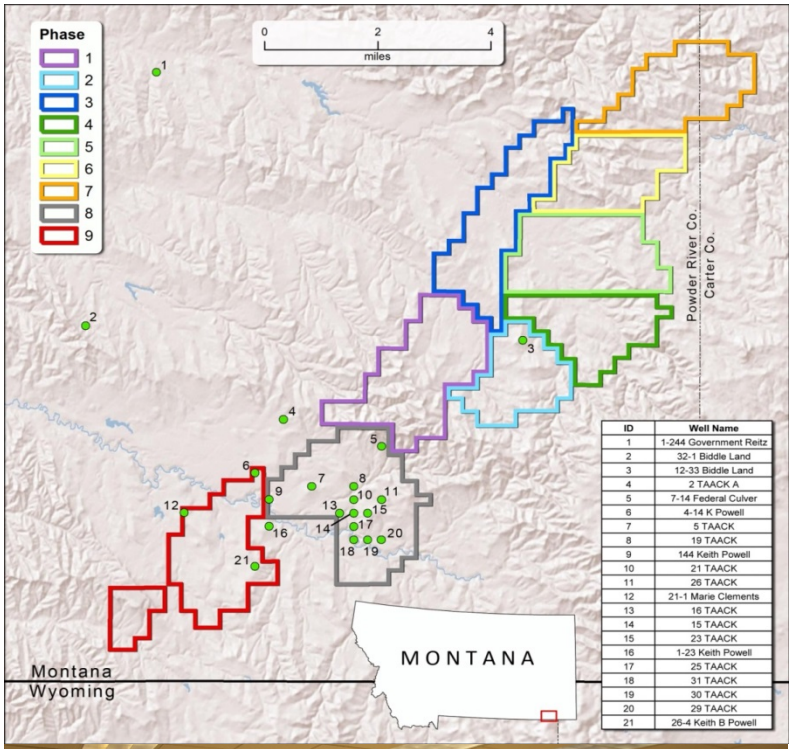
Characterization Wells

- Dedicated data collection, Well 05-06 OW drilled, cored, logged, and outfitted (January 2012).
  - Provide modern high-resolution data sets (logs, core analysis, etc.).
  - Understand reservoir and seal properties.
  - Increase confidence in fluid movement predictions.
  - In situ pressures and temperatures.
  - Provide downhole monitoring point.
  - Unobtrusive monitoring point.
- Replacement production Wells 56-14R and 33-14R drilled, cored, and logged (spring 2013).
  - Understand variability in reservoir and cap rock across Phase 1.
  - Tie seismic and well data in with dipole sonic logs.
  - Characterization of vertical and lateral seals.



USGS and BEG Subsurface Core Characterization

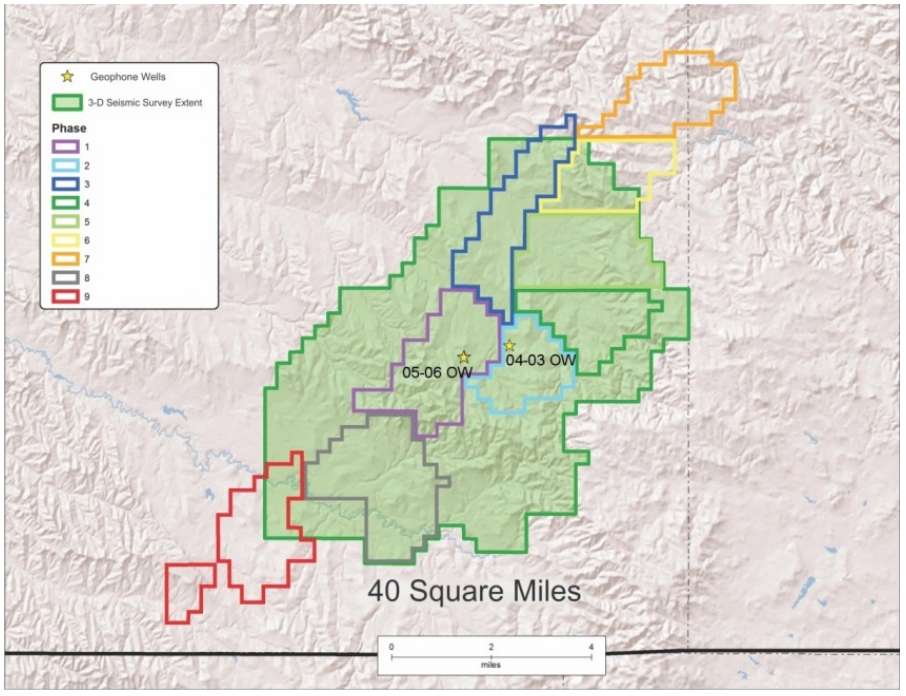
- Sixty-six cores examined thus far:
  - Fifty-eight at the U.S. Geological Survey (USGS)
  - Eight at the Bureau of Economic Geology (BEG)
- Twenty-one cores sampled underwent detailed characterization (USGS).
- **Application**
  - Understand mineralogical, depositional, and structural settings.
  - New porosity-to-permeability transforms.
  - Improved understanding of log response variations throughout the field.
- **Activities**
  - Improved interpretation of depo- and lithofacies, petrography, and overall geology.



3-D Seismic

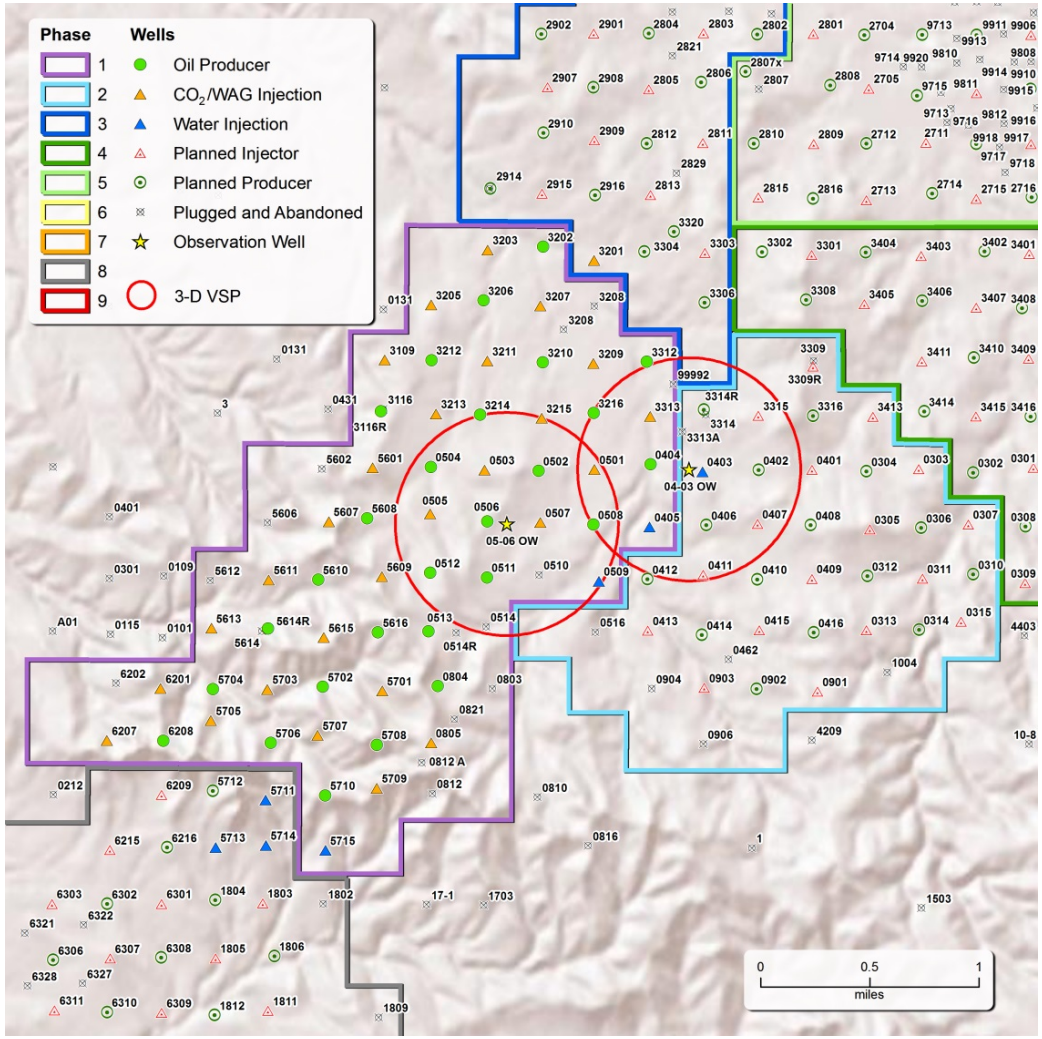
- Completed 40-square-mile baseline survey August 2012.
- Processed data being incorporated into 3-D geologic model.

- **Applications**
  - Characterize structure and properties
  - MVA



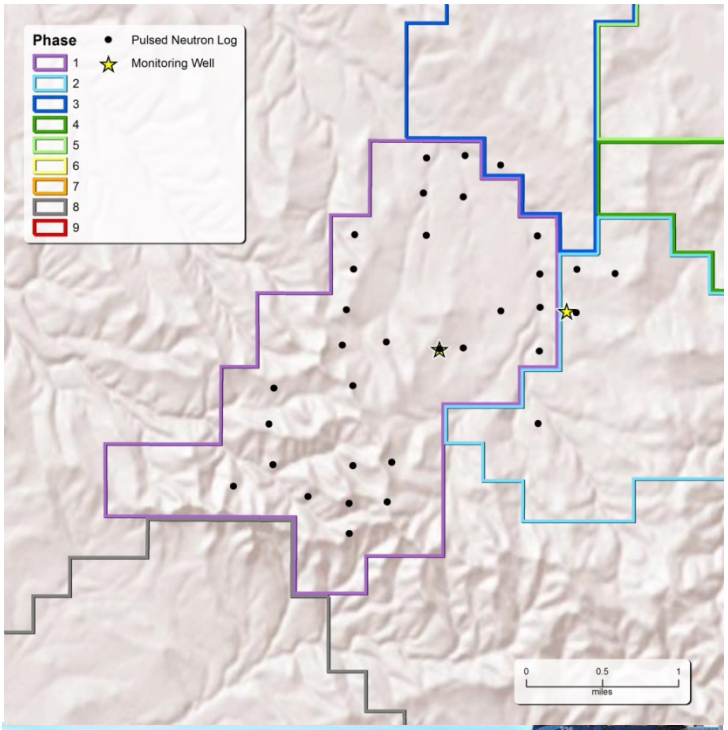
3-D VSP Surveys

- Data acquisition in May 2013
- **Three-component arrays**
  - 05-06 OW (60-level retrievable)
  - 04-03 OW (50-level permanent)
- **Applications**
  - 3-D seismic tie-in
  - Higher-resolution seismic image
  - MVA

