



# THE PLAINS CO<sub>2</sub> REDUCTION PARTNERSHIP: CO<sub>2</sub> INJECTION UPDATE AND RESULTS OF ADAPTIVE MANAGEMENT APPROACH

SCCS Annual Workshop 2017

Stanford University

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Since 2003

- Nine U.S. states
- Four Canadian provinces
- 120+ partners and growing
- Regional expertise/global applications
- Demonstrating carbon capture and storage (CCS)



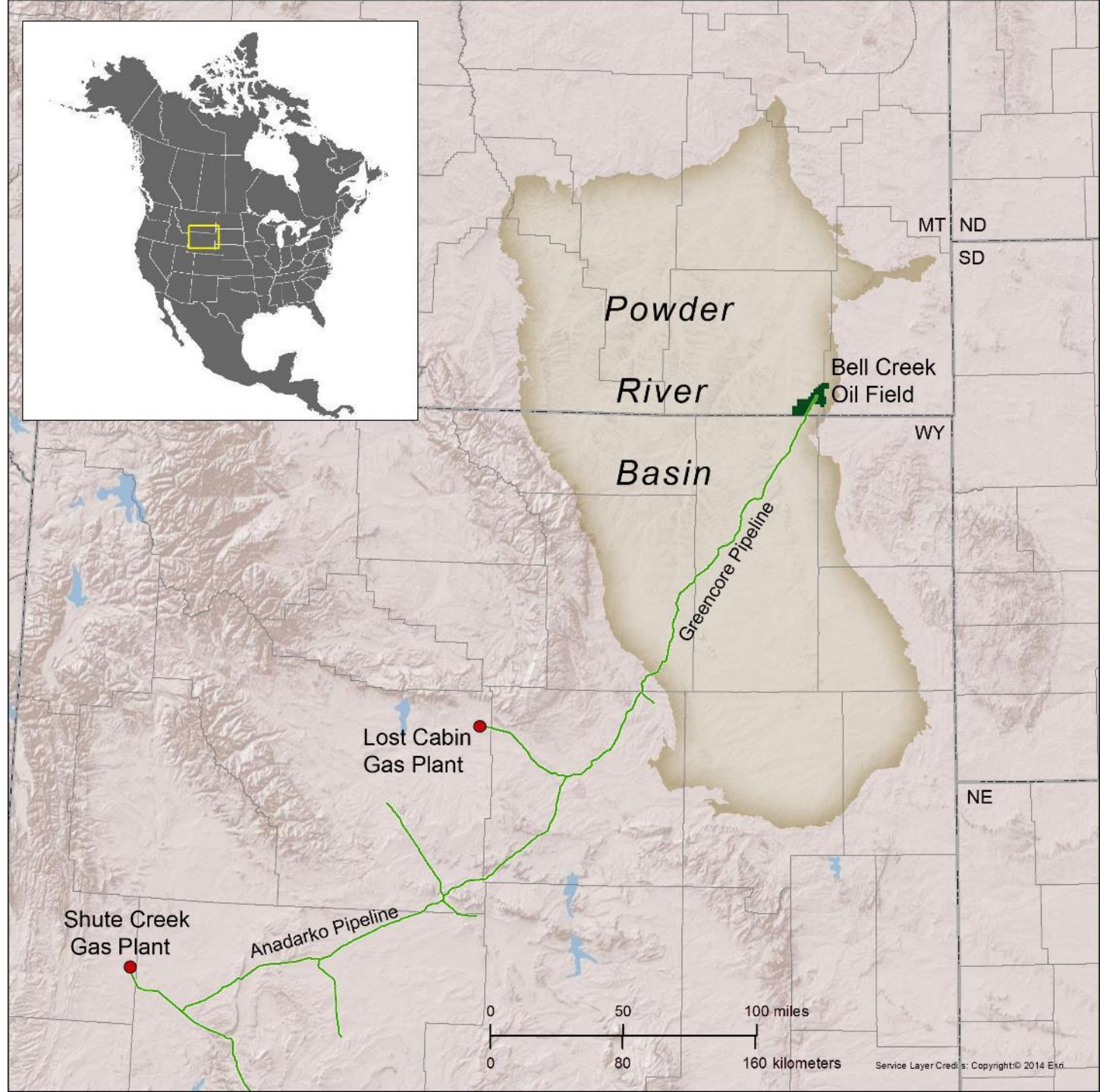
# PCOR PARTNERSHIP OBJECTIVES

- Safely and permanently achieve CO<sub>2</sub> storage on a commercial scale.
- Establish a relationship between the CO<sub>2</sub> enhanced oil recovery (EOR) process and long-term storage of CO<sub>2</sub>.
- Establish monitoring, verification, and accounting (MVA) methods to effectively monitor CO<sub>2</sub> storage.
- Use commercial oil/gas practices as the backbone of MVA strategies, and augment with additional cost-effective techniques.
- Share lessons learned for the benefit of similar projects across the region.



