Bell Creek MVA Overview

CSLF CO_2 Monitoring Interactive Workshop

Rome, Italy
April 18, 2013

Edward N. Steadman

Energy & Environmental Research Center (EERC)…
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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

Plains CO_2 Reduction (PCOR) Partnership

Partnership

11/12

PCOR Partnership Perspectives

Philosophy

- Compatible with commercial operations
- Cost-effective/value-added
- Minimal interference with commercial operations
- Cognizant of public perception
- Scientifically defensible
- Address project risks
- Targeted
- Effective
  - Proven or high-potential/value technologies
  - Relevant
  - Site-specific

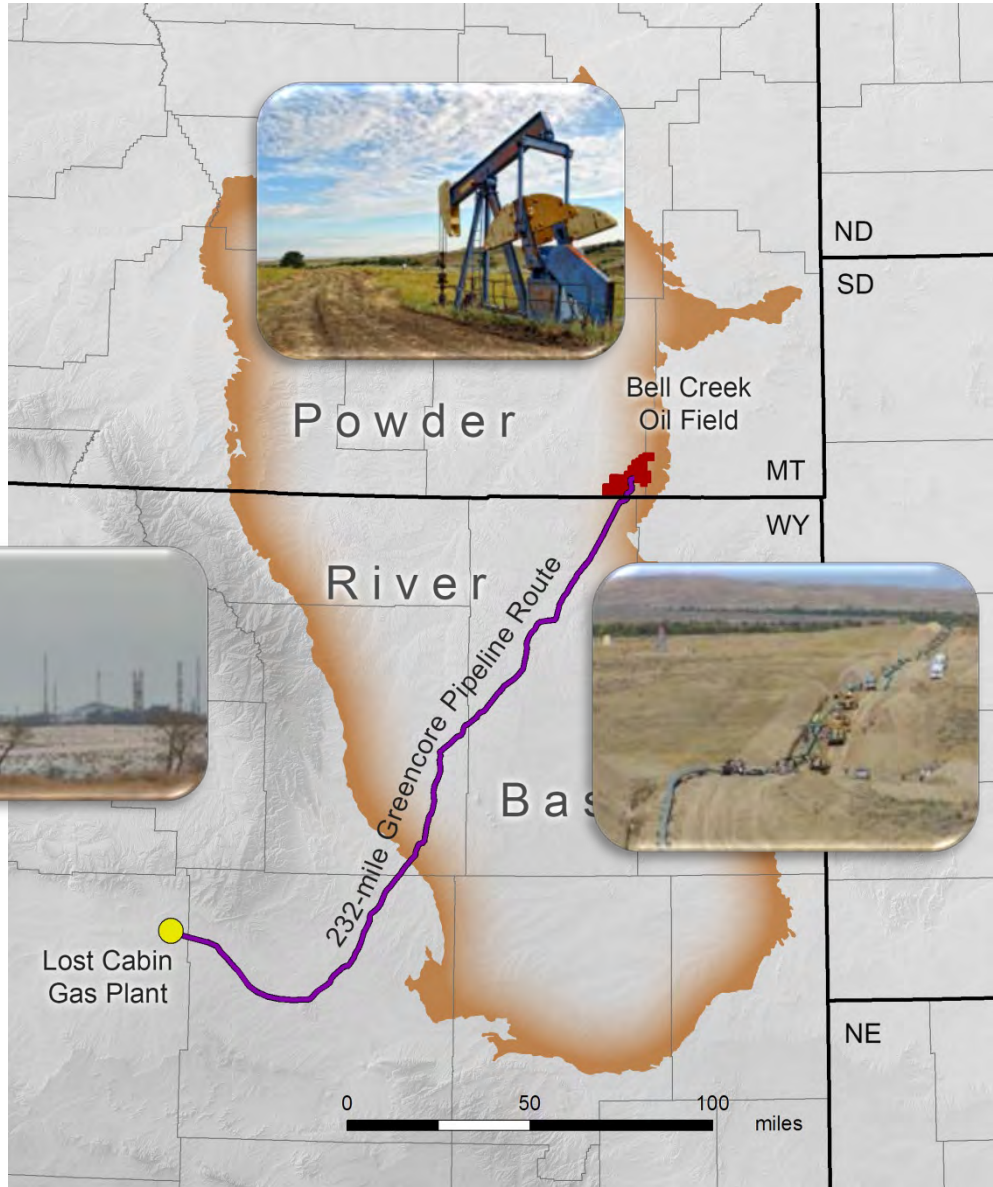
PCOR Partnership Perspectives (continued)

Demonstrate

- Carbon dioxide (CO_2) storage can be safely and permanently achieved on a commercial scale in conjunction with enhanced oil recovery (EOR).
- Oil-bearing sandstone formations are viable sinks with significant storage capacity to help meet near-term U.S. objectives.
- Monitoring, verification, and accounting (MVA) methods can be established to safely and effectively monitor commercial-scale simultaneous CO_2 EOR and CO_2 storage projects.
- Provide a technical framework for accounting of CO_2.
- Lessons learned can benefit similar projects across the region.
- Establish relationship between the CO_2 EOR process and long-term storage of CO_2.