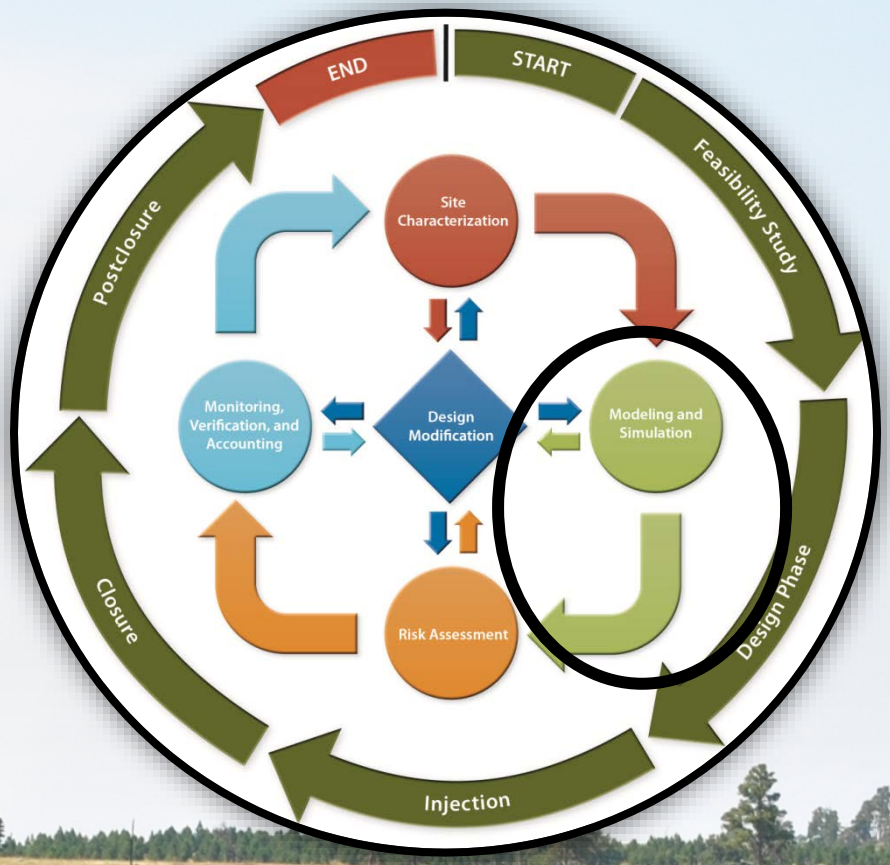


PNLs

- Thirty-three baseline logs completed (Q4 2012 – Q2 2013)
  - Sigma, from total depth up to 200 feet
  - Carbon/oxygen (C/O), reservoir interval
- Repeat logs under discussion.
- **Applications**
  - Sigma:
    - Improved geologic understanding
    - Measure gas/liquid fluid saturations
  - C/O:
    - High-resolution water/oil/gas saturation data over the reservoir

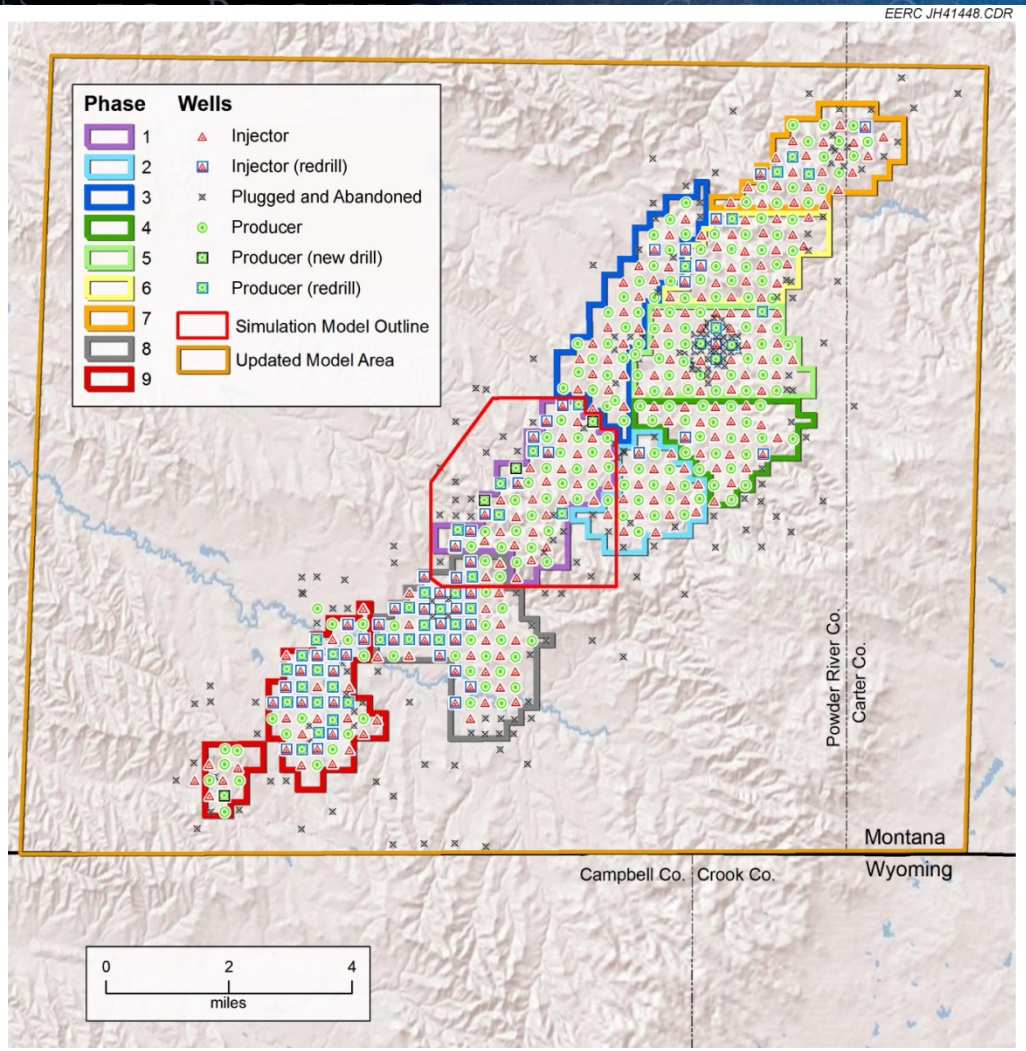


Modeling and Simulation Goals



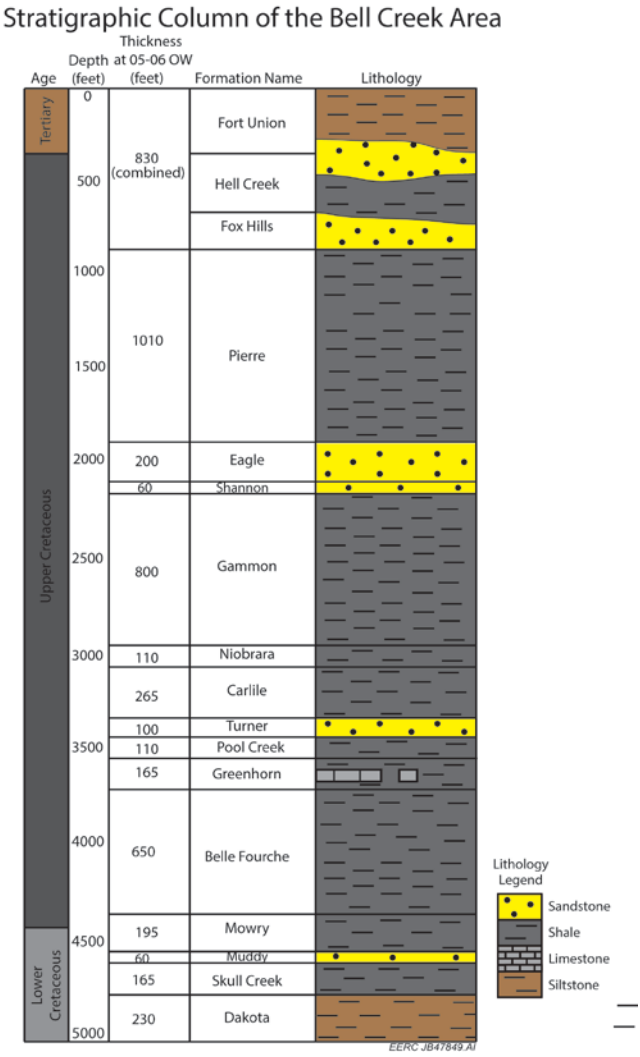
Modeling and Simulation Efforts

- 200-mi^2 domain models
  - Surface through Madison Formation
  - Mowry Formation through Skull Creek Formation
  - 3-D Mechanical Earth Model (MEM)
- 7.75-mi^2 multiphase flow numerical simulation models
- PVT and equation-of-state modeling
- 1-D MEM
- Shallow subsurface geochemical modeling



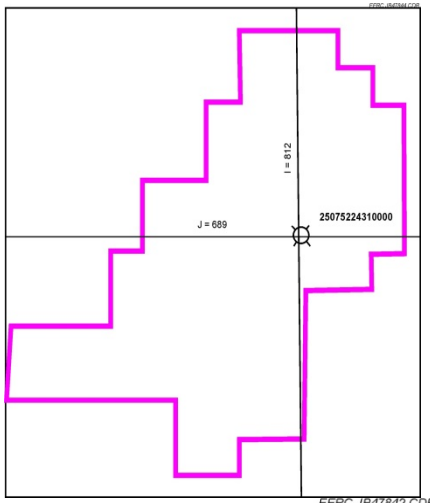
200-mi² Domain Models

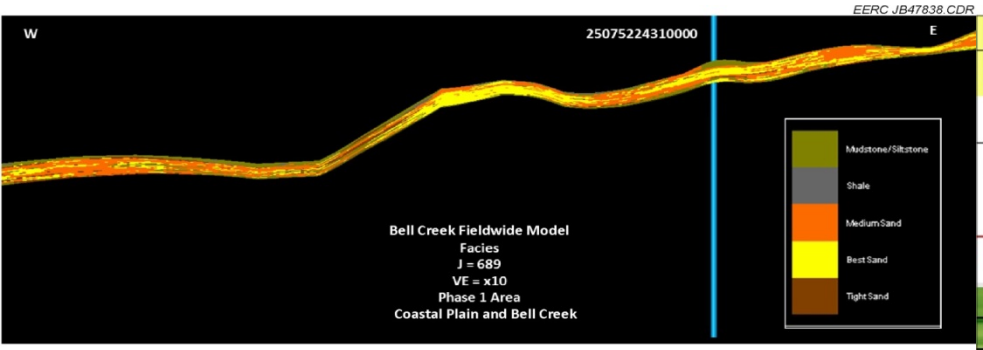
- **Surface through reservoir model**
  - Software: Petra, geographic information system (GIS), and Petrel®.
  - Used to house all characterization data and provide a consistent approach to other models.
- **Reservoir and seals model**
  - Software: Techlog® and Petrel.
  - Used to better understand the injection horizon, lateral pinchouts, and over- and underlying seals.
- **3-D MEM**
  - Software: Petrel, Techlog, GEM™, Tough2, and FLAC®3D.
  - Currently under construction.
  - Used to predict geomechanical changes to the reservoir and surrounding formations as a result of injection and production activities and to identify potential risk areas, assess the local and regional stress regime, and guide MVA strategies.