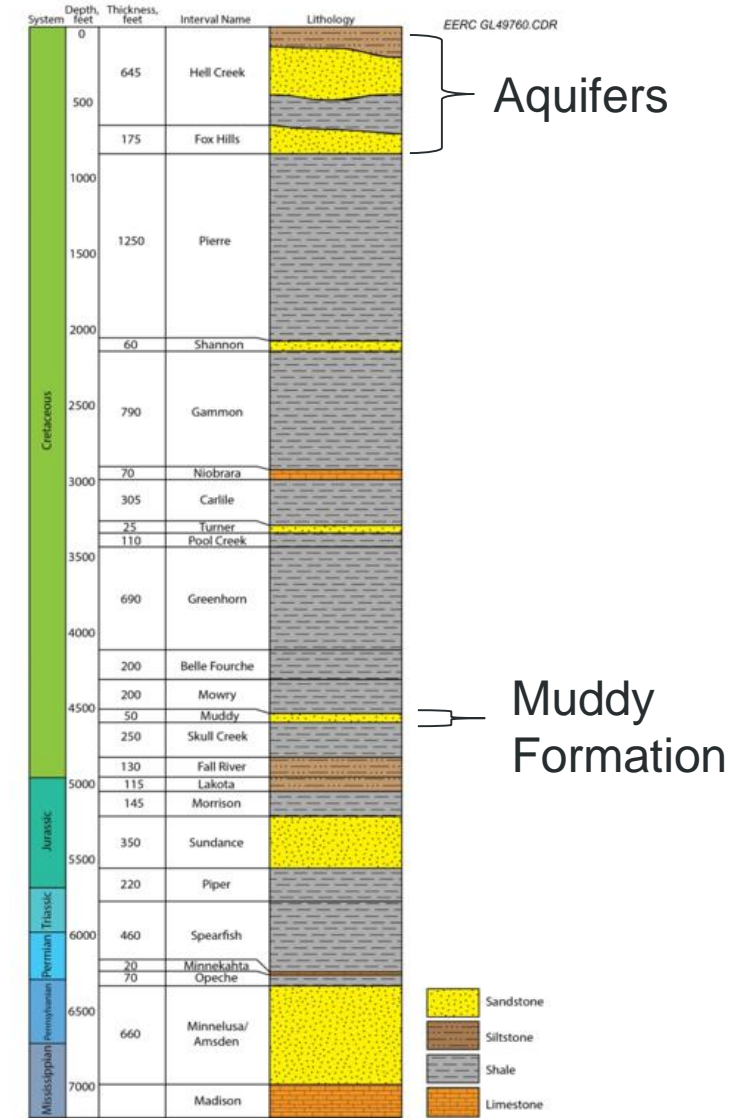
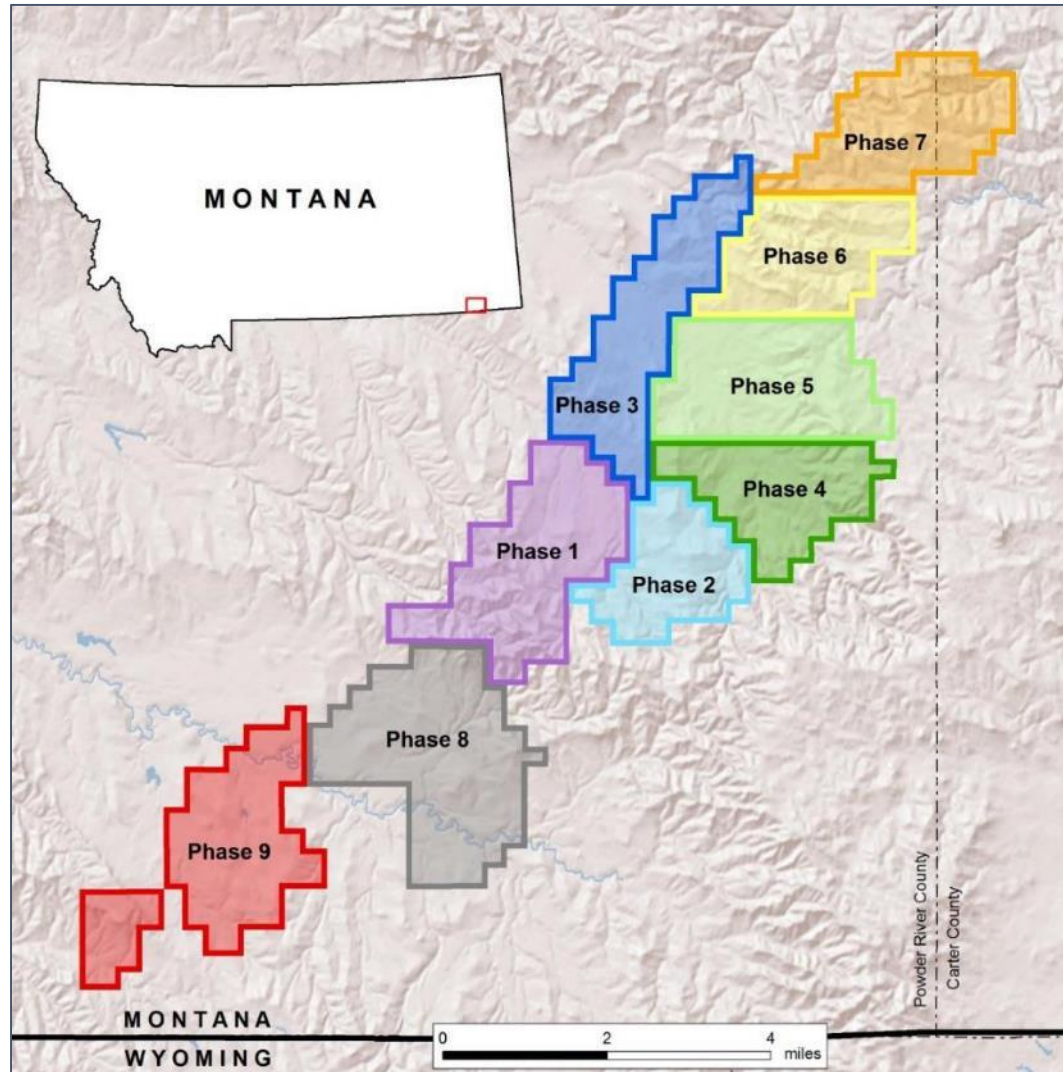
# BELL CREEK

- The Bell Creek oil field is operated by Denbury Onshore LLC.
- CO<sub>2</sub> is sourced from ConocoPhillips' Lost Cabin natural gas-processing plant and ExxonMobil's Shute Creek gas-processing plant.
- The Energy & Environmental Research Center (EERC), through the PCOR Partnership, is studying CO<sub>2</sub> storage associated with commercial CO<sub>2</sub> EOR.



# FIELD DEVELOPMENT

- Primary production and waterflooding produced ~37.5% original oil in place (OOIP).
- **Estimated 40–50 million incremental bbl of oil.**
- **Estimated 12.7 million tonnes of CO<sub>2</sub> stored.**

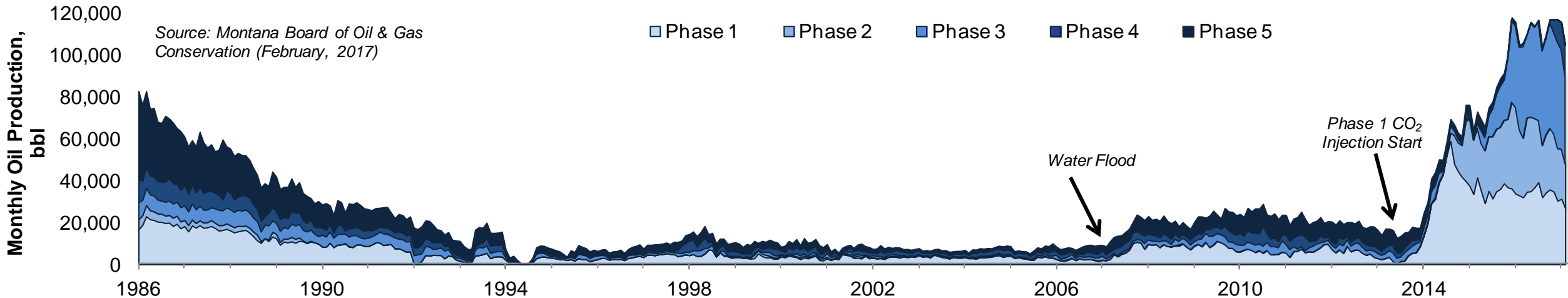
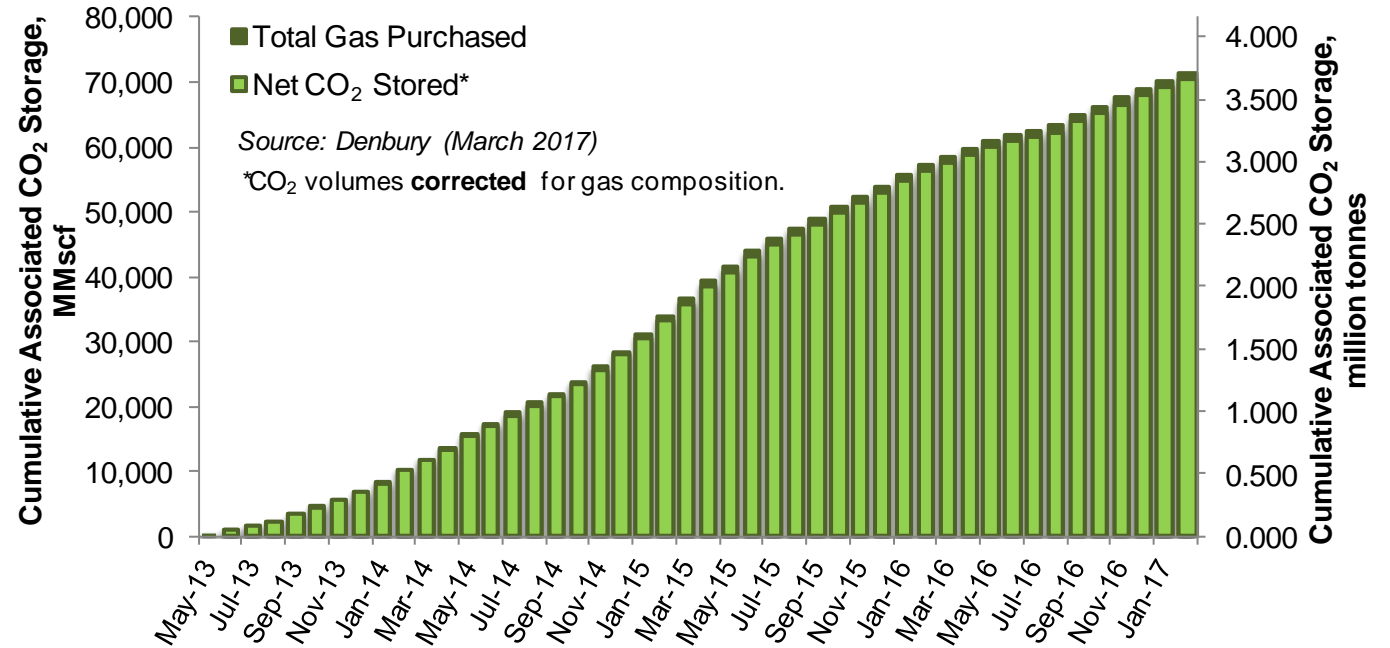