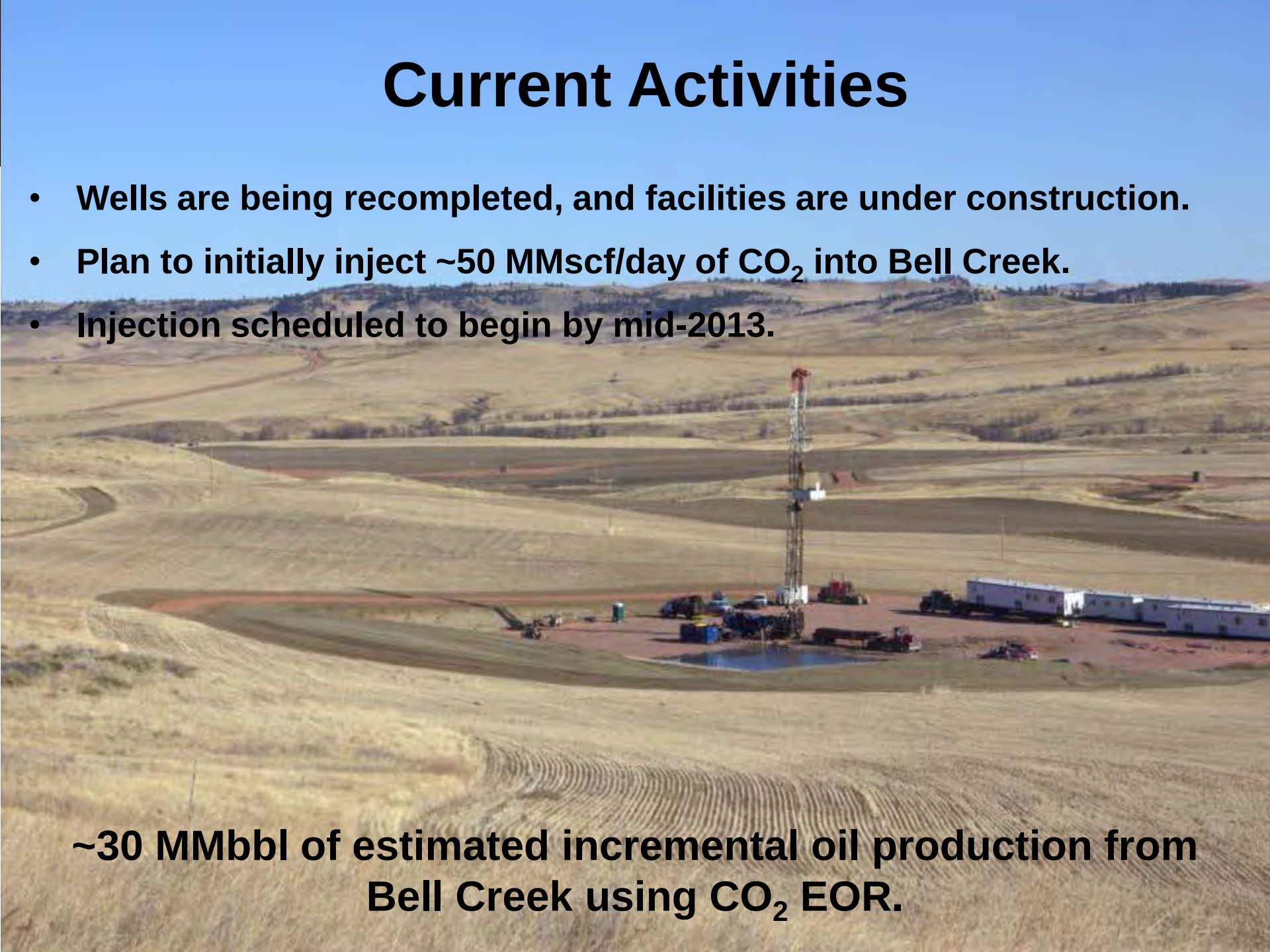
Bell Creek CO_2 EOR and Potential Storage Project

- Bell Creek oil field is owned and operated by Denbury Resources Inc. (Denbury).
- CO_2 is sourced from ConocoPhillips' Lost Cabin natural gas-processing plant.



