
EERC
Critical Challenges.
Practical Solutions.

# DEMONSTRATION OF SECURE $CO_2$ GEOLOGICAL STORAGE ASSOCIATED WITH ENHANCED OIL RECOVERY IN THE PCOR PARTNERSHIP REGION

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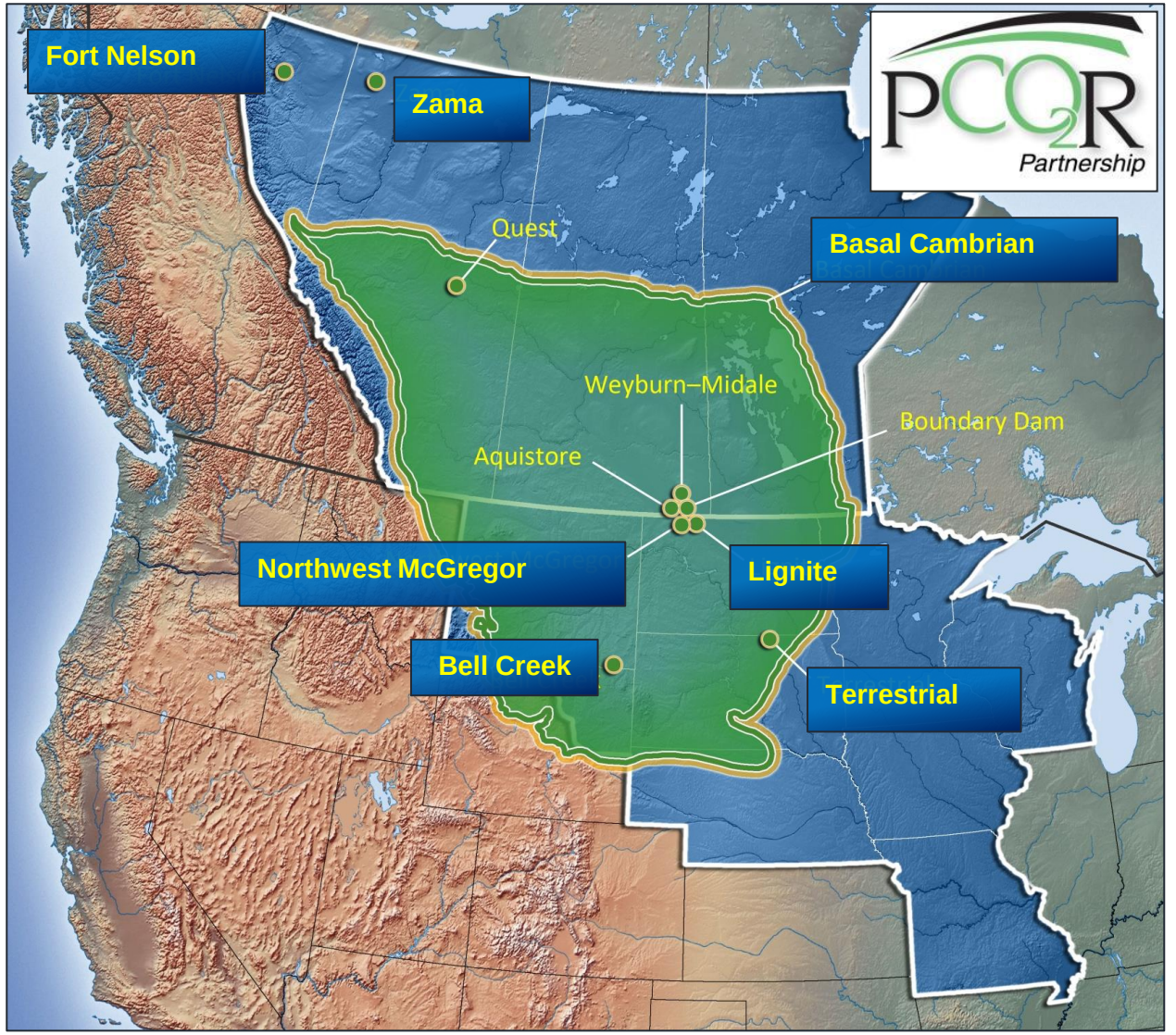
Principal Geologist

Critical Challenges. Practical Solutions.

# PLAINS $CO_2$ REDUCTION (PCOR) PARTNERSHIP

- Region includes:
  - Nine states.
  - Four Canadian provinces.
  - Over 3.6 million $km^2$.
- Several completed field projects.
- Over 3 million tons of $CO_2$ stored and monitored in association with $CO_2$ enhanced oil recovery (EOR).
- More than 120 partners.