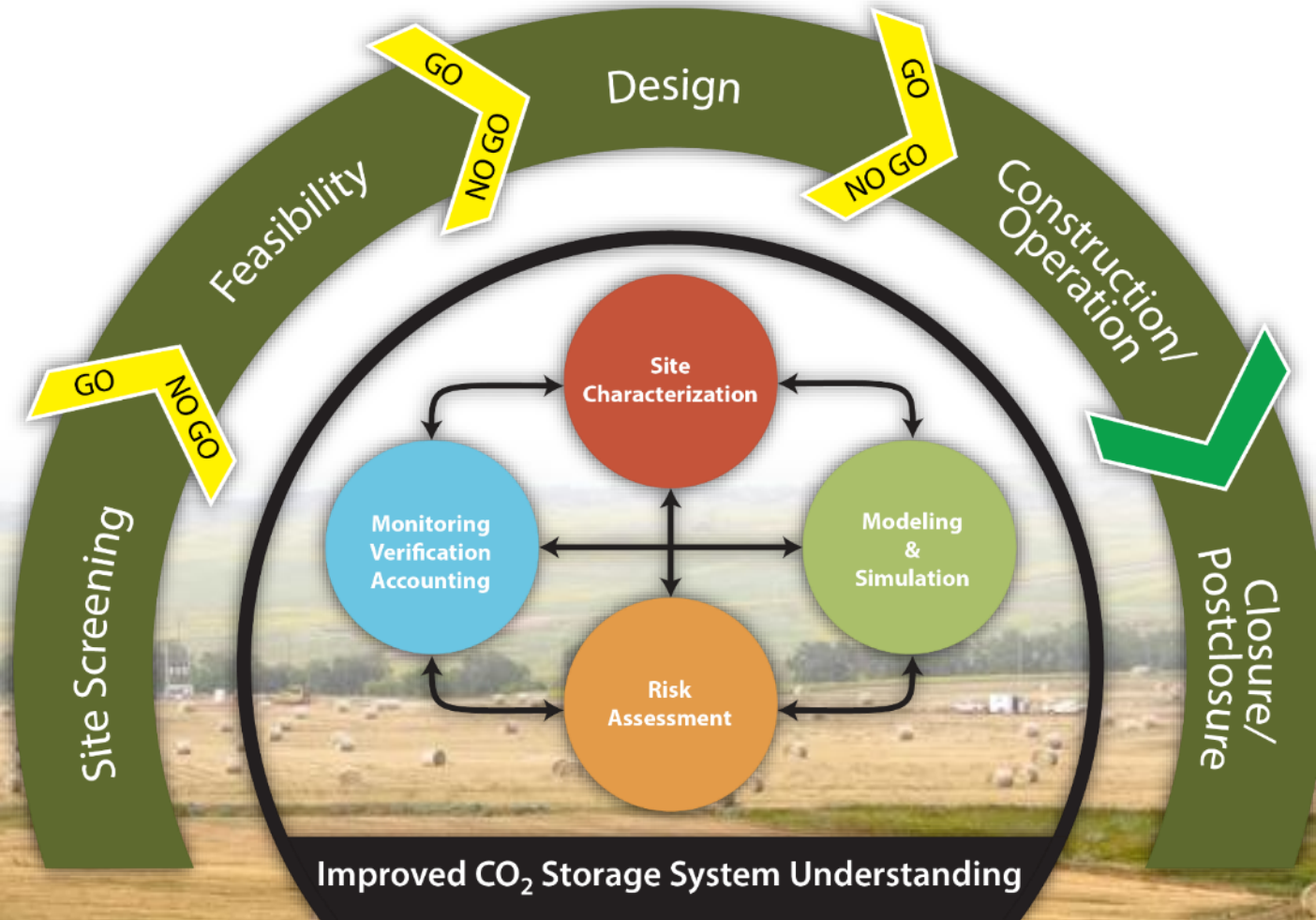
# CO<sub>2</sub> INJECTION

As of February 2017

- Oil Produced: ~3.5 million barrels  
(source: Montana Board of Oil and Gas Database)
- CO<sub>2</sub> Stored: ~3.7 million tonnes  
(source: Denbury Purchase Volume)  
\* Corrected for gas composition.