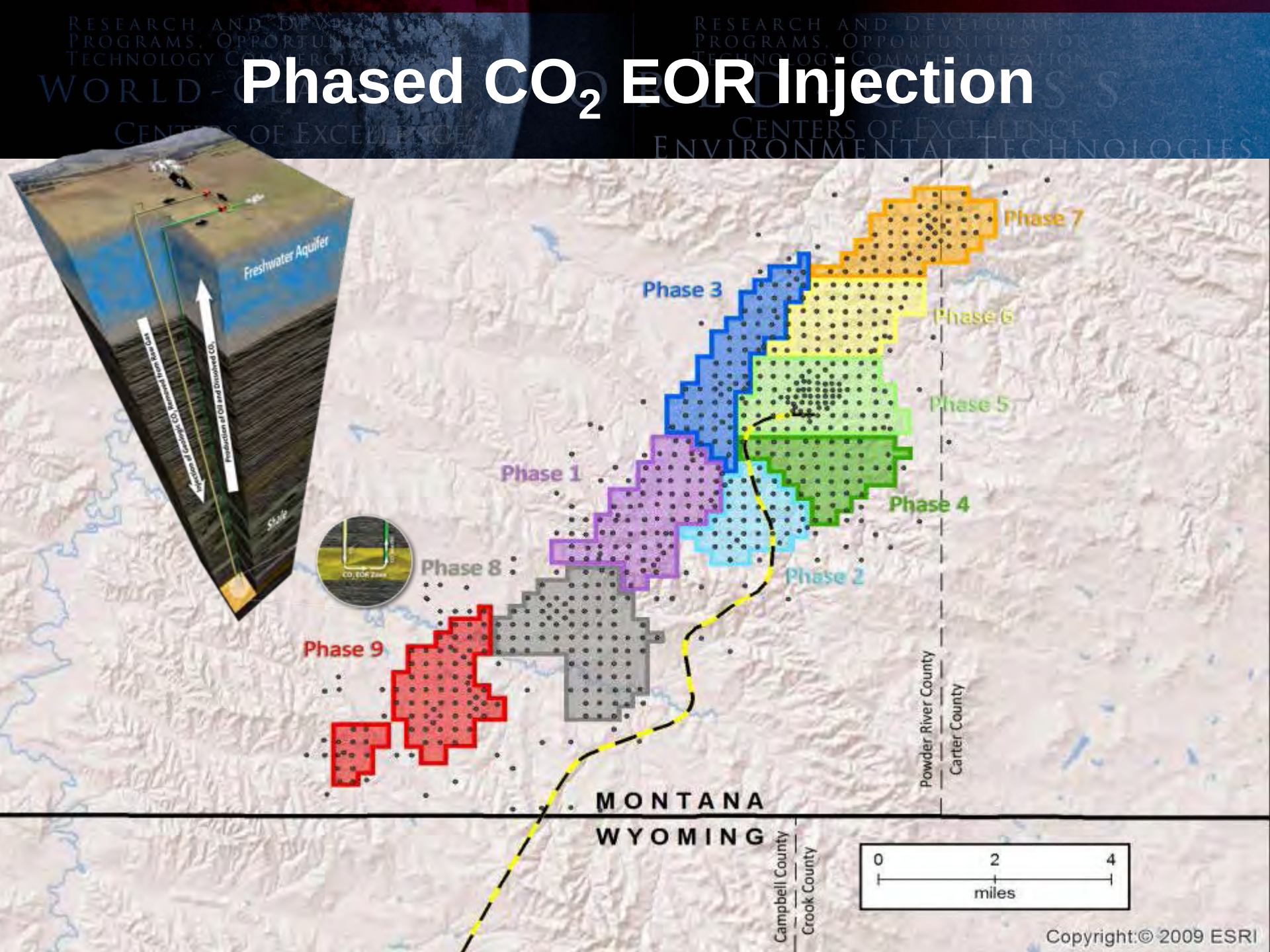
Current Activities

- Wells are being recompleted, and facilities are under construction.
- Plan to initially inject ~50 MMscf/day of CO_2 into Bell Creek.
- Injection scheduled to begin by mid-2013.



~30 MMbbl of estimated incremental oil production from Bell Creek using CO_2 EOR.

Phased CO_2 EOR Injection



PCOR Partnership Activities at Bell Creek

- Developing an integrated approach to MVA.
- Focused on site characterization, modeling and simulation, and risk assessment as a guide for developing an MVA strategy.

Site Characterization

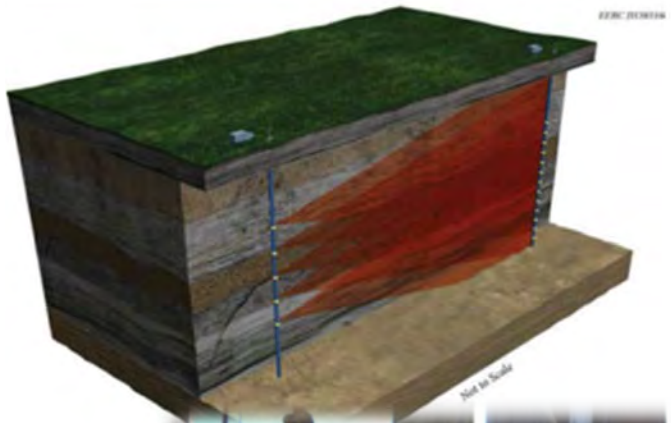
- Outcrop
- Core libraries (U.S. Geological Survey and Bureau of Economic Geology)
- Historic data (well files)
- LIDAR
- Dedicated data collection and monitoring well (05-06 OW) (December 2011)
  - Well log collection and analysis
  - Core collection and analysis
  - Downhole pressure and temperature sensors
- Baseline 3-D surface seismic survey (summer 2012)
- Two dedicated groundwater-monitoring wells (winter 2012–2013)
- 27 pulsed neutron logs (PNLs) (winter 2012–2013)
- Collected cores from two wells in Phases 1 and 2 (March 2013)
- Dedicated geophone well (spring 2013)
- Two Baseline 3-D vertical seismic profiles (VSPs) (spring 2013)

Site Characterization (continued)

- The Muddy sandstone (only producing reservoir):
  - Depth = 4300–4650 ft
  - Gross thickness = 30–45 ft (net 15–25 ft)
  - Normal permeability range = 100–1000 mD
  - High porosity = 25%–35% (loosely consolidated)
  - Oil gravity = 32 –41 API

Bell Creek MVA Program Goals

- Demonstrate CO_2 storage can be safely and permanently achieved on a commercial scale in conjunction with an EOR project.
- MVA methods can be established to effectively monitor a commercial-scale EOR CO_2 storage project.
  - Baseline data acquisition
    - Establish preinjection conditions
  - Verify site security
  - Track movement of CO_2
    - Update risk assessment and simulation results
    - Identify fluid migration pathways
    - Evaluate containment
  - Establish relationship between the CO_2 EOR process and long-term storage of CO_2
  - Determine ultimate fate of CO_2