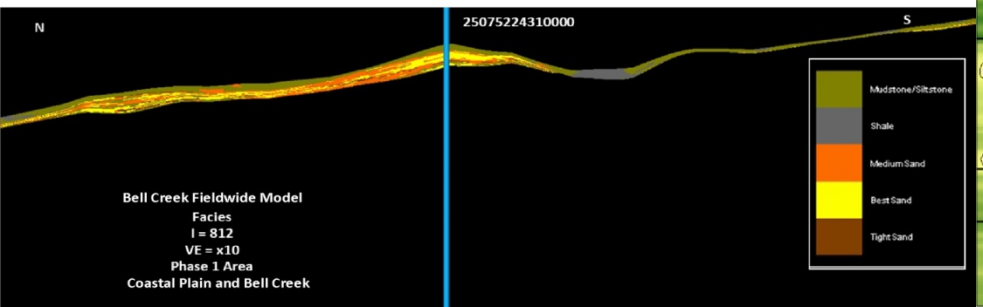


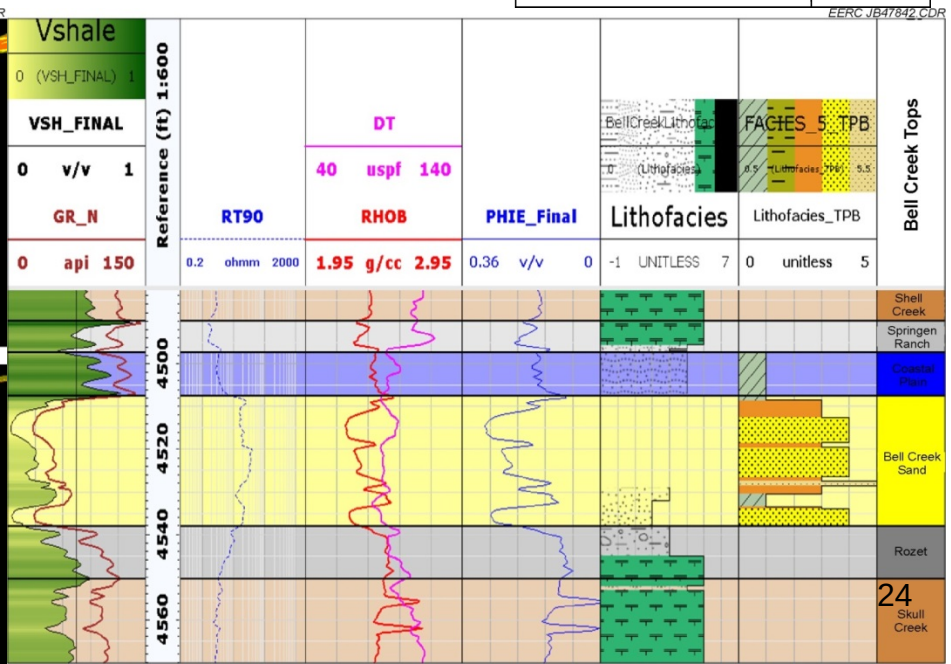
Detailed Geologic Model

- Includes updated PETRA database
  - Lidar-corrected well locations and elevations.
  - QA/QC of well logs from 748 wells.
  - Core data from 25 wells.
- 200 mi^2 (100 million cells in static model).
- Populated with lithofacies, porosity, permeability, and water and oil saturation.



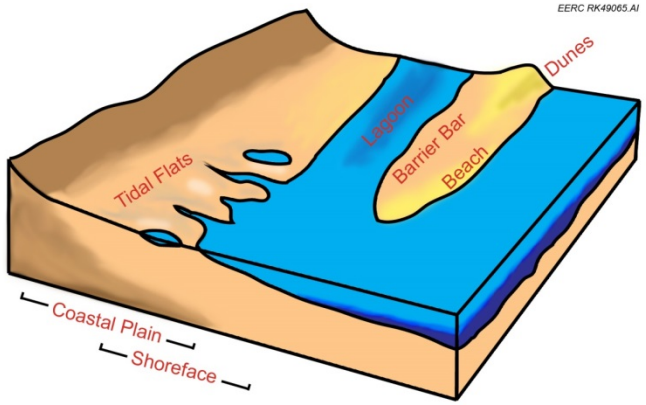




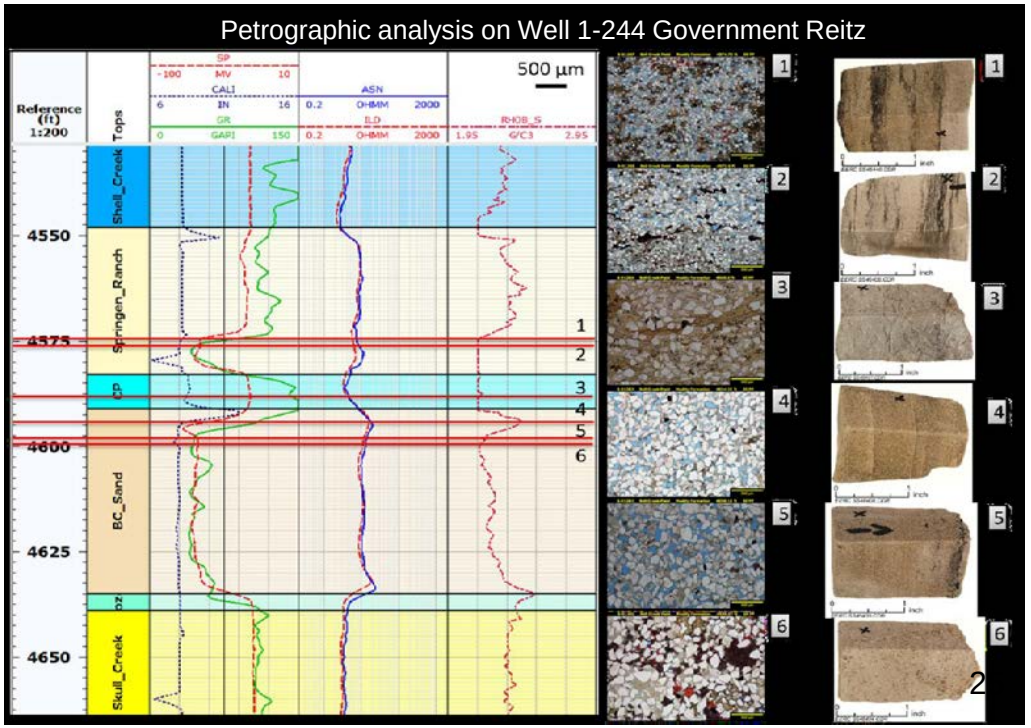


Future Updates

- Incorporation of newly collected characterization and MVA data:
  - 3-D seismic.
  - VSPs.
  - PNLs.
  - Facies model derived from detailed core petrographic analysis of 21 USGS wells.
  - Include characterization from observation and redrill wells (e.g., 33-14R, 56-14R, 05-06 OW).



Petrographic analysis on Well 1-244 Government Reitz



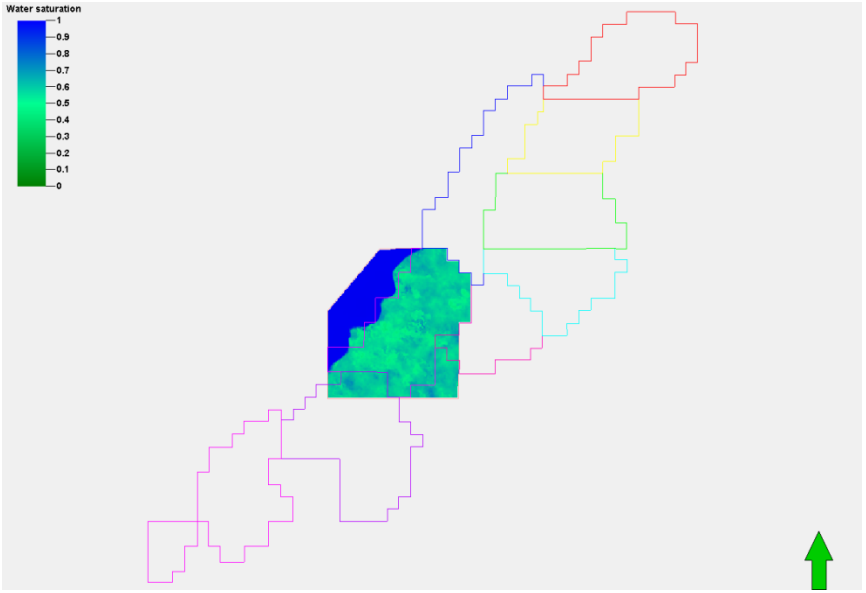
Numerical Simulation Model

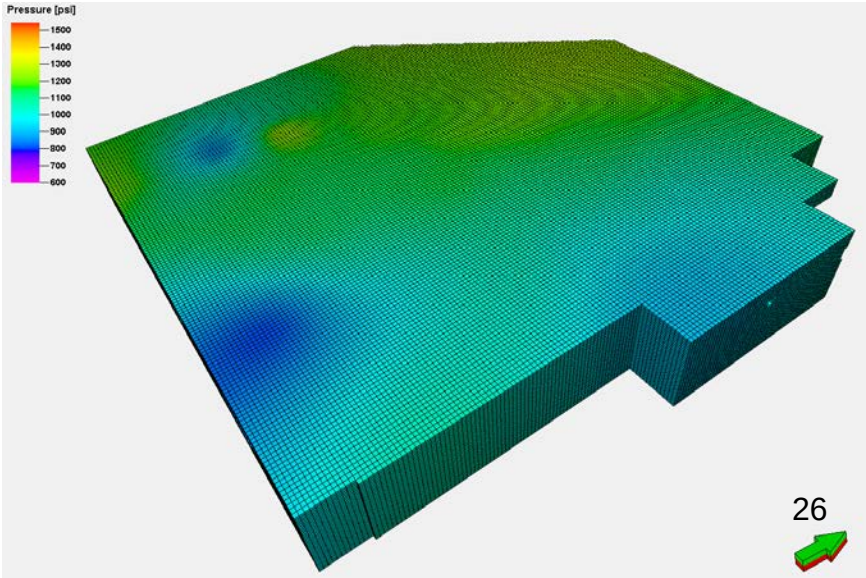
Characteristics

- 520,926-cell model clipped from regional model (7.75 mi^2).
- Coastal Plain and Bell Creek reservoir zones are included.
- Incorporates 75 production wells and 35 converted injection wells.
- Incorporates SCAL and PVT data.

Applications

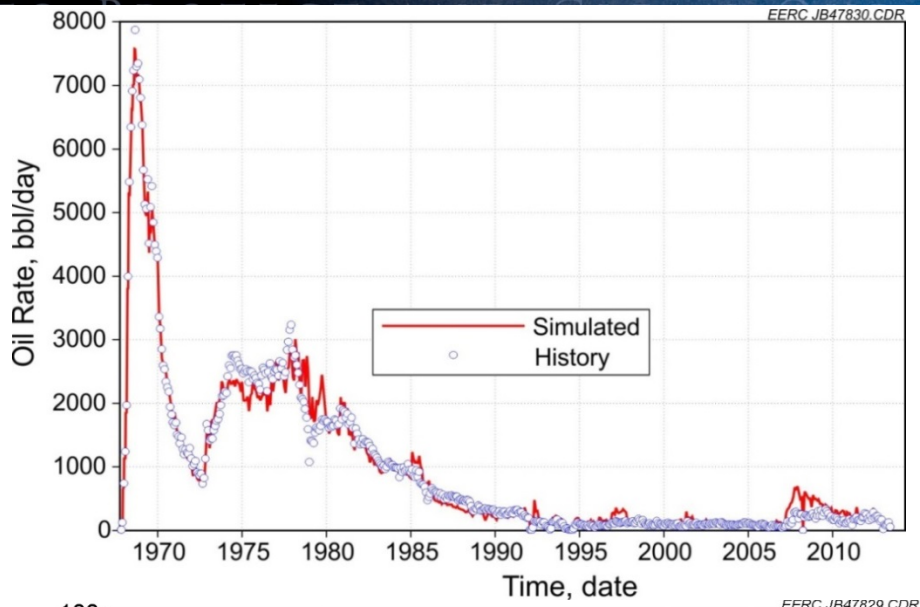
- Used to determine breakthrough times at wells and optimal times for repeat MVA techniques.
- Used to predict storage capacity, sweep efficiency, recovery factor, and utilization factor.