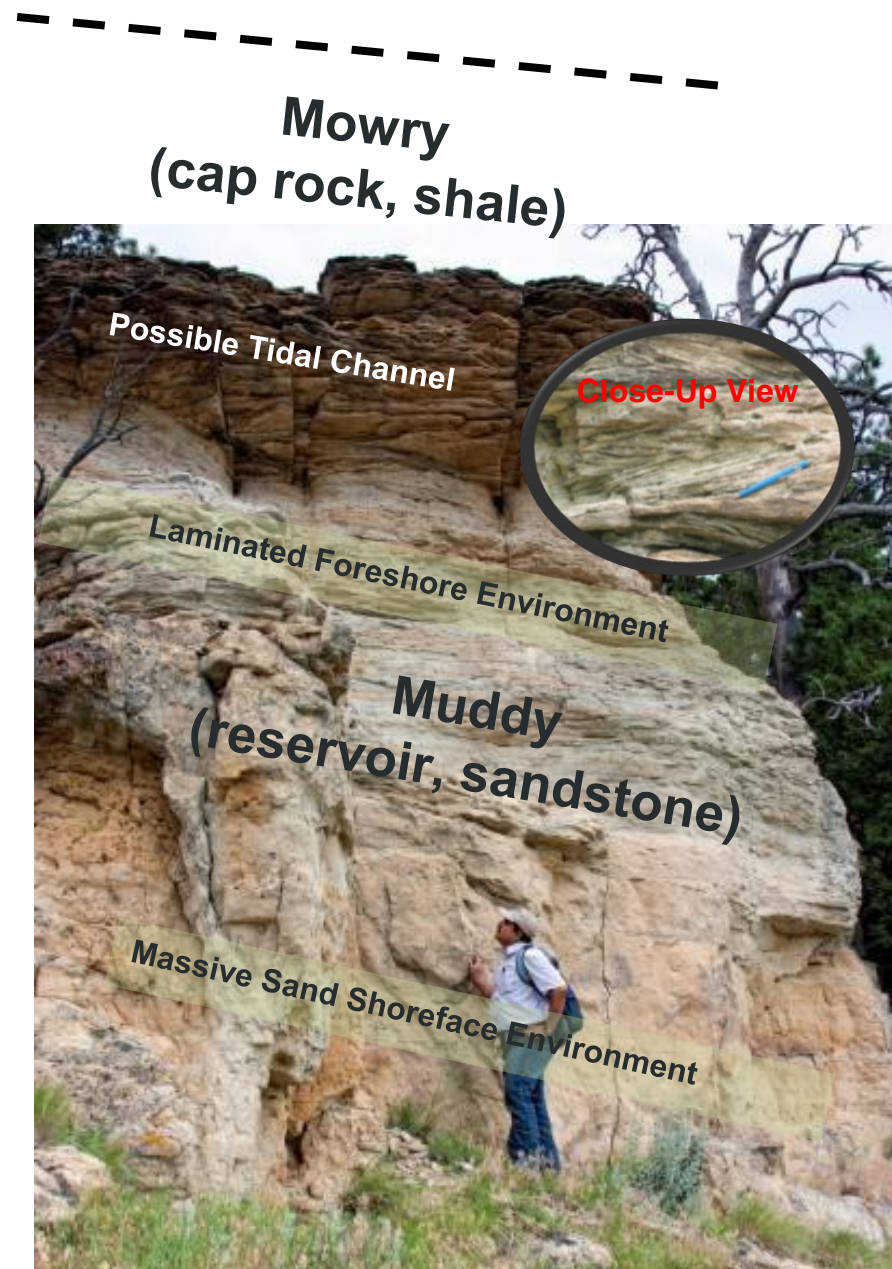


# ADAPTIVE MANAGEMENT APPROACH



# SITE CHARACTERIZATION ACTIVITIES COMPLETED

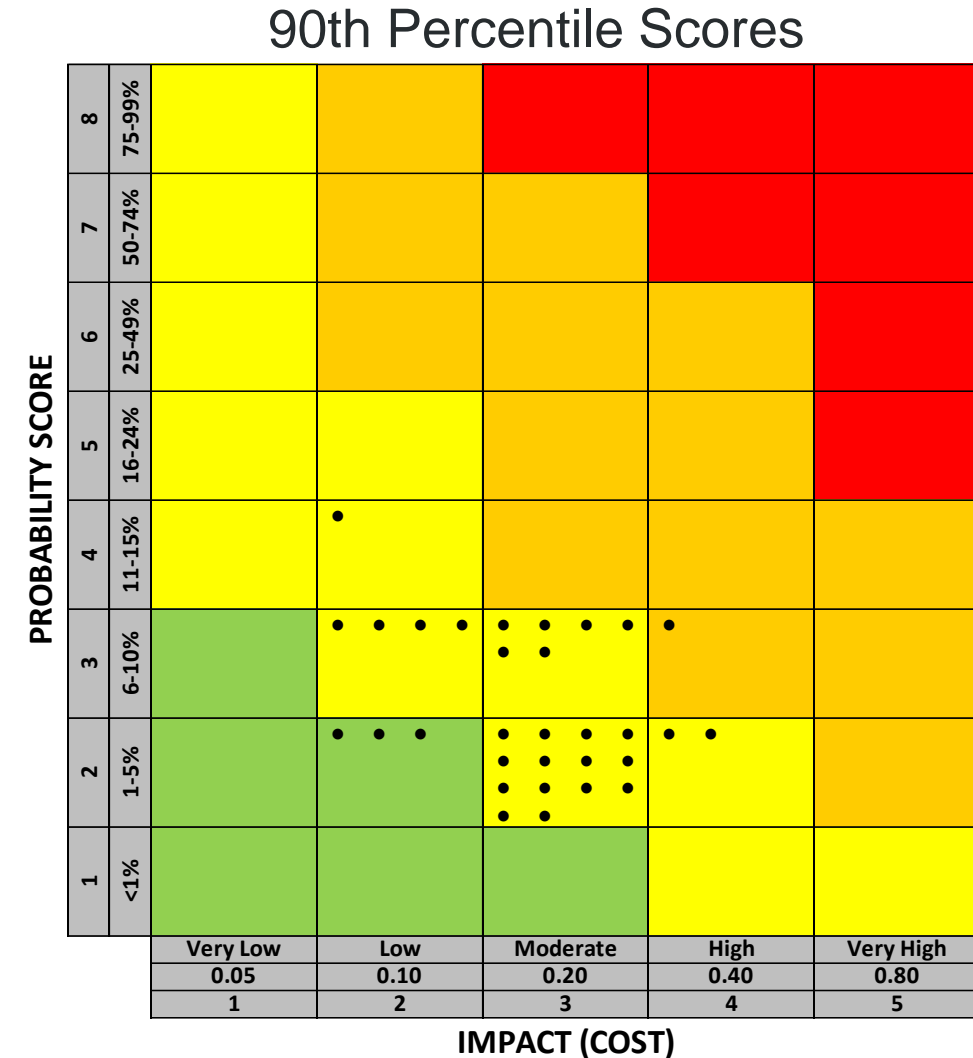
- Reviewed historic well files and operations data
- Collected and analyzed lidar (light detection and ranging) data
- Investigated outcrops
- Drilled characterization wells
- Analyzed core
- Conducted 104-km<sup>2</sup> (40 mi<sup>2</sup>) 3-D seismic survey
- Collected baseline 3-D vertical seismic profiles (VSPs)
- Collected pulsed-neutron logs (PNLs)





# BELL CREEK RISK MAPPING

- Under the most likely scenario, all of the 31 project technical risks mapped within either the Low (green) or Transition (yellow) fields.
- **None of the risks in the risk register mapped into the High (red) category or represented an unacceptable level of risk.**