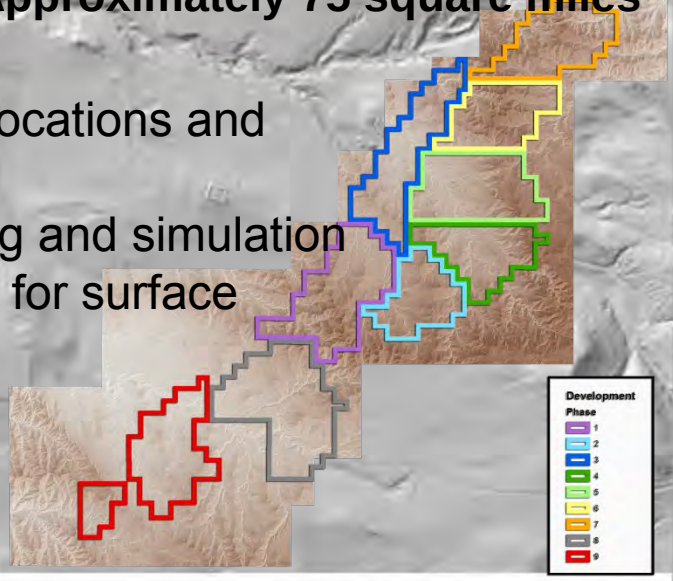


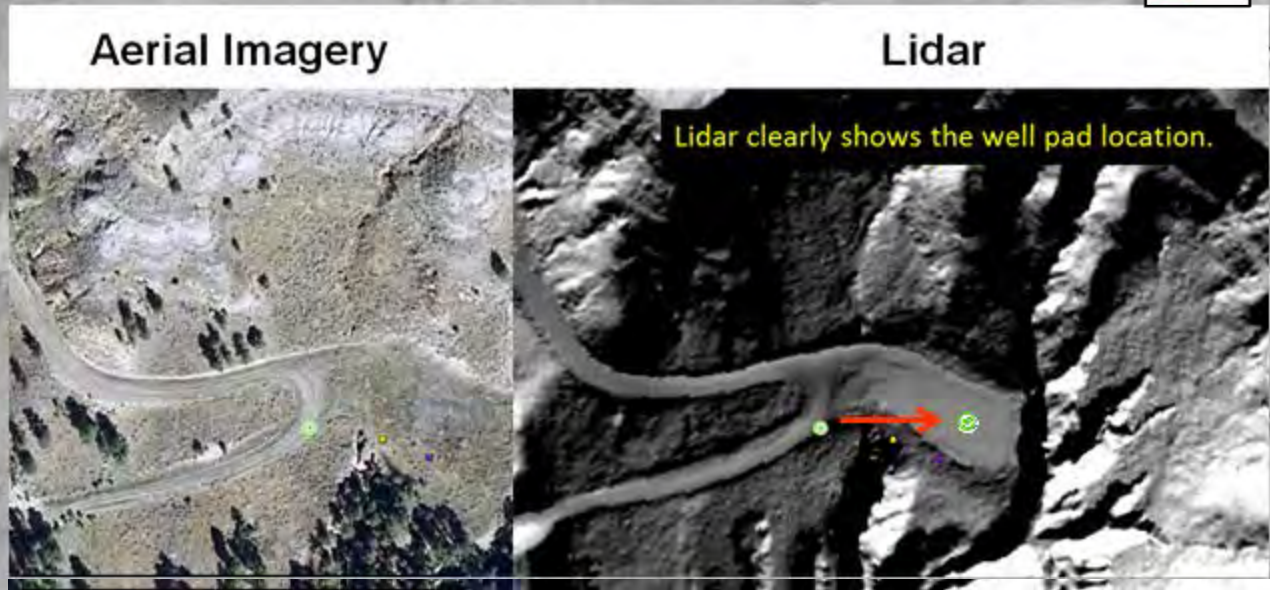
LIDAR

Area covered by LIDAR: Approximately 75 square miles

Objective

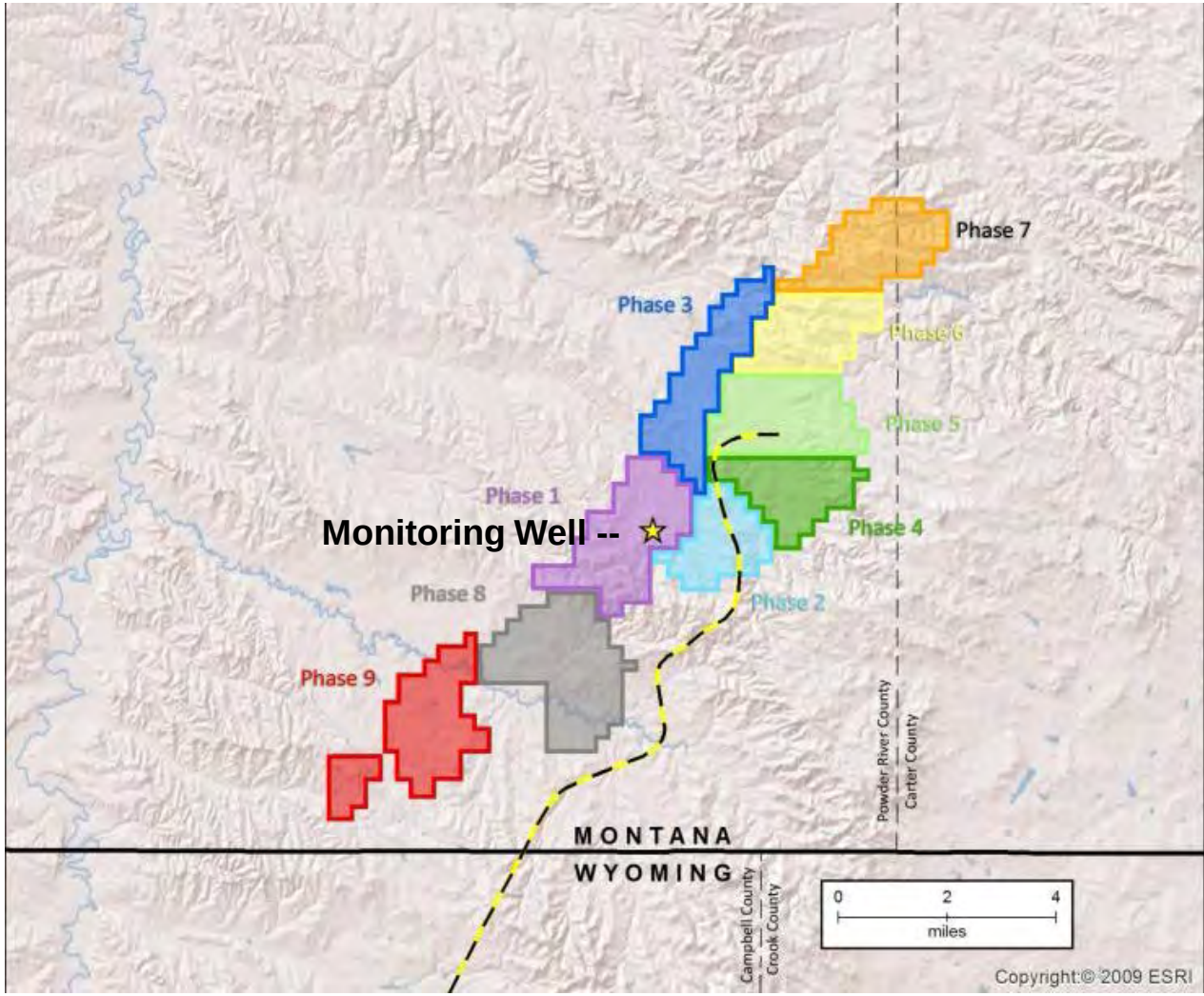
- Precisely place well locations and elevations
  - Geologic modeling and simulation
  - Locate wellheads for surface monitoring