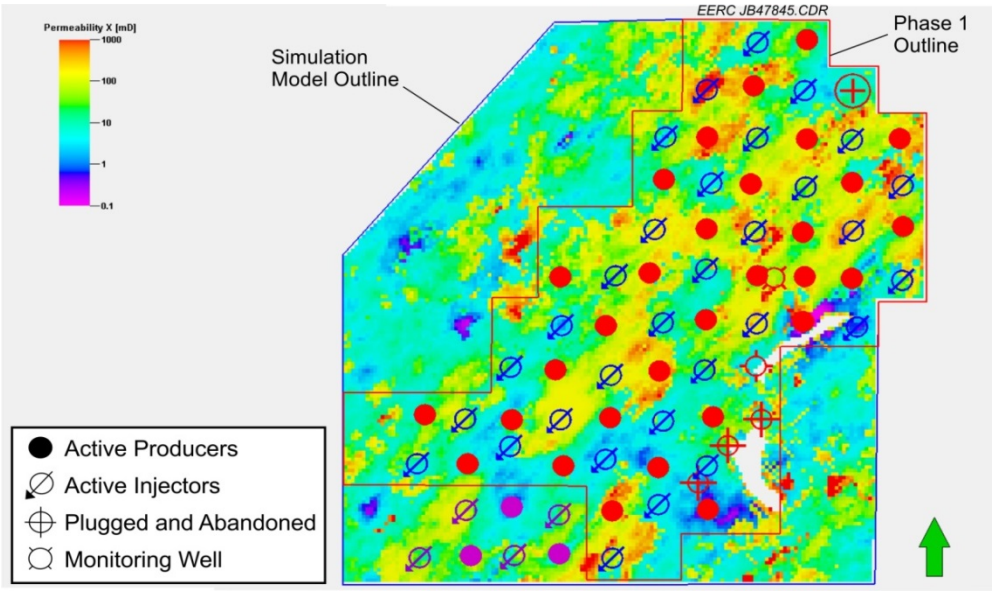


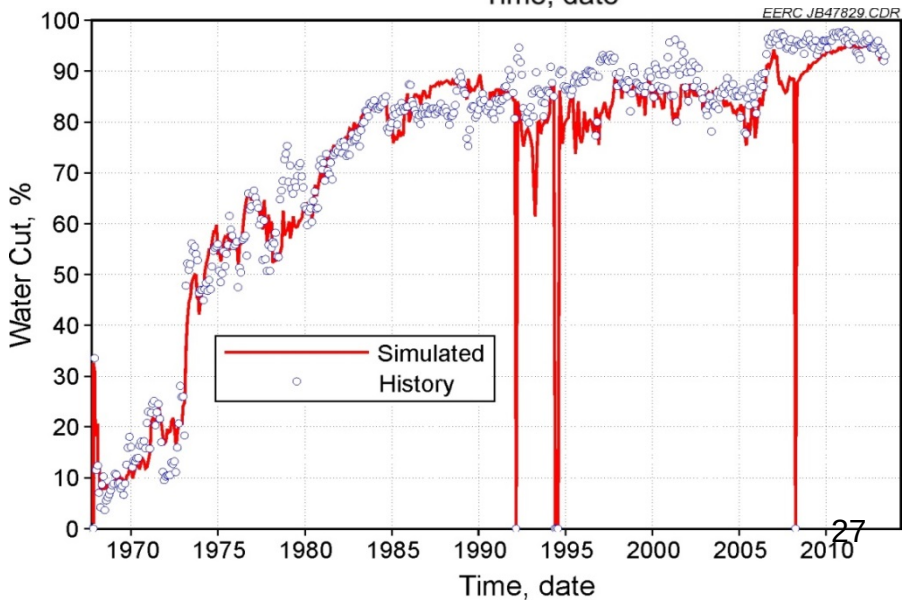


History Match

- PVT model was closely matched to lab data for original oil and current oil.
- Historic production, injection, and water cut rates were matched.
- Used total liquid rate as a control for history match.
- A good match also achieved for pressure; however, little historical pressure data were available.



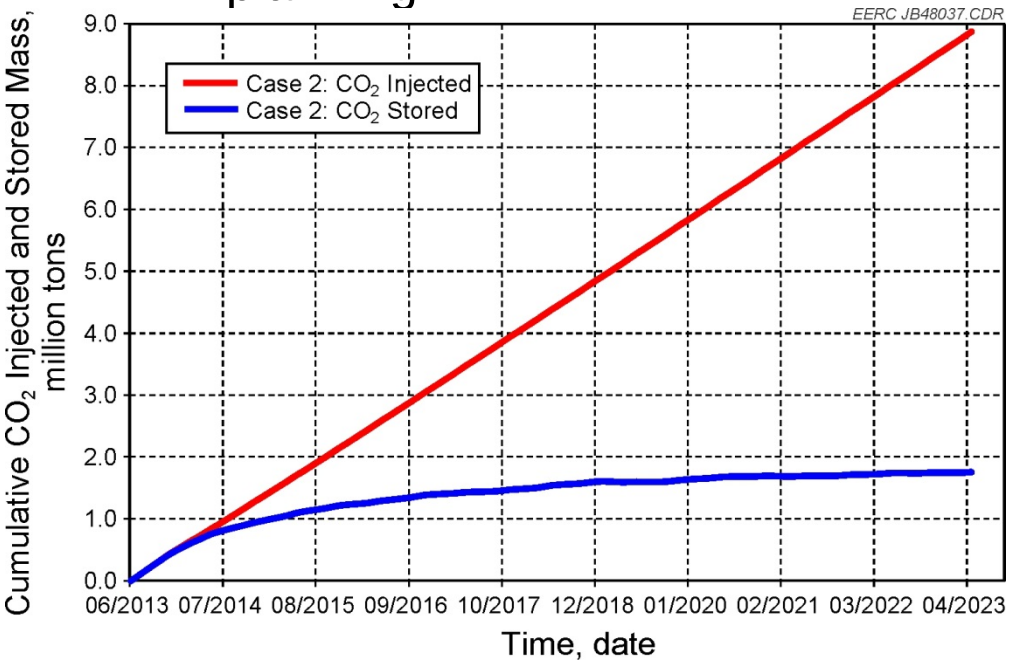


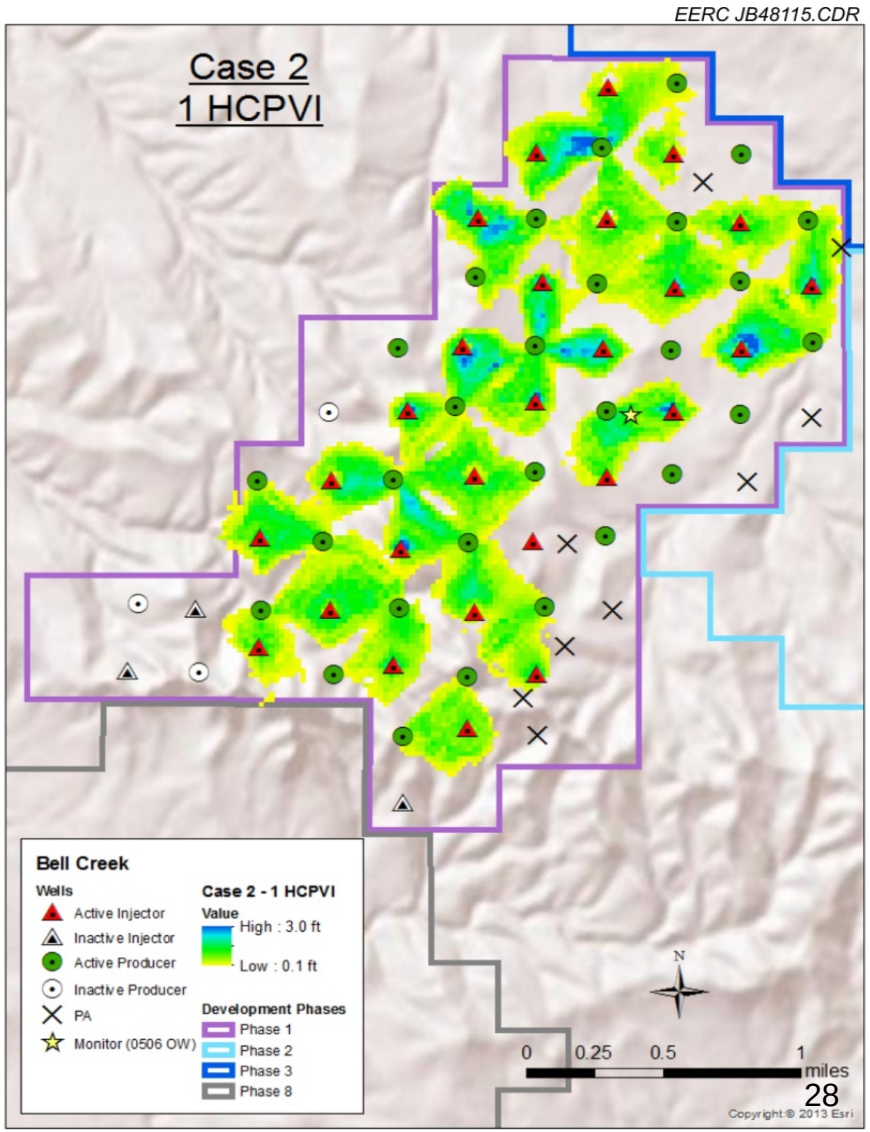


Predictive Simulations

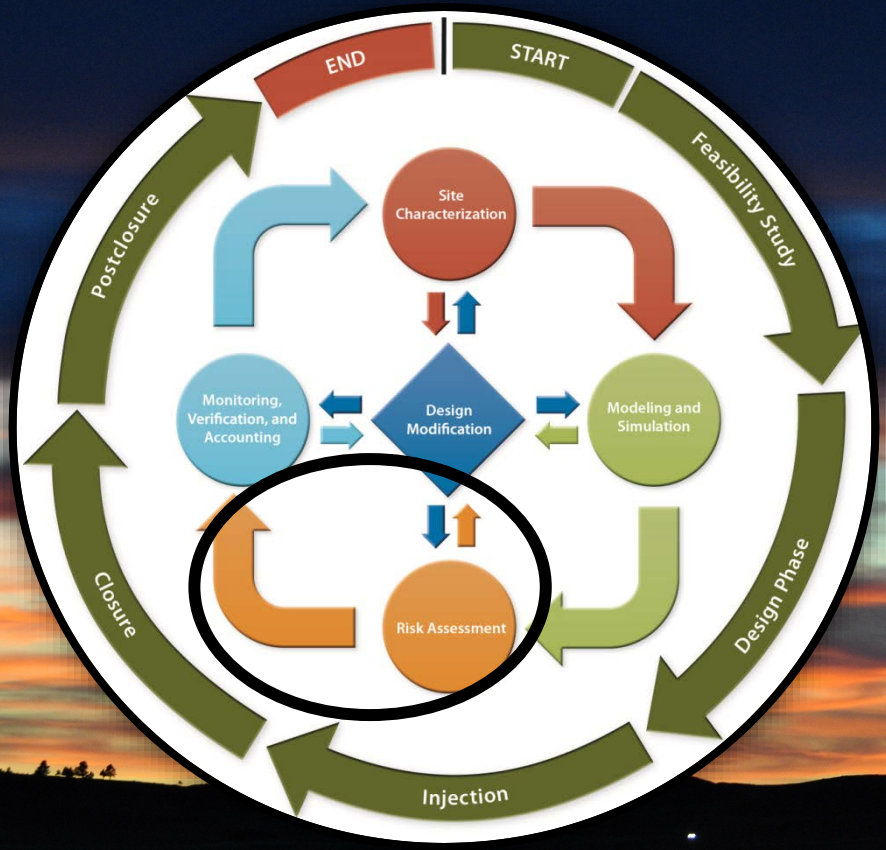
Prediction Observations

- First breakthrough at production wells expected after 3 months of production and 5 months at the monitoring well.
- By September 30, 2017, approximately 4 million tons of CO_2 will be injected in Phase 1, with approximately 1.5 million tons stored.
- Results used in risk assessment and MVA planning.