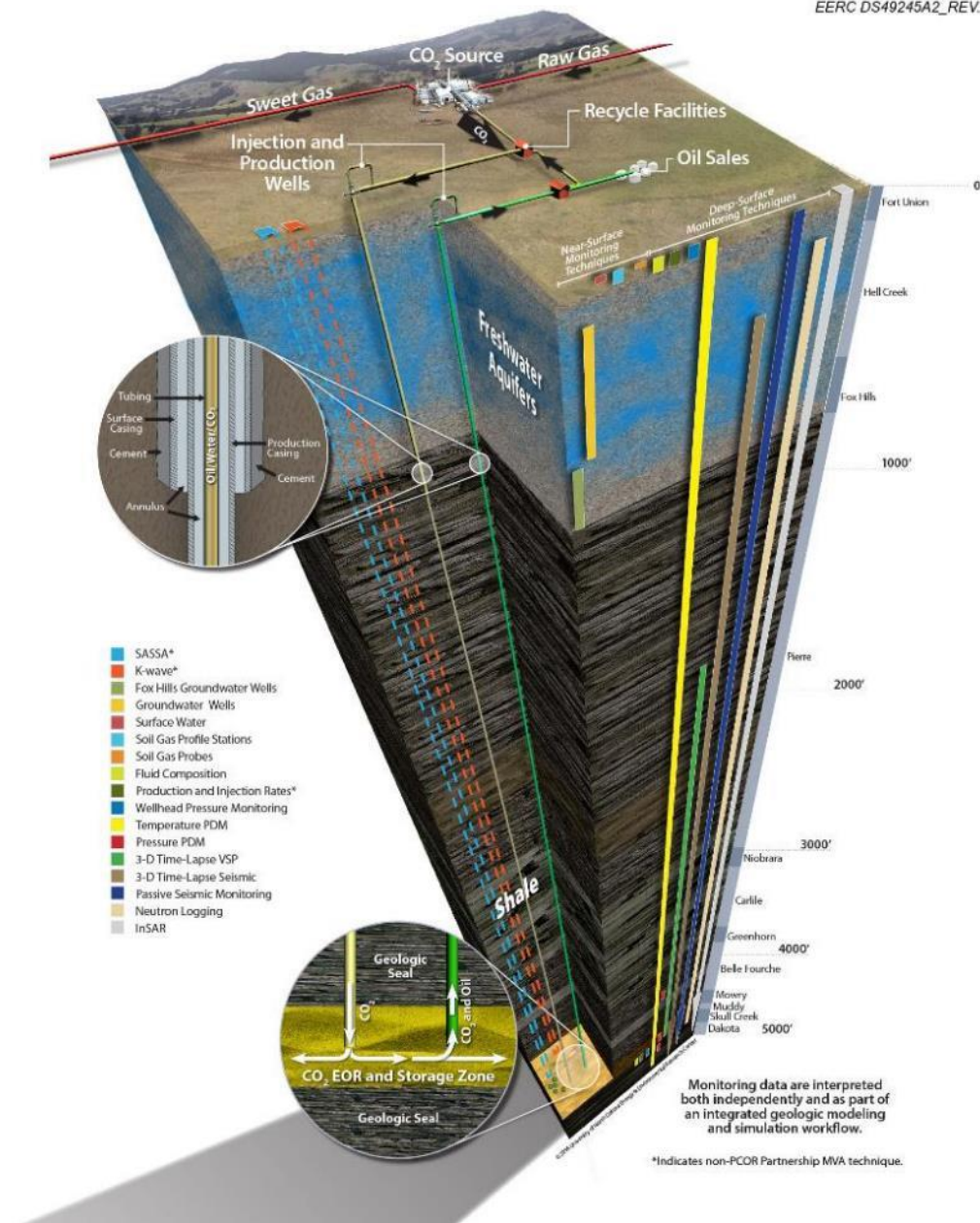


# MVA

- 16 techniques
- 1.5 years of preinjection monitoring
- 3+ years of operational monitoring

Demonstrate and validate monitoring techniques and their associated economics to inform viable MVA strategies for commercial-scale CCS.

Building off of the backbone of commercial operations data.





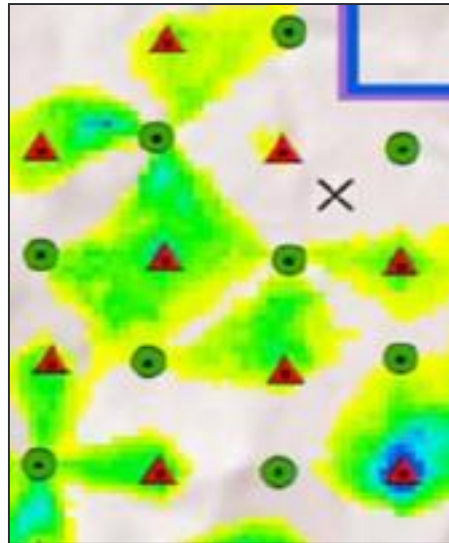
# MVA ADDRESSING PROJECT RISKS

MVA Technologies	Subsurface Technical Risks Addressed									
	Reservoir Capacity	Reservoir Injectivity	Reservoir Retention	Containment						Induced Seismicity
				Vertical Migration			Lateral Migration			
				CO <sub>2</sub>	Oil	Brine	CO <sub>2</sub>	Oil	Brine	
<b>Soil Gas</b>										
Soil gas probes				X						
Soil gas profile stations (SGPS)				X						
<b>Water</b>										
Surface water				X	X	X				
Groundwater wells				X	X	X				
Fox Hills/Hell Creek wells				X	X	X				
<b>Production/Injection Rates</b>	X	X	X							
<b>Pressure/Temperature</b>										
Wellhead P&T		X					X	X	X	
Downhole P&T				X	X	X	X	X	X	
Distributed fiber optic temperature				X	X	X	X	X	X	
Bottomhole pressure		X					X	X	X	
<b>Geophysics</b>										
3-D surface seismic	X	X	X	X			X			
3-D vertical seismic profile (VSP)							X			
Passive seismic										X
<b>Pulsed-Neutron Logs (PNLs)</b>	X		X	X	X	X	X	X	X	
<b>Other</b>										
InSAR		X					X	X	X	
SASSA				X			X			
Krauklis seismic wave (K-wave)	X			X			X			

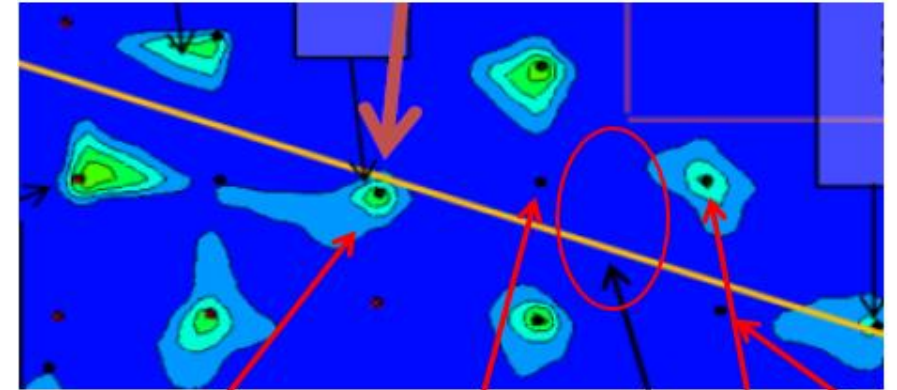
# SIMULATION-GUIDED MVA

- Simulation was used to predict location and saturation of CO<sub>2</sub>.
- 2-D seismic line used to confirm ability of seismic to detect CO<sub>2</sub> in the reservoir.
- Results supported decision to conduct large 3-D survey.