Monitoring and Characterization Well

- Goals
  - Characterization data
  - Correct historic data
  - Increase confidence in fluid movement predictions
  - In situ pressures and temperatures
  - Identify out-of-zone fluid migration
  - Provide monitoring point that is unobtrusive to oil field operations



Surface and Near-Surface MVA Program

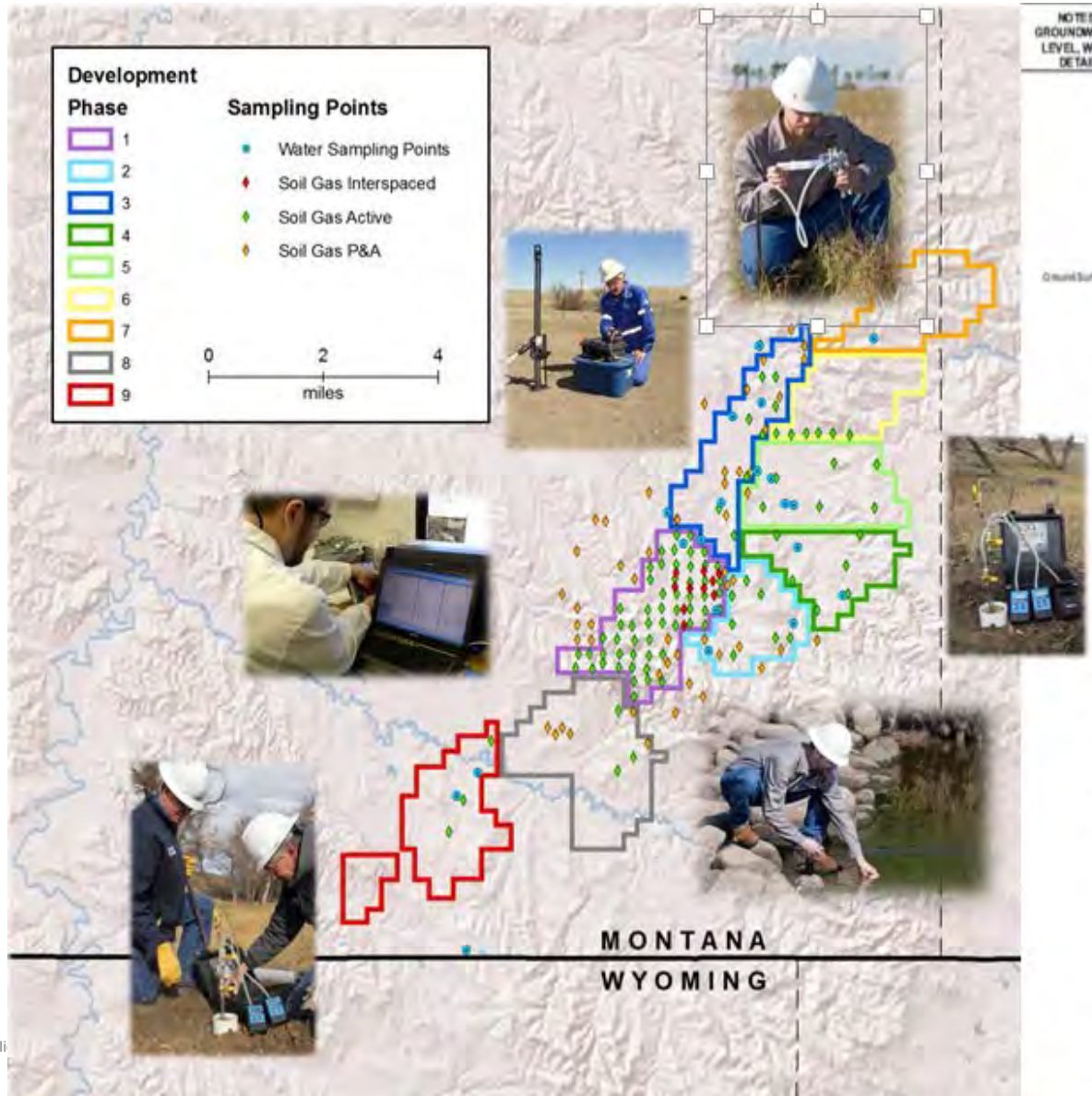
- Objectives
  - Verify site security
  - Identify and understand preinjection and postinjection anomalies
  - Update risk assessment based on monitoring data