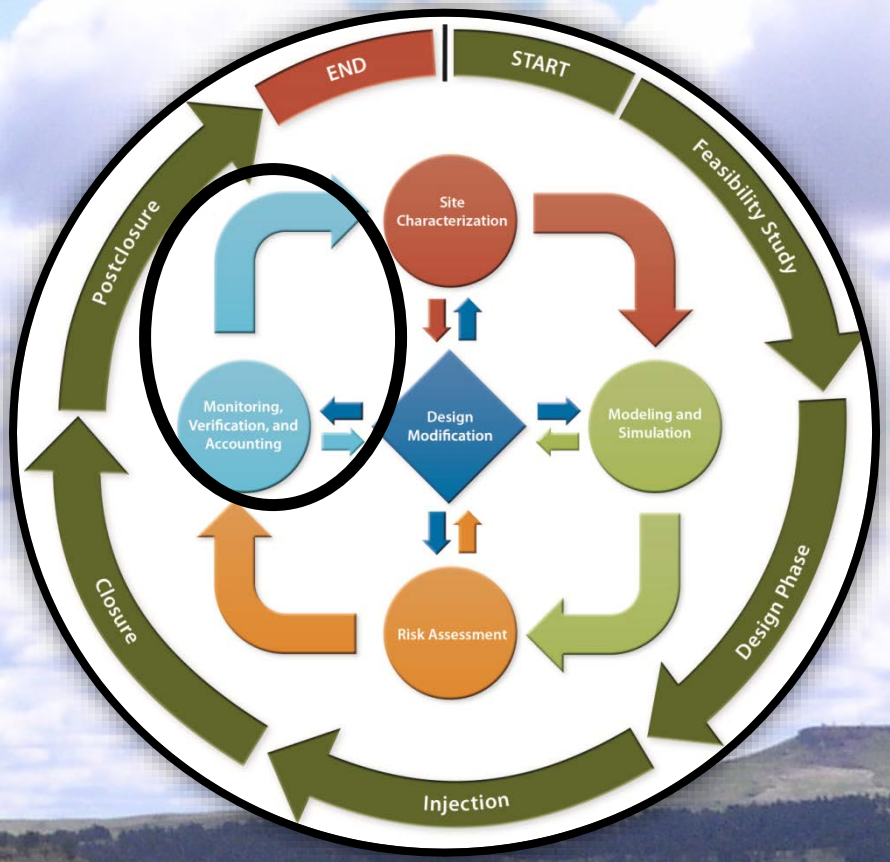
Risk Assessment and Mitigation Goals



Risk Assessment and Mitigation Workflow

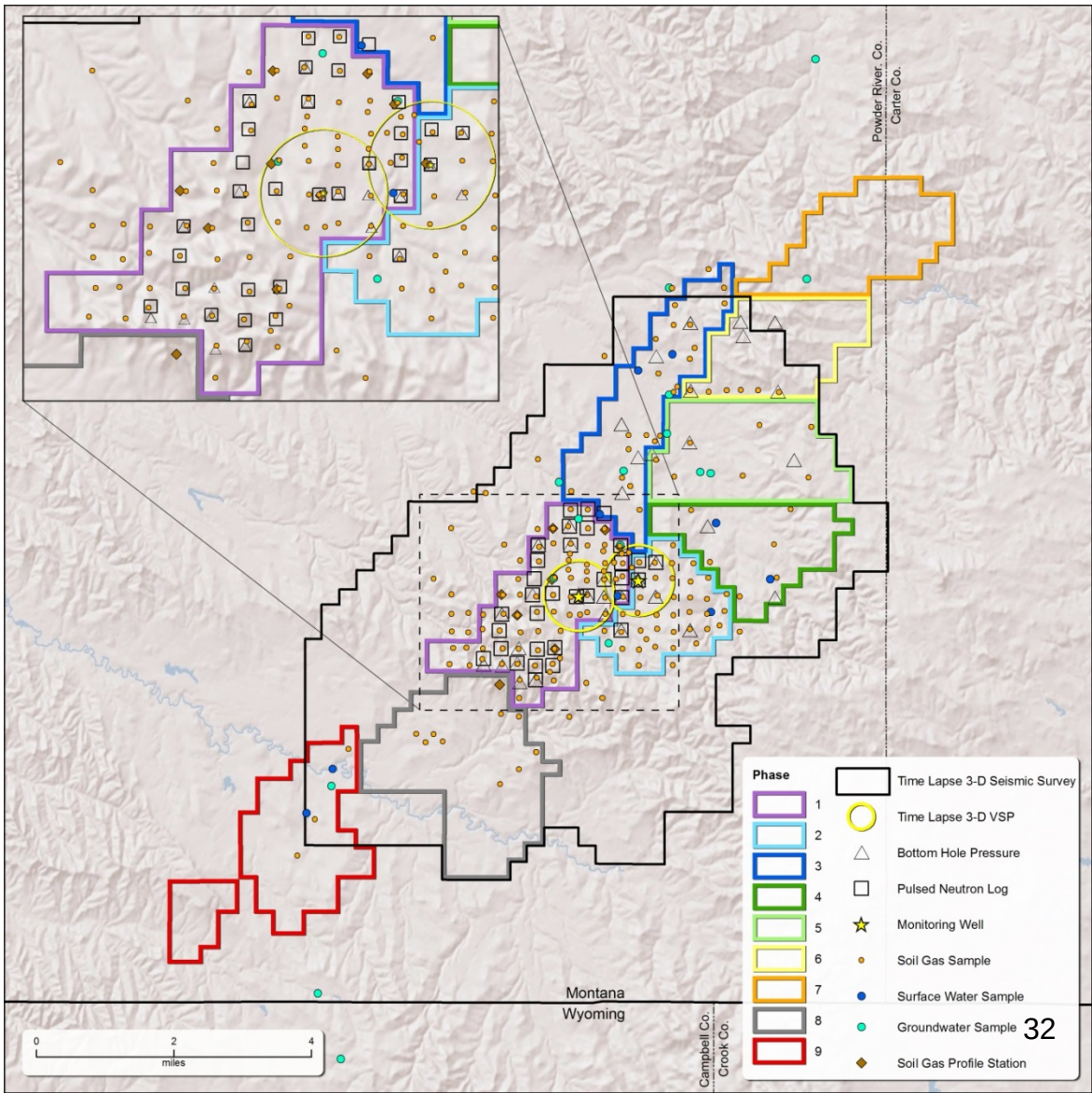
- Identify relevant subsurface risks related to storage (expert panel).
- Rank the relative likelihood of occurrence and potential magnitude of impact.
- Complete risk register.
- Decision point to proceed.
  - No critical risks identified which would preclude the project from moving forward.
  - Implement strategies to reduce the likelihood and/or impact of unacceptable risks.
- Evaluate hazard mechanisms.
  - Monitor relevant hazards.
  - Mitigate where applicable.
- Identify available remediation strategies for relevant risks.
  - Evaluate based on cost-effectiveness.