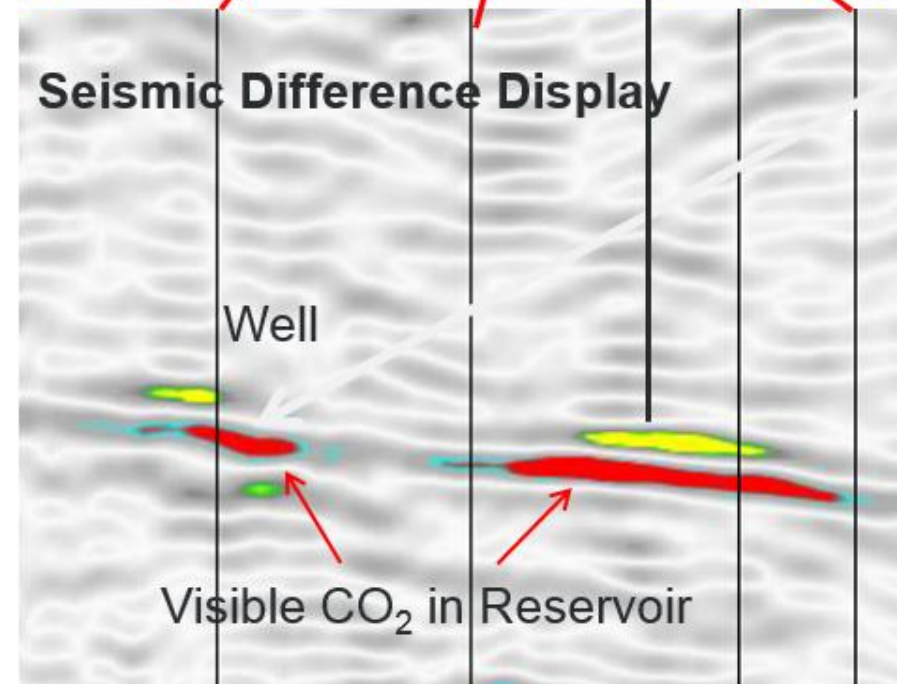
Predictive Simulation Results (CO<sub>2</sub> plumes)



Seismic Line Overlaying Simulation



Seismic Difference Display





# MVA-GUIDED SIMULATION

- Pressure and fluid communication revealed by 4-D seismic helped explain Phase 1 model history-matching issues.
- A combined Phase 1 and 2 was developed in response.

**CO<sub>2</sub> Banking Against Permeability Barrier**

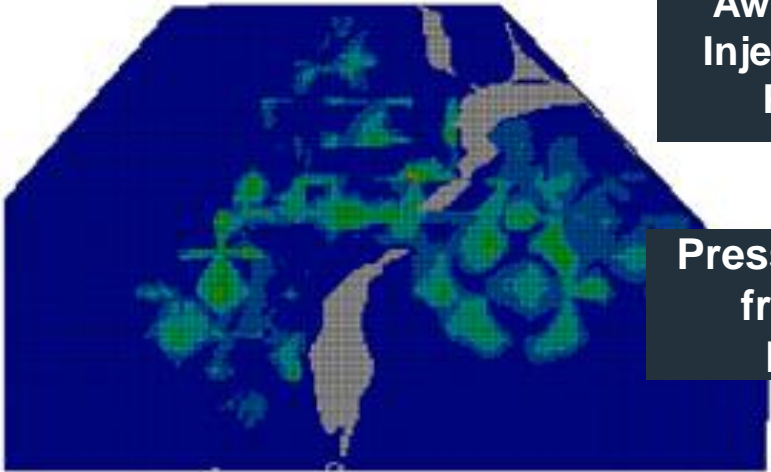
**Higher Amplitude in Phase 2 Relative to Phase 1 due to Higher Pressure Buildup**

**Fluid and Pressure Communication Between Phases 1 and 2**

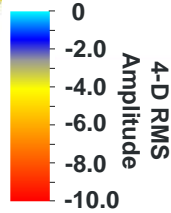
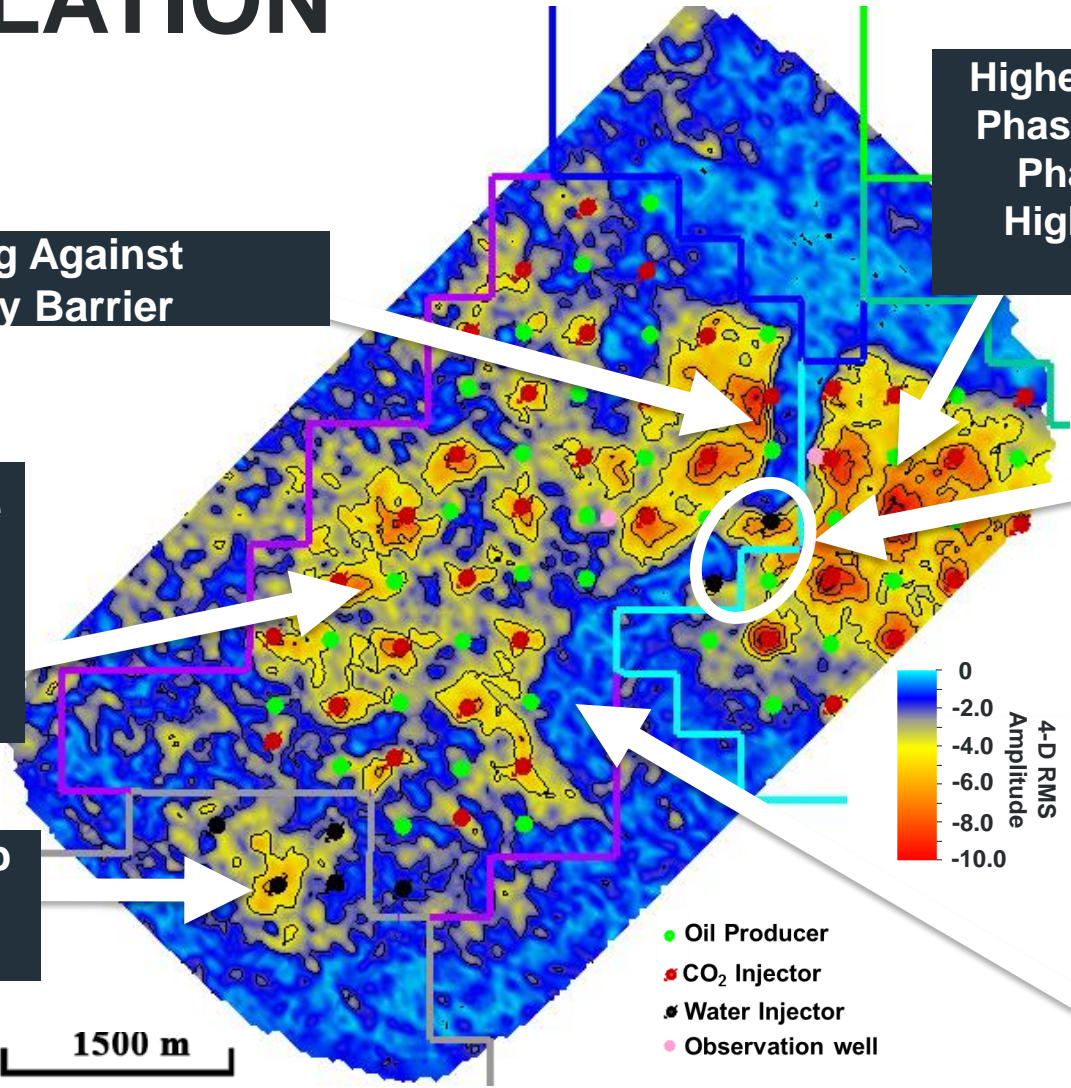
**CO<sub>2</sub> and Pressure Moving Updip Away from the Injector Toward Producer**