- Surface and near-surface monitoring program:
  - Soil gas
    - ♦ P&A (plugged and abandoned) wells
    - ♦ Active injection and production wells
    - ♦ Interspaced samples
  - Water
    - ♦ Residential wells
    - ♦ Stock wells
    - ♦ Surface waters

Surface and Near-Surface MVA Program (continued)

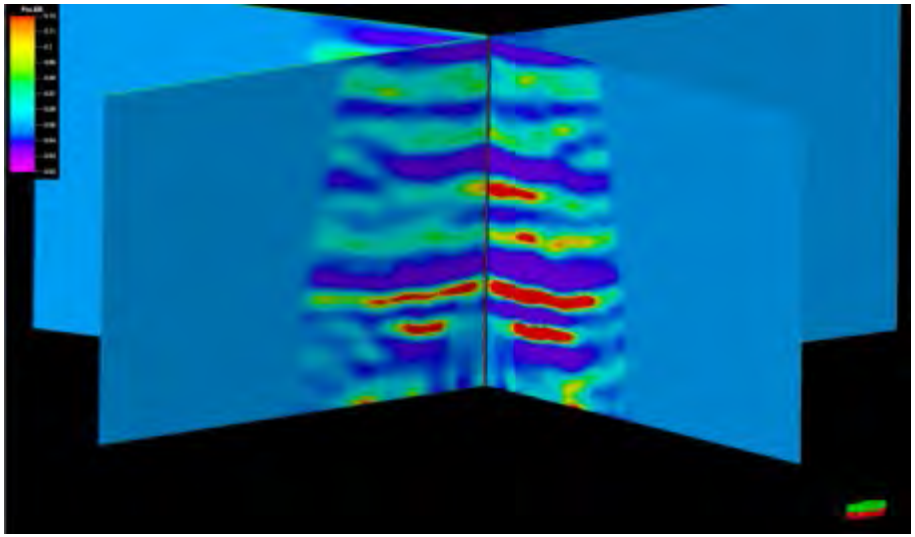
- 1-year baseline data set (November 2011 – November 2012)
  - Seasonal soil gas, groundwater, and surface water chemistry variations over range of microenvironments
- Identify and understand anomalies and verify site security:
  - Natural biological processes
  - Seasonal variations
  - Agricultural practices
  - Migration from depth

Provide scientifically defensible evidence to confirm or refute environmental impact claims.



Reservoir MVA Program

- Objectives
  - Verify site security
  - Establish preinjection reservoir and subsurface conditions
  - Update risk assessment based on monitoring data
  - Track movement of CO_2 and subsurface fluid migration
  - Establish relationship between the CO_2 EOR process and long-term storage of CO_2
  - Input for simulation
- Reservoir-monitoring program:
  - Continuous
    - Wellhead and bottomhole pressures (BHPs)
    - Permanent downhole monitoring equipment
  - Periodic
    - Seismic
    - Well logs
    - Pressure surveys
    - Tracer analysis (?)