MVA Program Goals

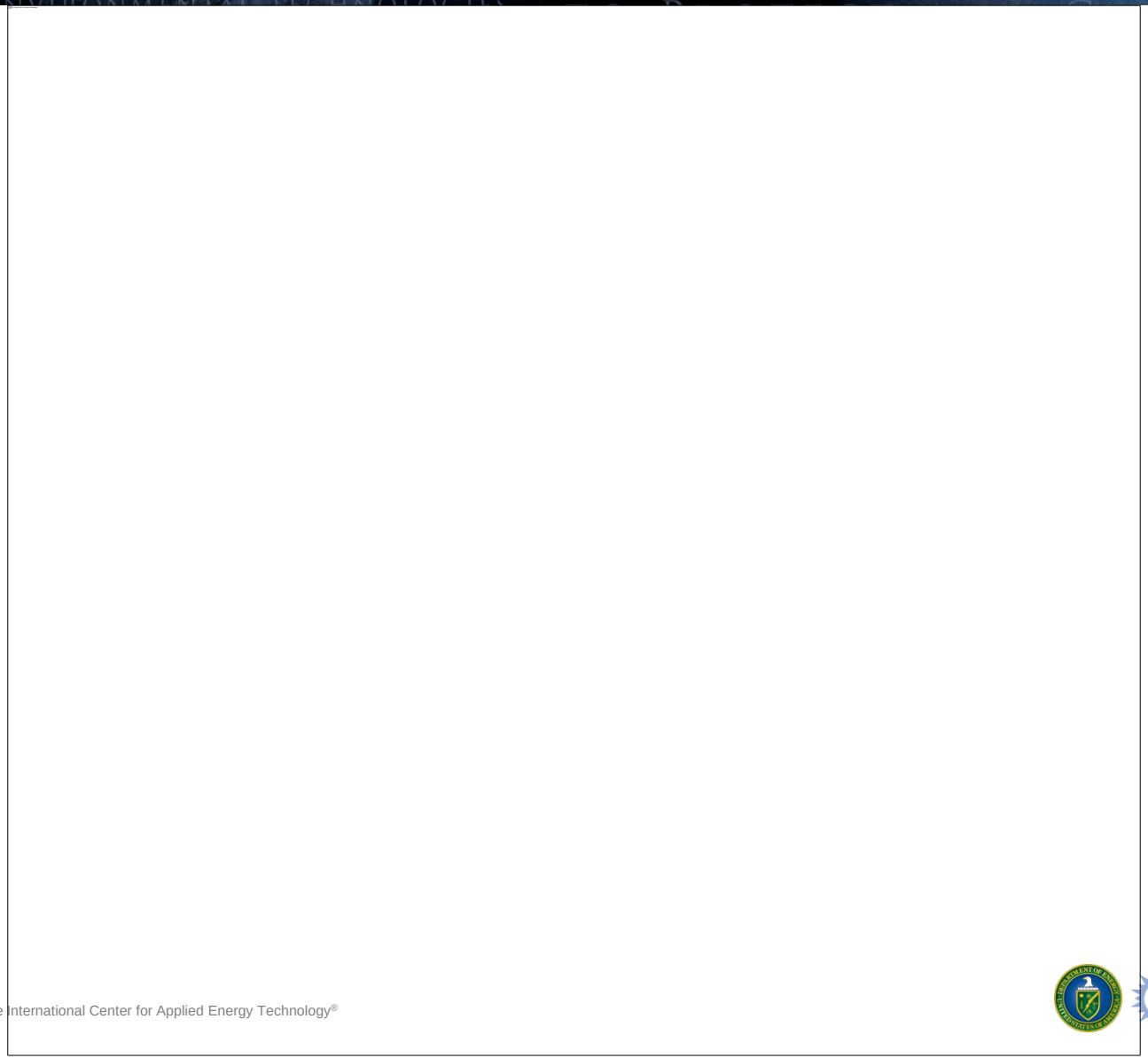


MVA Strategy

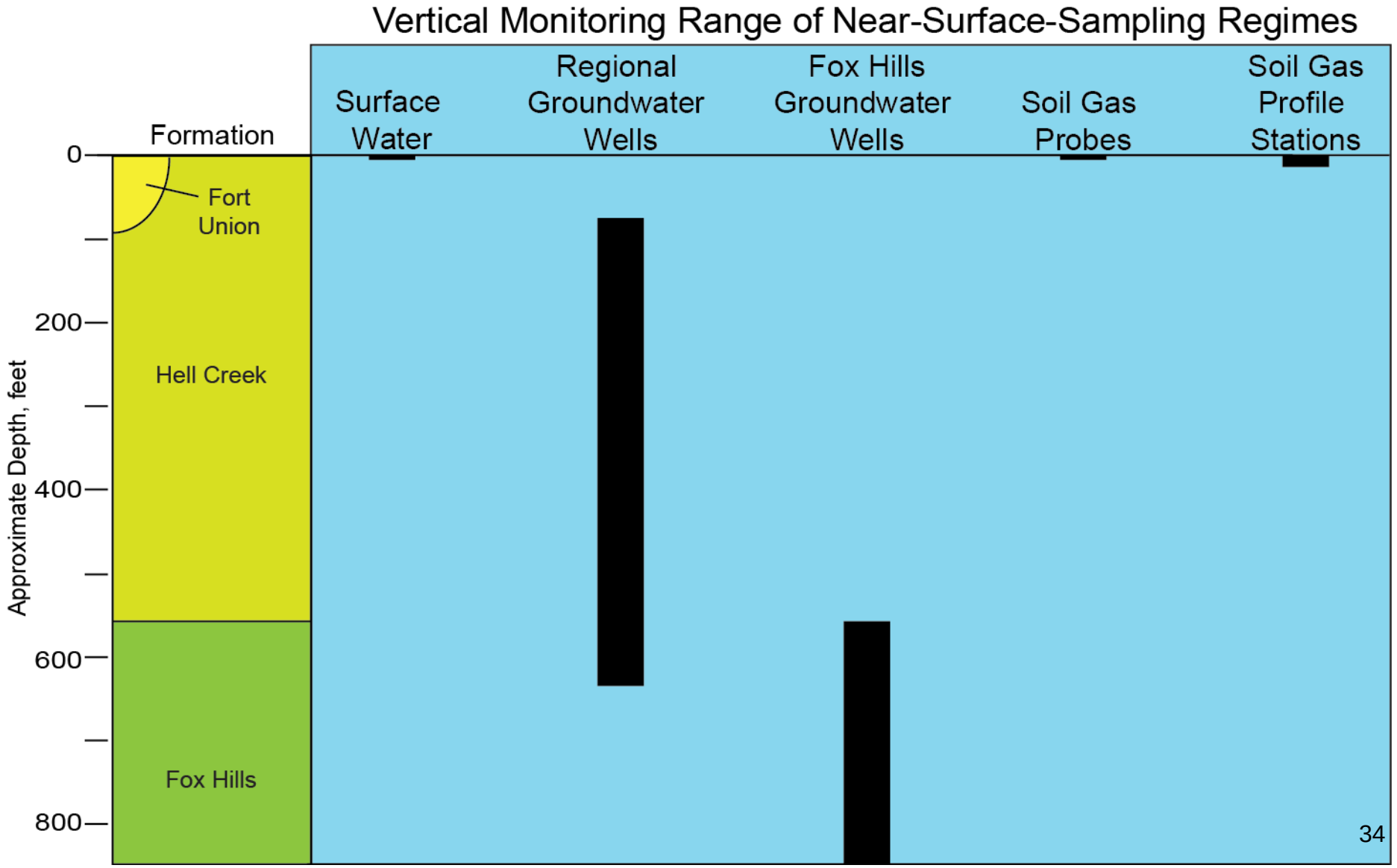
- CO_2 MVA program overlaid on a commercial EOR project:
  - Guided by site characterization, modeling, simulation, and risk assessment.
  - Compatibility with commercial project.
  - Opportunity to supplement MVA program with commercial data.
  - Focused on Phase 1 injection area.
- Two-pronged approach:
  - Surface and near-surface.
  - Reservoir.



MVA Efforts



Near-Surface MVA Coverage



Soil Gas-Monitoring Program

Soil Gas

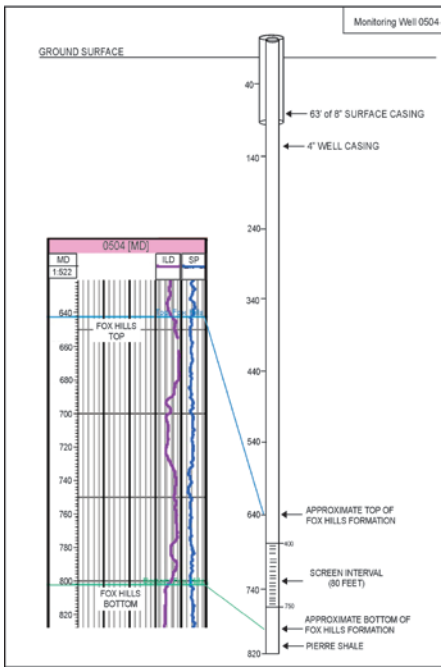
- Ten fixed-location soil gas profile stations installed in Phase 1 area.
  - Sampled monthly during injection.
- Six quarterly fieldwide sampling events (soil gas probes and profile stations) to provide preinjection baseline.
  - Full sampling annually during injection operations.

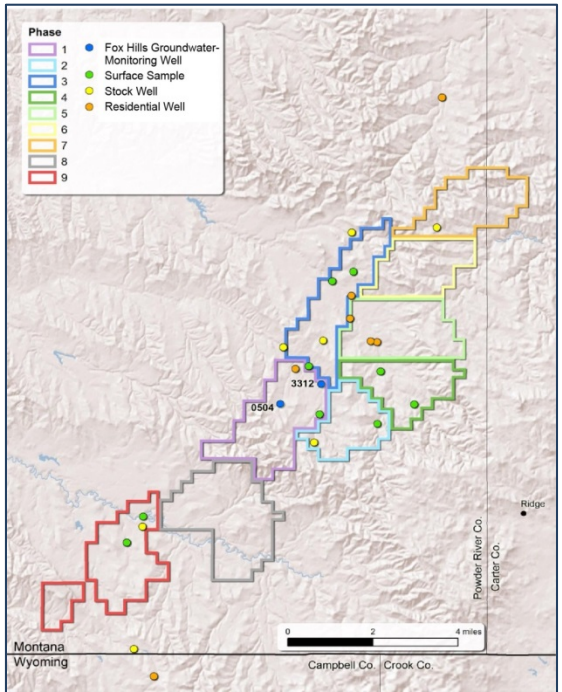
Water

- Six quarterly fieldwide baseline sampling events:
  - November 2011 – April 2013
- Annual sampling during the operational phase.

Fox Hills Groundwater-Monitoring Wells

- Two monitoring wells installed (Q1 2013).
- Drilled to the deepest underground source of drinking water (USDW) – the Fox Hills aquifer.
- Baseline sampling event with field and detailed laboratory analyses. Fox Hills drill cuttings and groundwater used in CO_2–rock exposure testing.





Water and Gas Analysis Program

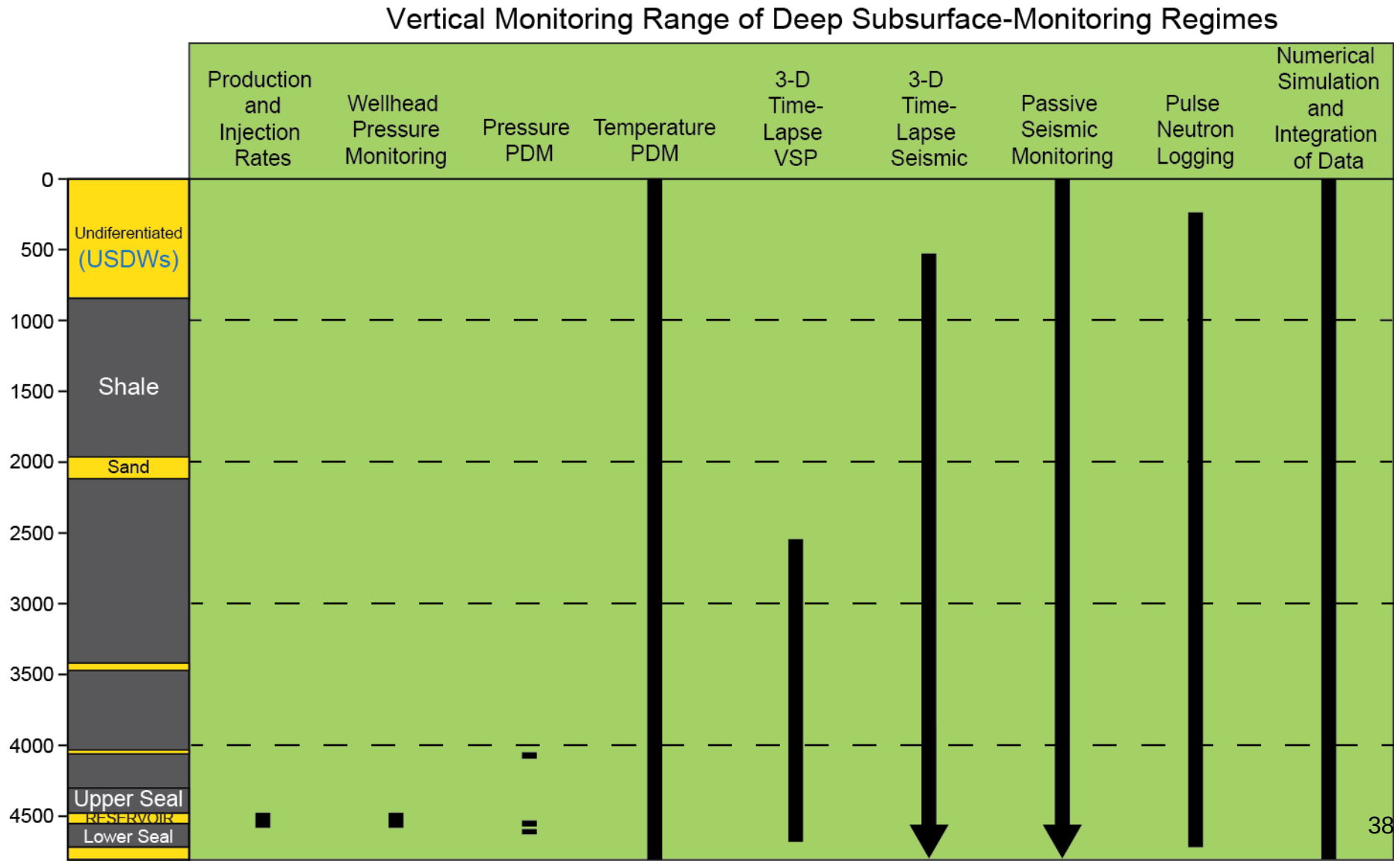
Soil Gas Analysis

- Compositional analysis (nitrogen, oxygen, methane, CO_2), including volatile organic compounds (VOCs), and isotopic signatures of CO_2 and CH_4.

Water Analysis

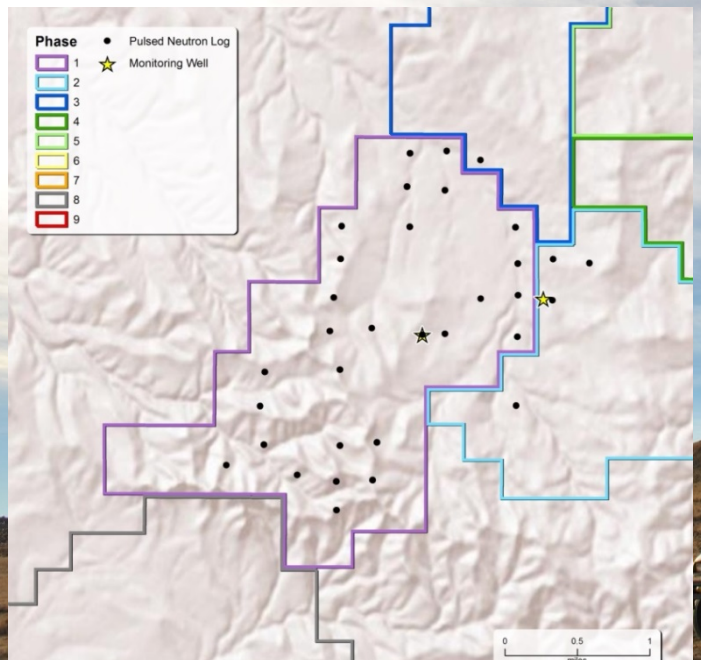
- CO_2, alkalinity, pH, major ions, metals, dissolved gases, TDS, organics, inorganics, hydrocarbons, and isotopes.