**Pressure Buildup from Water Injection**

**Southeastern Extension of the Permeability Barrier**

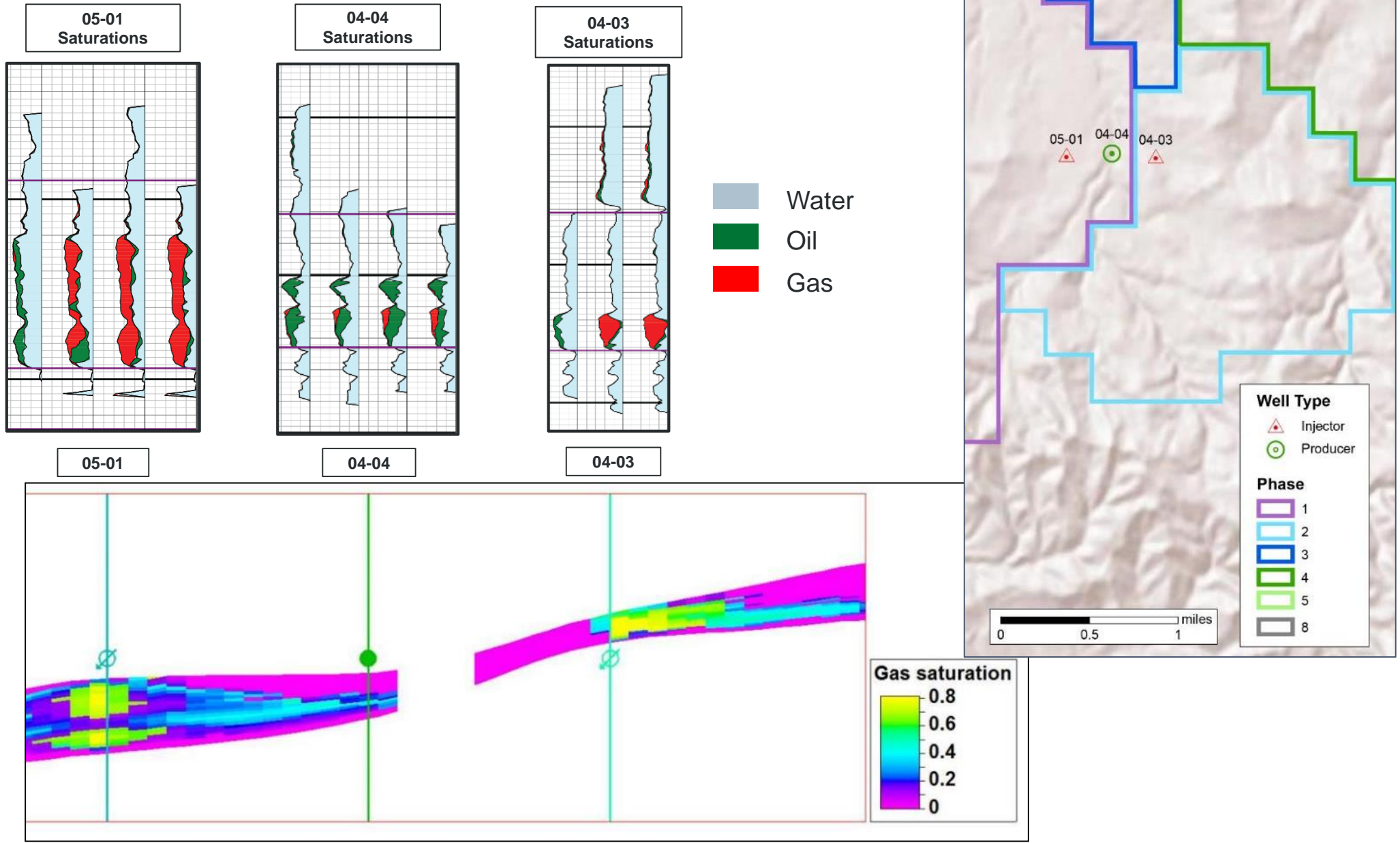


WAG, 1 HCPVI



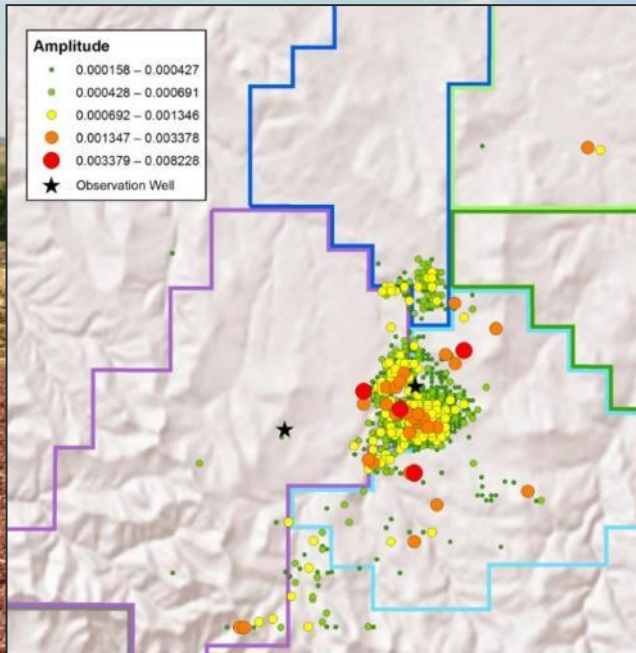
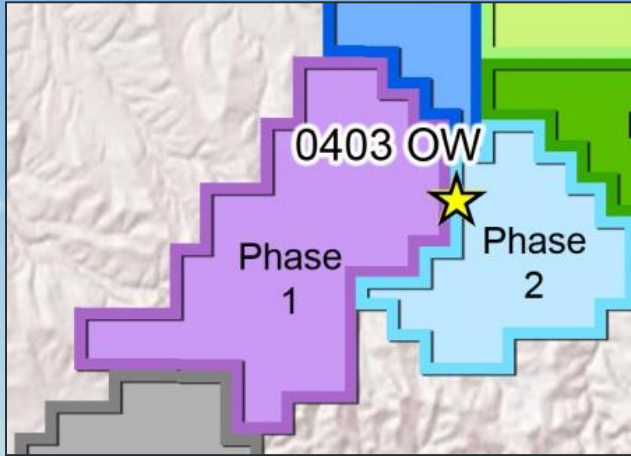
- Oil Producer
- CO<sub>2</sub> Injector
- Water Injector
- Observation well