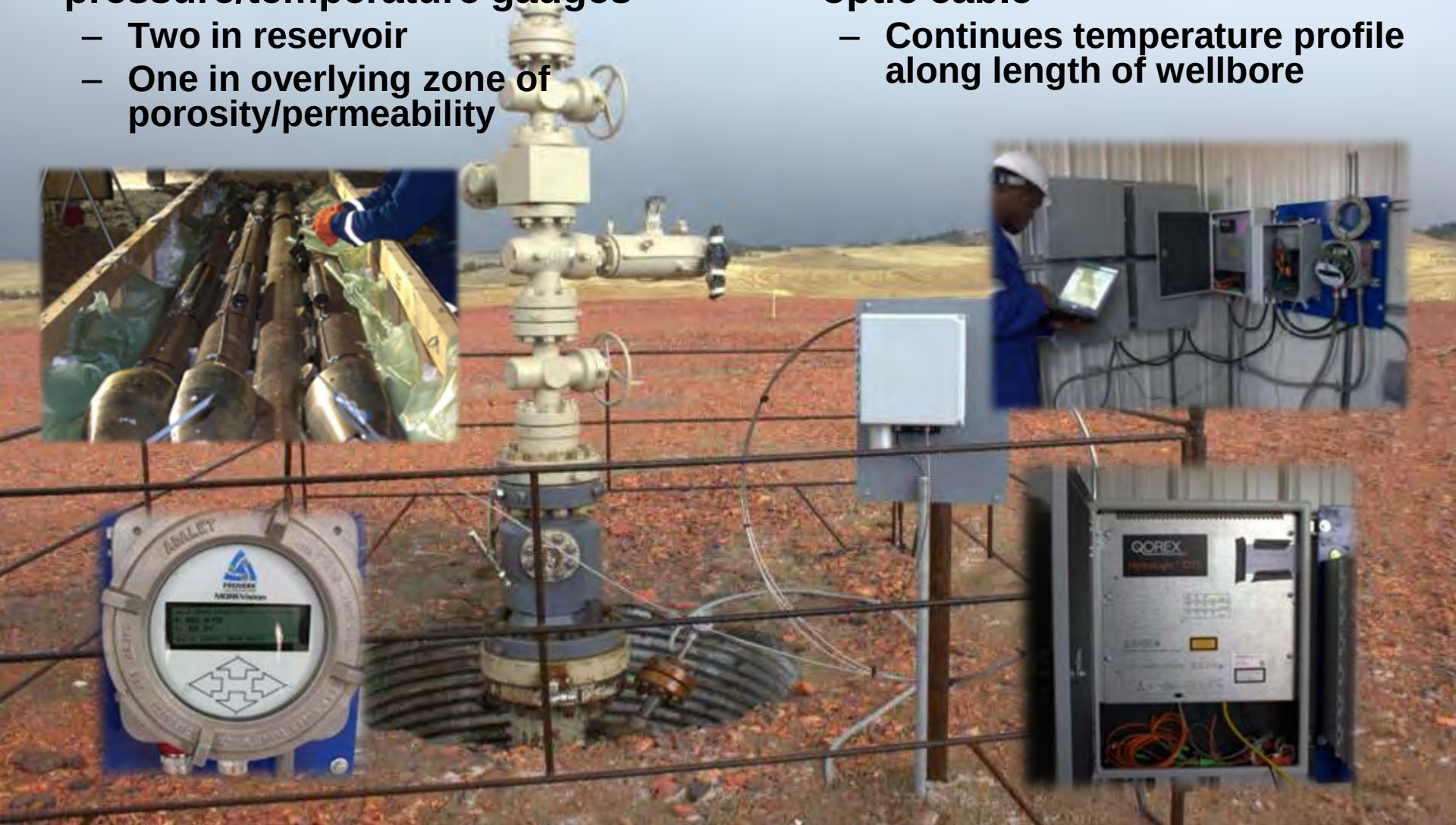


Reservoir MVA Program (continued)

- Utilize existing infrastructure (commercial EOR project)
- Active wells outfitted with real-time sensors:
  - Surface and production casing pressure
  - Flowline and tubing pressure
  - Production tests and flow logs

Monitoring and Characterization Well Real-Time Data

- **Three casing-conveyed pressure/temperature gauges**
  - **Two in reservoir**
  - **One in overlying zone of porosity/permeability**
- **Distributed-temperature fiber optic cable**
  - **Continues temperature profile along length of wellbore**

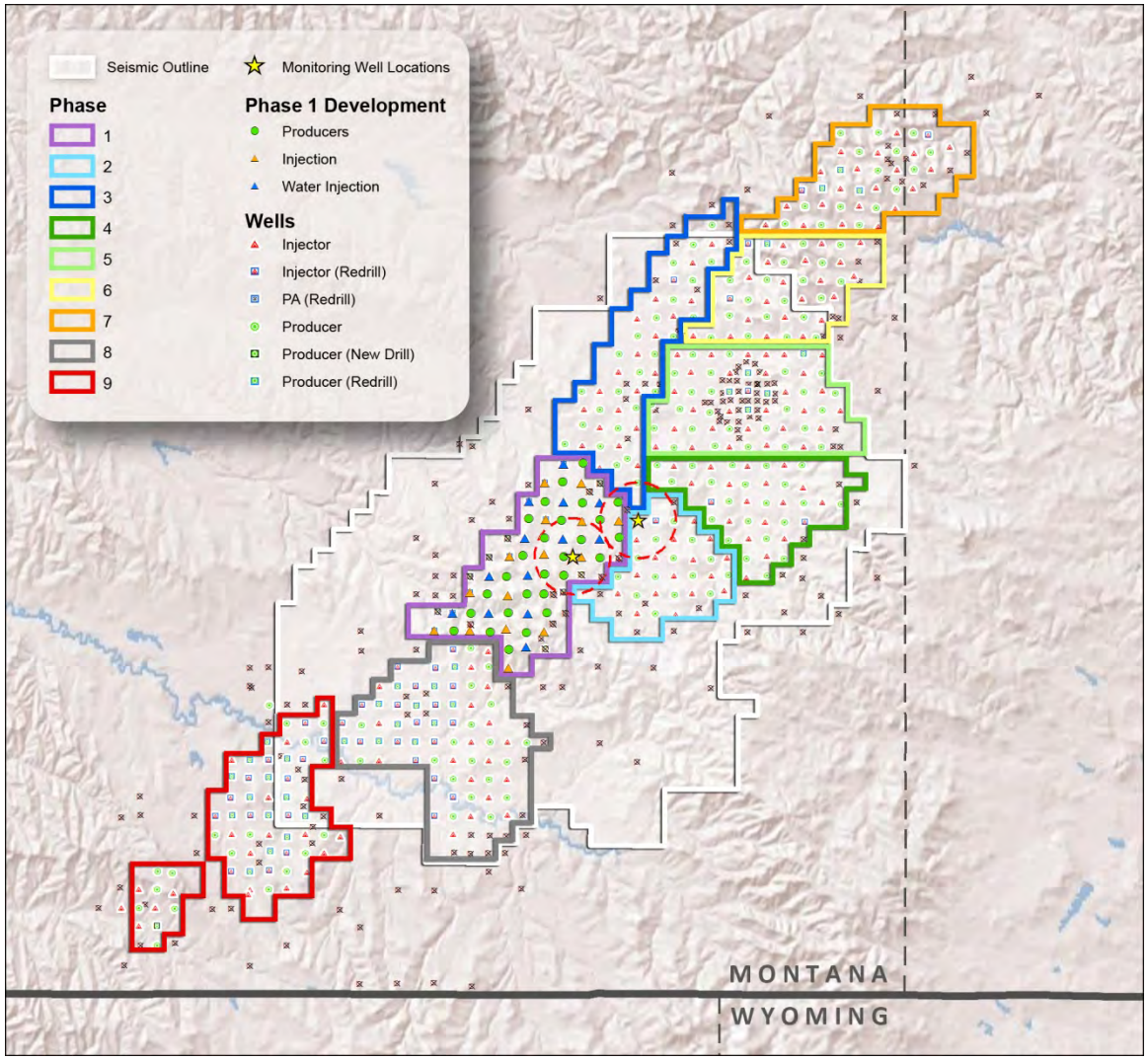


Seismic

- Assist with updip/downdip boundaries and reservoir structure.
- Provide baseline data for time-lapse seismic plume tracking.
  - Check shot and seismic source testing completed November 2011.
  - 40-mile^2 3-D baseline survey completed summer 2012.
  - Two 3-D 50-level VSP surveys spring 2013:
    - 05-06 OW (deployable array)
    - 33-14 OW (permanent array)