Deep MVA Coverage



PNL Monitoring

- **33 baseline logs completed (Q4 2012 – Q2 2013):**
  - **C/O (reservoir interval).**
  - **Sigma (from total depth up to 200 feet).**
- **Repeat logs at select locations based on flood performance applications**



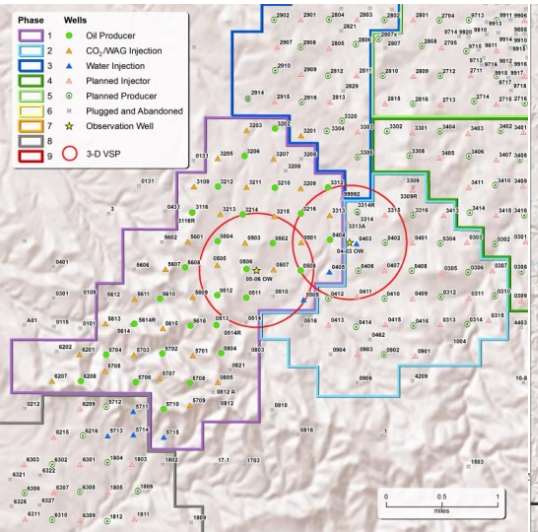
Time-Lapse Seismic

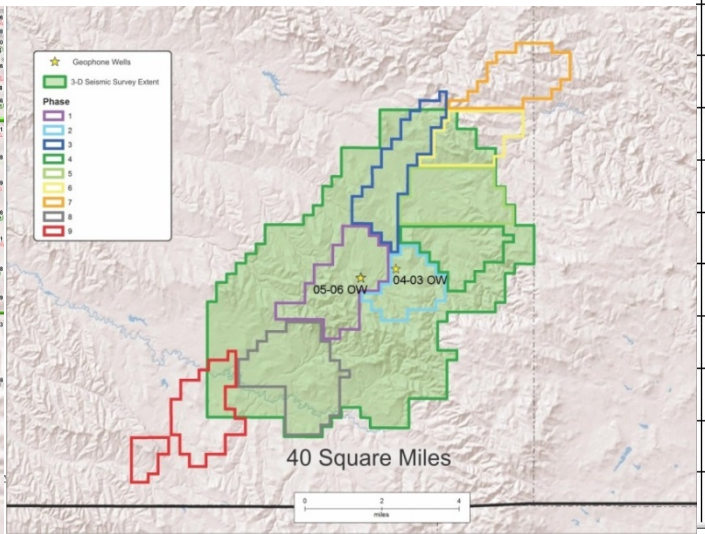
3-D VSP

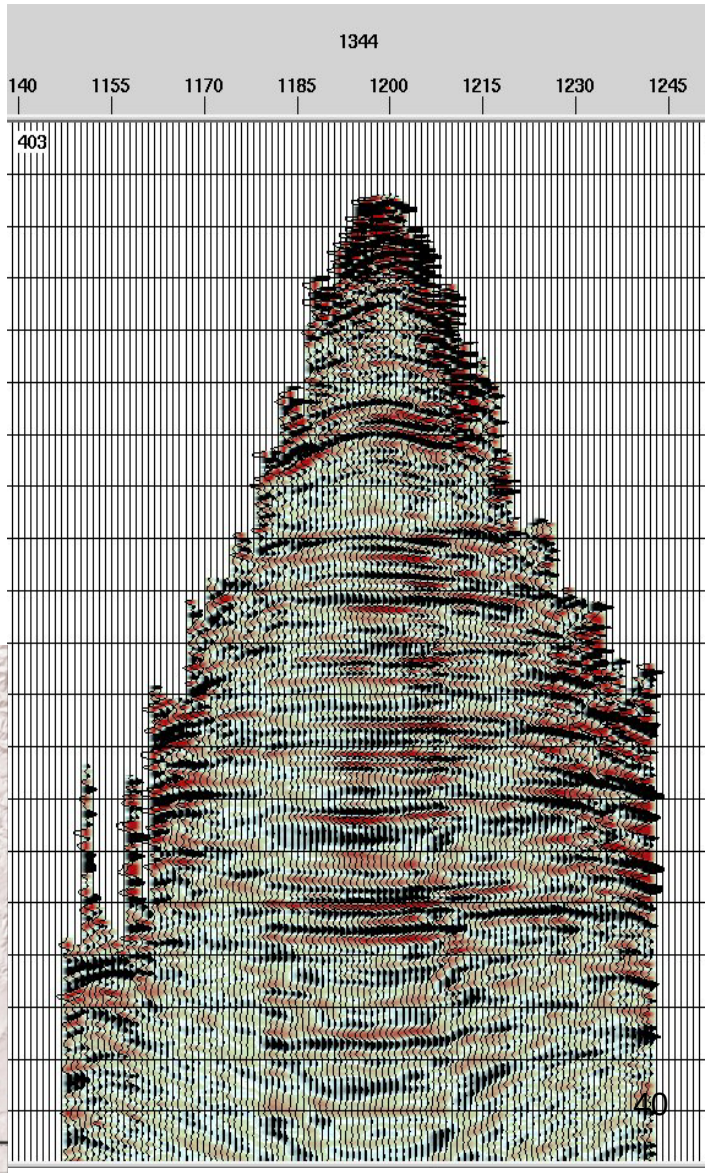
- Baseline, 50-level, three-component 3-D VSP conducted in 05-06 OW and 04-03 OW monitoring wells in May 2013.
- Repeat surveys are anticipated in 2014, depending on flood performance and acquisition restrictions.

3-D Surface Seismic

- Potential repeat based on monitoring results, CO2 breakthrough times, and injection schedule.
- **Applications**
  - Sweep/storage efficiency.
  - Lateral and vertical CO_2 migration/containment.
  - Identify distribution of heterogeneities.

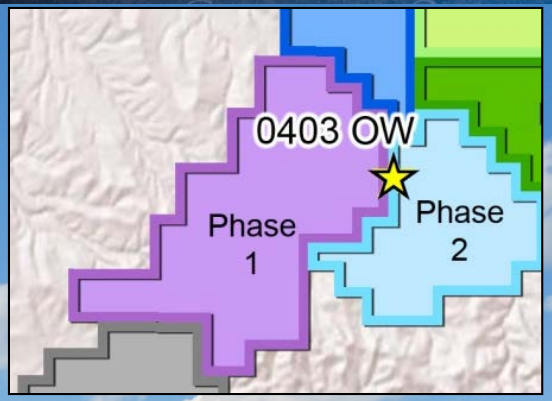


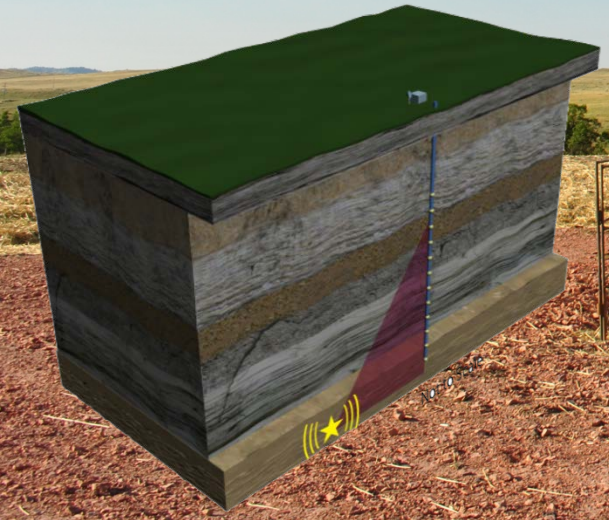




Passive Seismic Monitoring

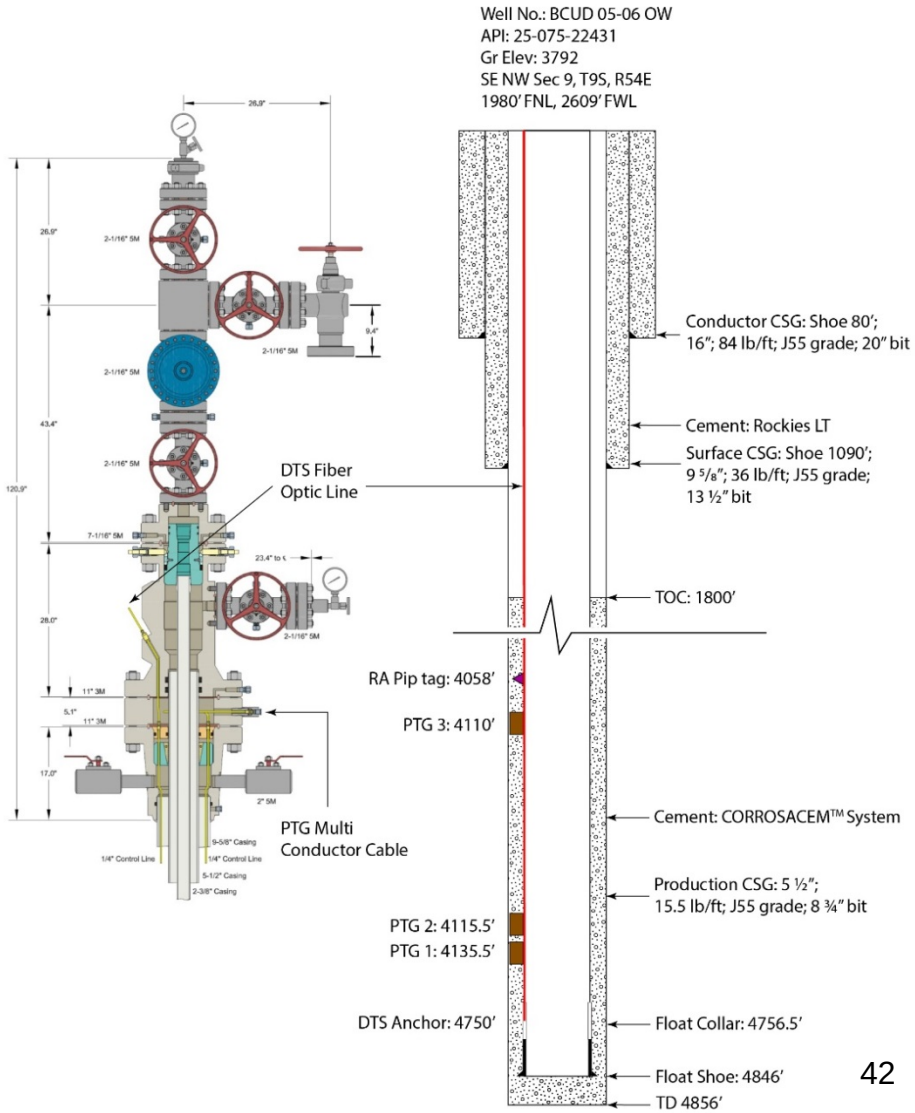
- Continuous passive seismic monitoring using geophone array in 04-03 OW.
- One year of monitoring complete.
- **Application**
  - MVA
  - Detection of microseismic events