# MVA FOR MODEL VALIDATION – PULSED-NEUTRON LOGGING





# PASSIVE SEISMIC MONITORING



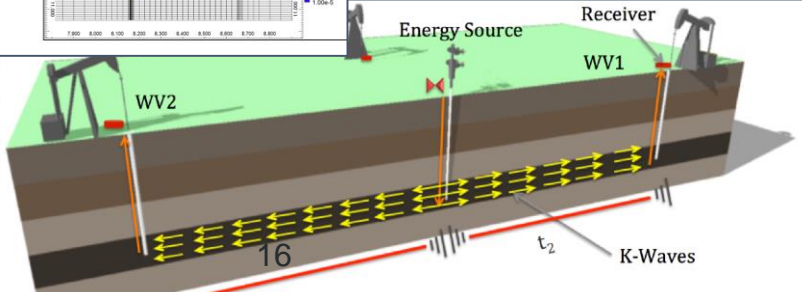
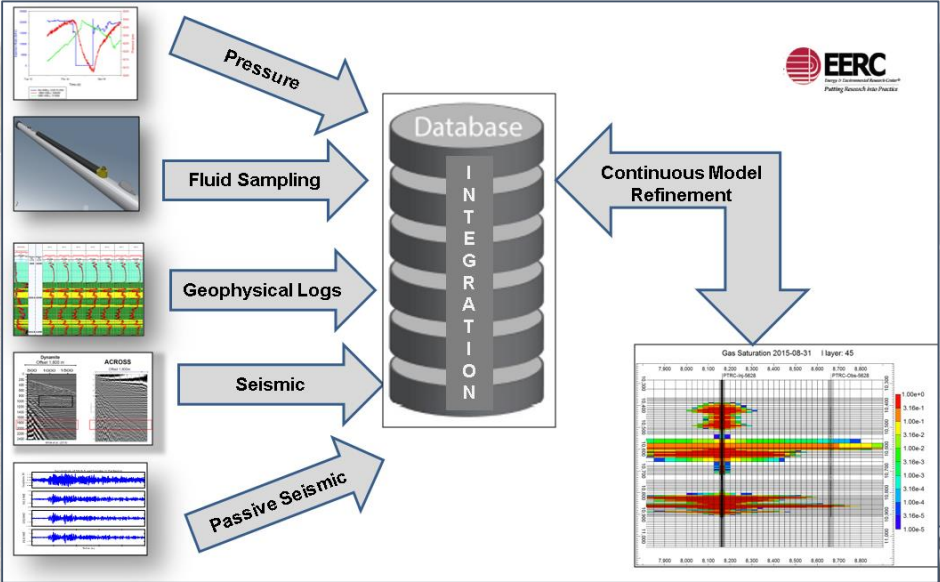
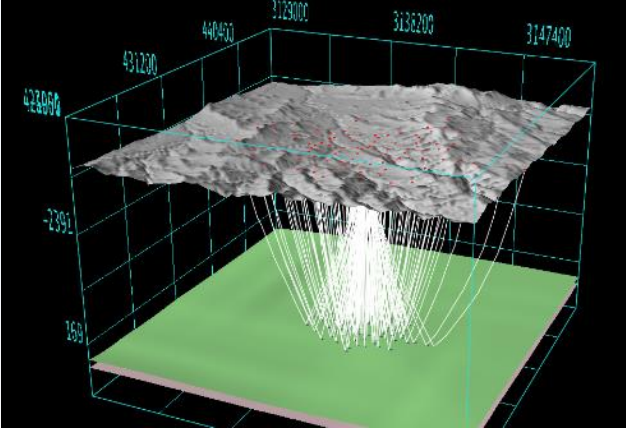
- 50-level geophone array.
- Near-continuous monitoring since May 2013 – 3 years of data (~100 TB).
- Data processing is ongoing – early analysis suggests that all events are  $<M1$  and related to surface or well activity.





# FUTURE OF MONITORING

- Integrated
  - Improve performance forecasts
  - Inform operational decisions
  - Address risks
- Actionable results
- No impact on operations
- Low environmental impact
- Focus on fast processing
- Semiautonomous
- Scalable
- Efficient and strategic acquisitions
- Cost-efficient/enhanced value
- Intelligent monitoring
- Key indicators vs. robust solutions





# DEMONSTRATION OF EMERGING GEOPHYSICAL MONITORING TECHNIQUES

## SASSA

A NEW way to track CO<sub>2</sub>

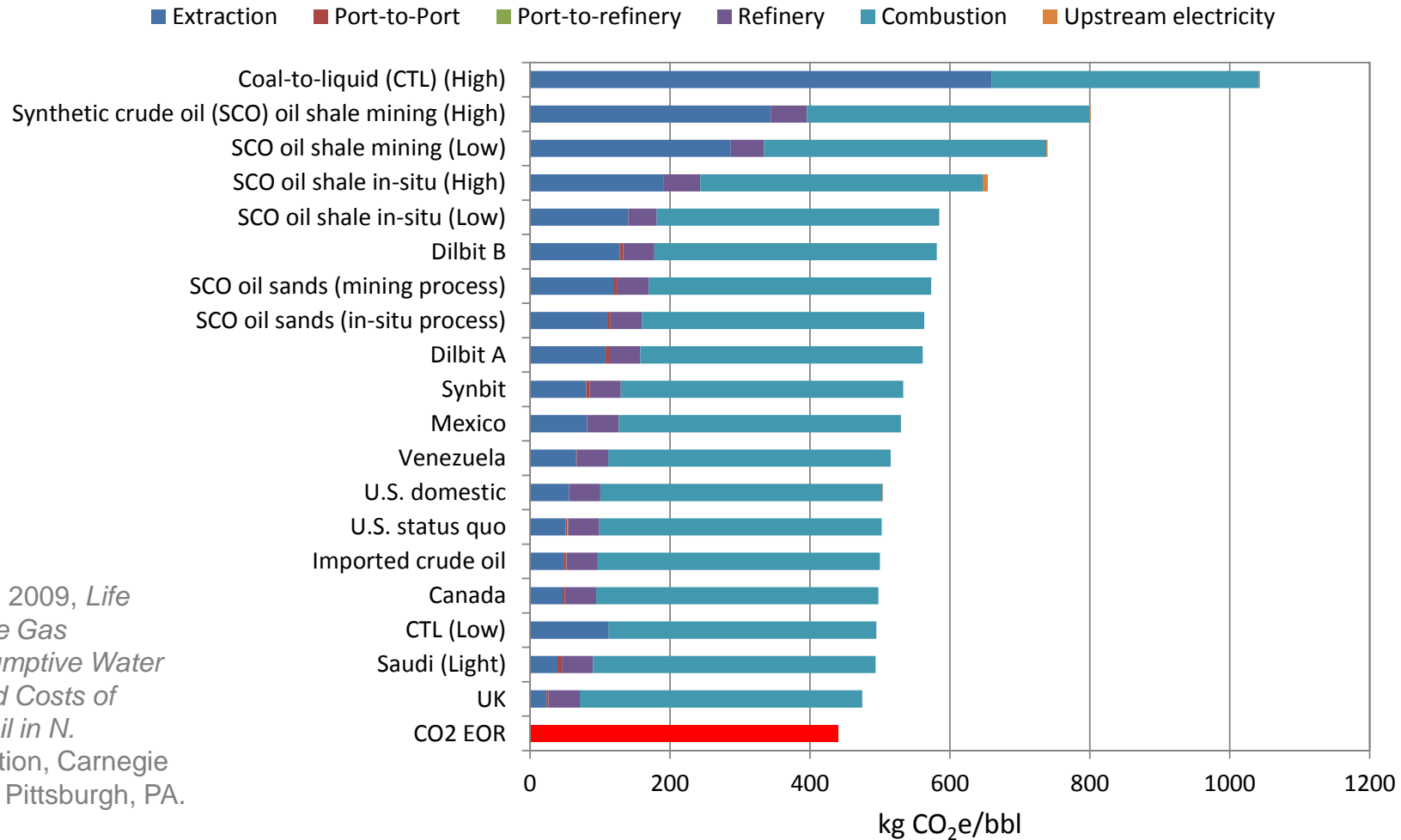
- Autonomous receivers and semipermanent stationary source
- Interpret boundary of CO<sub>2</sub> front
- Monitor CO<sub>2</sub> progression between wells or around sensitive areas
- Monitoring of overlying zones

## K-Wave

A NEW subsurface signal to possibly track CO<sub>2</sub>

- Scalable
  - Potential autonomous operation
  - Rapid processing
  - Low impact
  - Reduced acquisition cost
  - Guide timing and extent of other surveillance
  - Inform timely operations
    - Conformance
    - Pattern analysis
    - Intelligent monitoring systems
  - Viable long-term monitoring
- Wellhead-mounted sources and receivers
  - Monitor CO<sub>2</sub> progression between wells

# COMPARING CO<sub>2</sub> EOR TO “REGULAR” OIL



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

# ACKNOWLEDGMENT

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