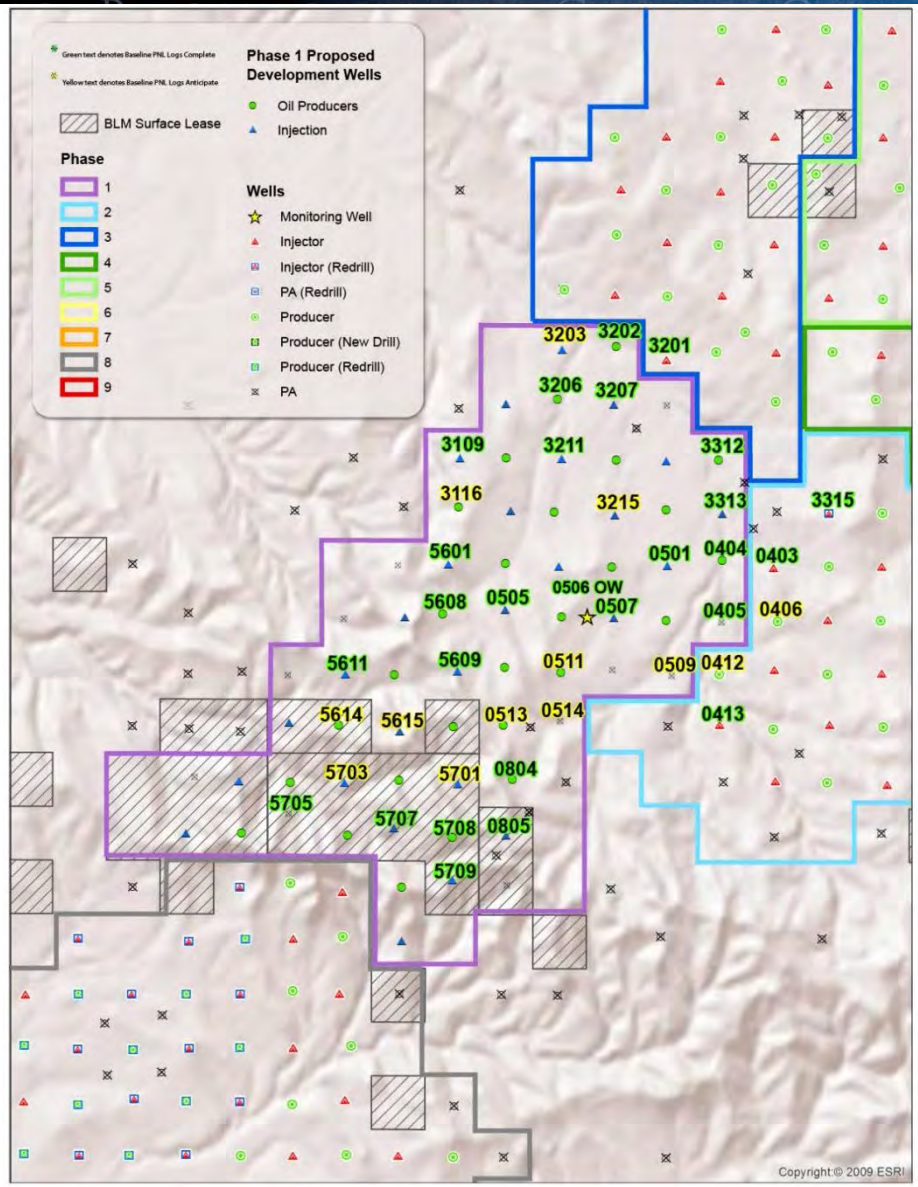
Time-Lapse Seismic

- Time-lapse 3-D surface seismic
  - Characterization
  - Lateral flow patterns
  - Pattern evaluation
- Time-lapse 3-D VSP
  - Evaluation of pattern
  - Channeling/lateral flow boundaries
  - Sweep
  - Correlation of PNLs
  - 3-D surface seismic calibration



PNLs

- Sigma mode from total depth (TD) to 200 ft
  - Fluid–gas saturations
- Carbon/oxygen mode over reservoir
  - Water–oil–CO_2 saturation
- Baseline and repeat(s)
  - Time-lapse CO_2 saturations changes (near-wellbore environment)
  - Porosity and gamma ray data from TD to surface (characterization)
- Completed baseline PNLs in 27 wells surrounding active injection area (Phase 1) in January 2013
  - Potential to log up to 13 additional wells prior to injection (pending availability)



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.

Summary

The PCOR Partnership is working closely with Denbury on an integrated approach to characterization, modeling, risk assessment, and MVA to evaluate the technical and economic viability of safe, long-term CO_2 storage in conjunction with a commercial EOR project.

- Plan to start injection of ~50 MMscf/day of CO_2 into Bell Creek by mid-2013.
- An estimated 30 million incremental bbl of oil will be recovered using CO_2 EOR at Bell Creek while permanently storing millions of tons of CO_2.

Contact Information

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

World Wide Web: **www.undeerc.org**
Telephone No. (701) 777-5279
Fax No. (701) 777-5181

Edward Steadman, Deputy Associate Director for Research
esteadman@undeerc.org

Field History

- **Discovered in 1967 (21,771 acres)**
- **Developed within 2 years (450+ wells)**
- **Primary production (solution gas drive), waterflooding, and two micellar polymer pilot tests**
- **Stock tank original oil in place (STOOIP) ~350 million barrels of oil (MMbo)**
- **Cumulative production 133 MMbo (~38% recovery)**