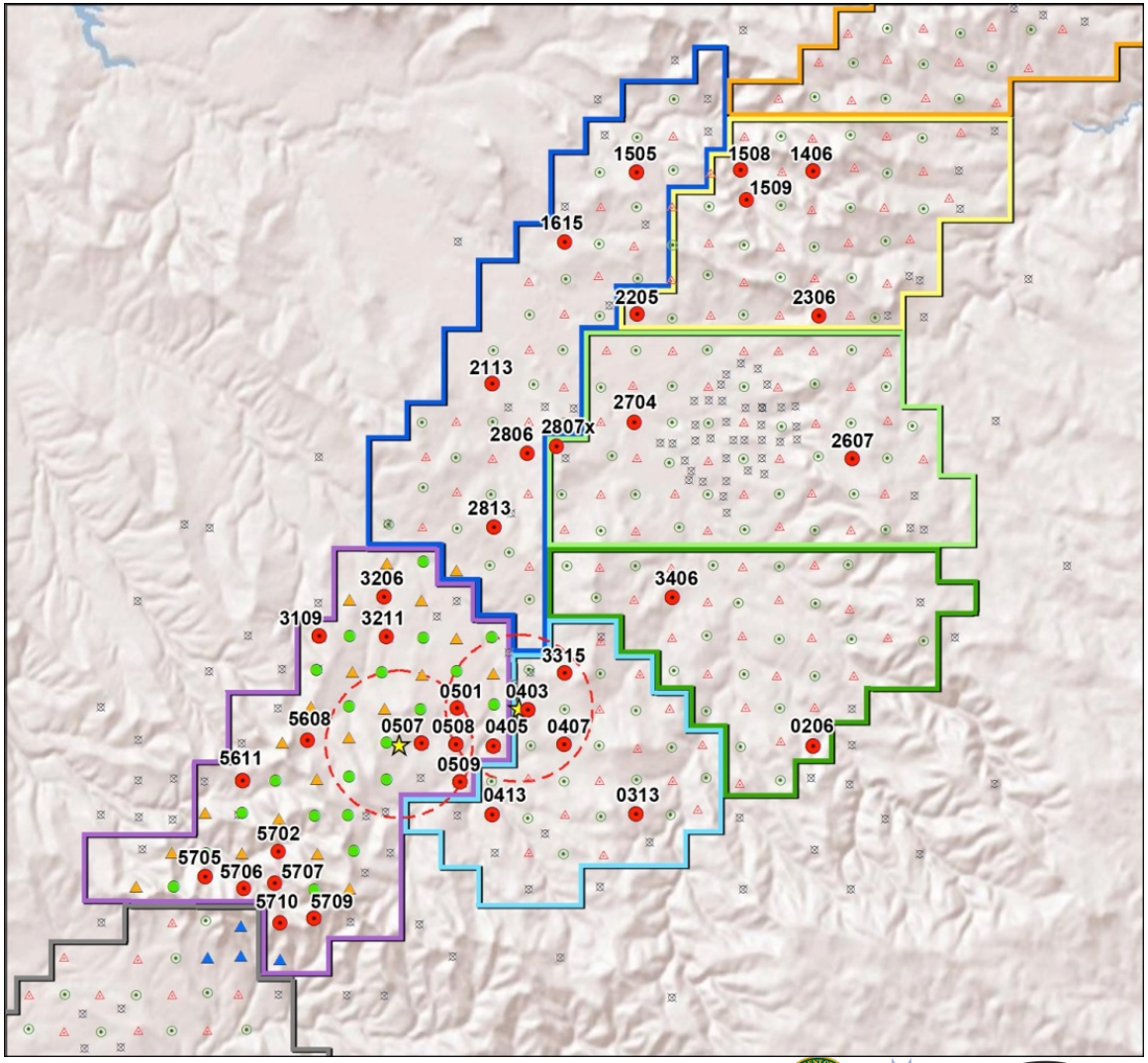
Dedicated Deep Monitoring Well (05-06 OW)

- Continuous data collection since April 2012
- Three downhole pressure/temperature gauges:
  - BC30 (4535.5 feet)
  - BC10 (4515.5 feet)
  - Belle Fourche (4110 feet)
- Fiber optic distributed-temperature system:
  - 1-meter interval



Bottom Hole Pressure (BHP) Surveys

- One hundred sixty-nine BHP survey data points collected from 15 baseline sampling months: April 2010 – May 2013.
- Supplied periodically by commercial EOR operator at 36 unique well locations throughout the field.



Wellhead Injection and Production Data

- Supplied by commercial EOR operator (452 well locations throughout the field).
  - Pressures recorded continuously.
  - Production data tested monthly.
  - Injection rates metered.

MVA Wrap-Up

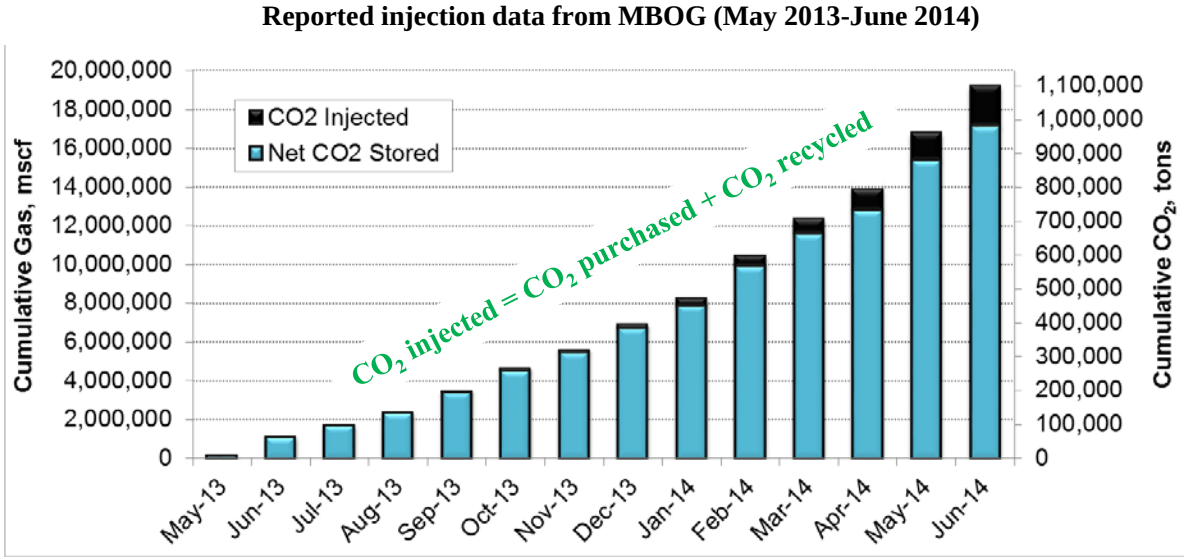
Identify level of monitoring needed to ensure safety, meet regulatory requirements, and provide insurance of project liability and/or identify areas of development needed to meet these goals.

Effectively monitor movement of injected CO_2 and reservoir fluids to evaluate storage efficiency, demonstrate safe and effective storage, identify fluid migration pathways, and determine the fate of injected CO_2.

Utilize economical technologies which provide high value to both the CO_2 storage and EOR components of the project where possible and have minimal impact to commercial EOR operations.

Field Observations and Initial Monitoring Results

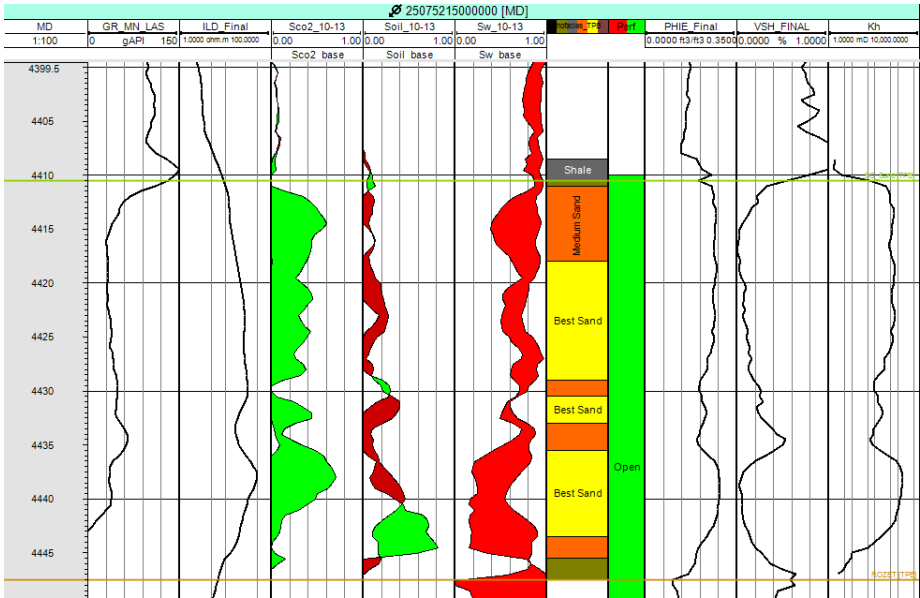
- CO_2 breakthrough in the field occurred after about 3–4 months.
- Injected and retained (stored) CO_2 roughly matches predictions after 1 year of injection.
- Work is under way to evaluate how well observed CO_2 saturations from PNL repeats match-predicted saturations at both injectors and producers.



Saturation Indicator

Increase

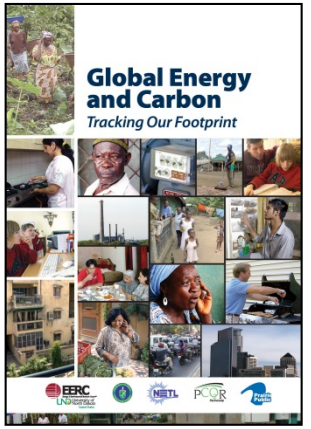
Decrease

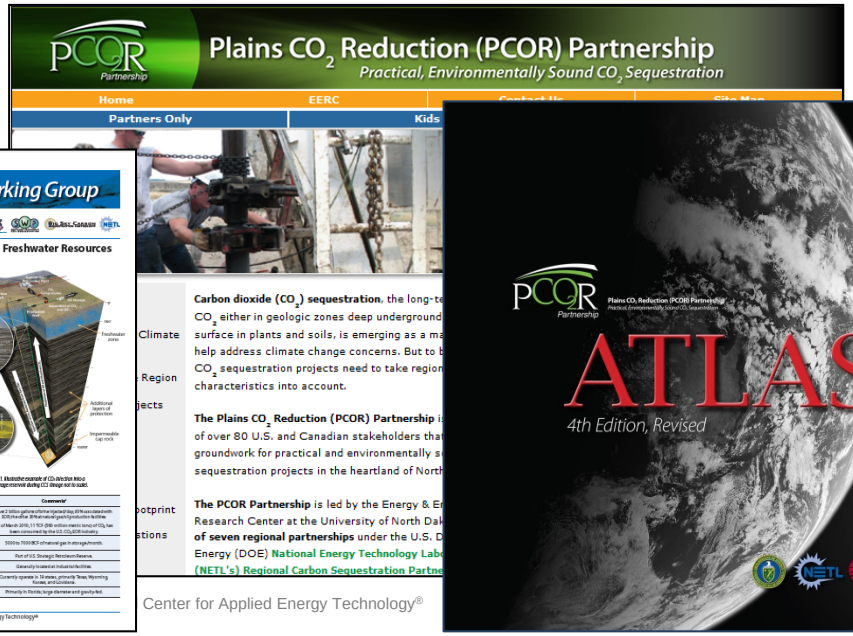


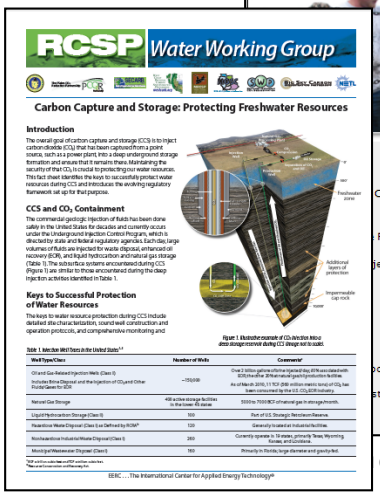
PCOR Partnership Outreach Materials

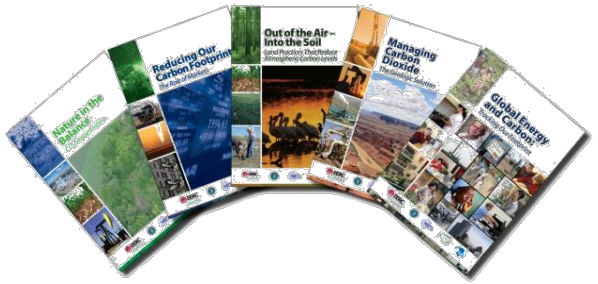
- Regional CO_2 sequestration atlas
- Fact sheets on key topics and projects
- Public Web site with downloadable materials
- CCS documentaries (public television broadcasts, Web streaming, and DVDs)
- Video clips
- Numerous technical reports

2012 Platinum Best of Show Aurora Award!









Overall Accomplishments and Key Findings

- **An adaptive management approach to MVA has been developed.**
- **Detailed site characterization is the critical basis for any effective CO_2 storage project and MVA program.**
- **Storage resource estimates indicate that 25 billion tons of CO_2 could be stored through CO_2-based EOR in projects like Bell Creek in the PCOR Partnership region alone.**

Lessons Learned

- Keys to success
  - Integrated approach to MVA, risk assessment, characterization, modeling, and simulation.
  - Public engagement and landowner relations.
  - Adequate planning and contingency plans during drilling and monitoring operations.
  - Communication:
    - Providing clear objectives to service providers and stakeholders.

Thank You!