# PCOR PARTNERSHIP

# PCOR PARTNERSHIP OBJECTIVES

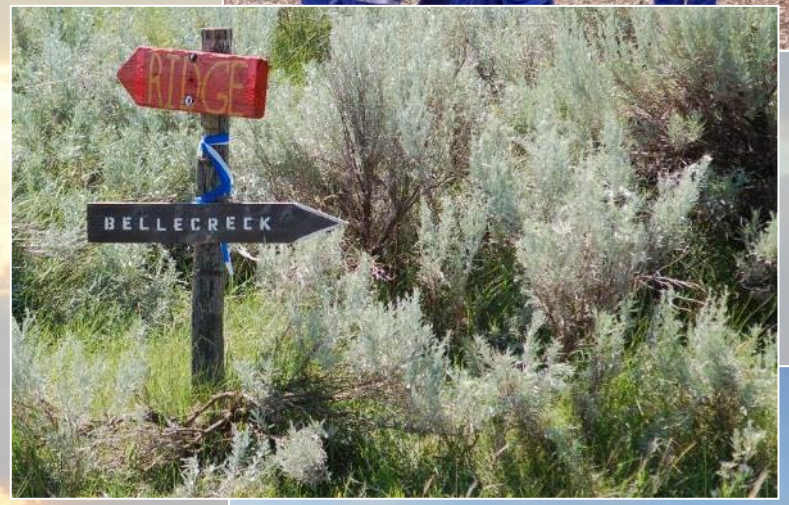
- Safely and permanently achieve $CO_2$ storage on a commercial scale.
- Establish a relationship between the $CO_2$ EOR process and long-term storage of $CO_2$.
- Establish monitoring, verification, and accounting (MVA) methods to effectively monitor $CO_2$ storage.
- Use commercial oil/gas practices 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.

# $CO_2$ EOR

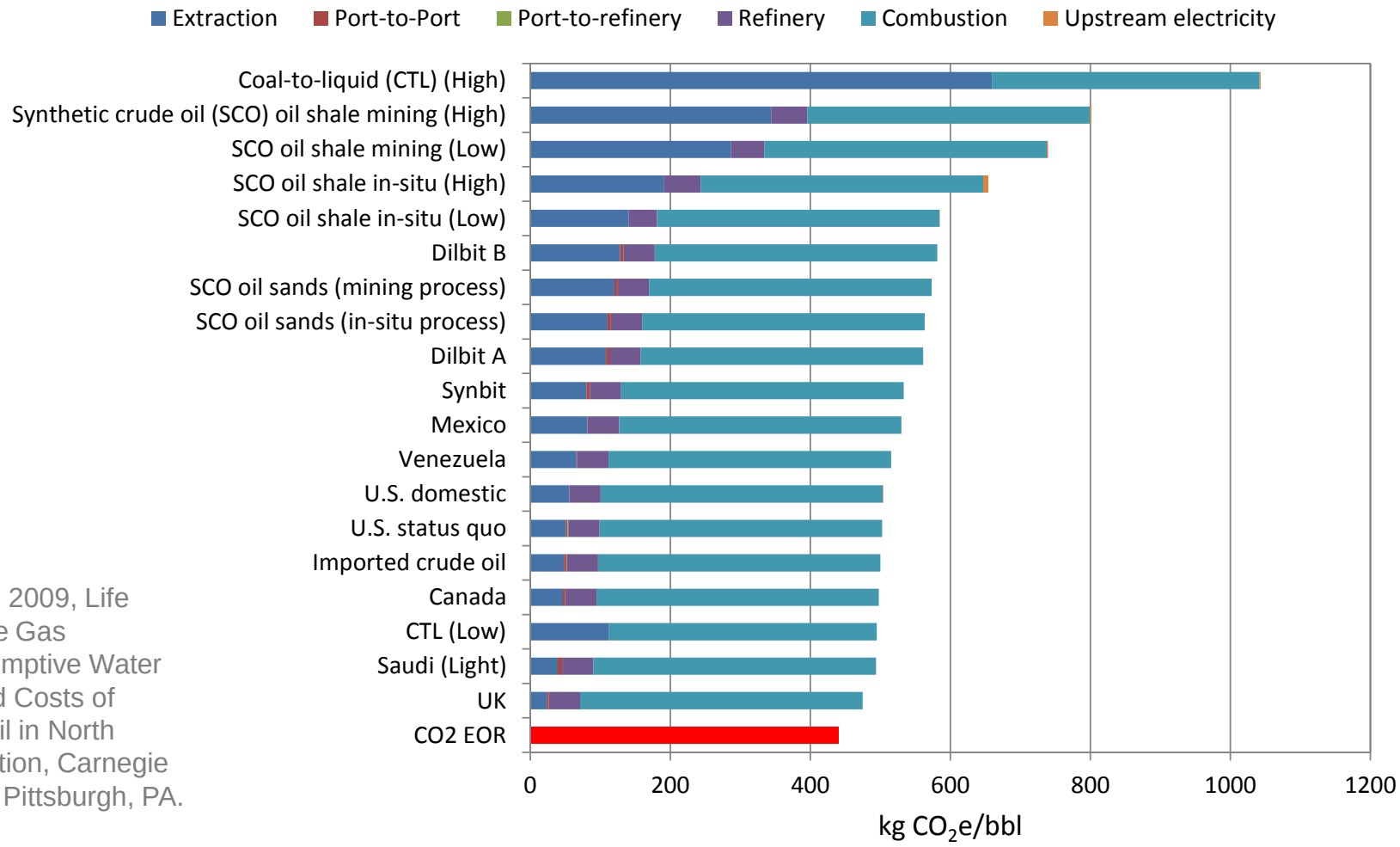
- **A great near-term storage option:**
- Over 40 years of handling and injecting large volumes of $CO_2$.
- Much of the infrastructure already in place.
- Storage cost can be offset by income from EOR.

## "Greener" than conventionally produced oil:

- Existing EOR operations are already storing $CO_2$.
- Nearly every tonne of $CO_2$ purchased is eventually stored.


# COMPARING $CO_2$ EOR TO "REGULAR" OIL




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

# JOURNAL ARTICLE

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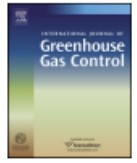


## How green is my oil? A detailed look at greenhouse gas accounting for $CO_2$-enhanced oil recovery ($CO_2$-EOR) sites

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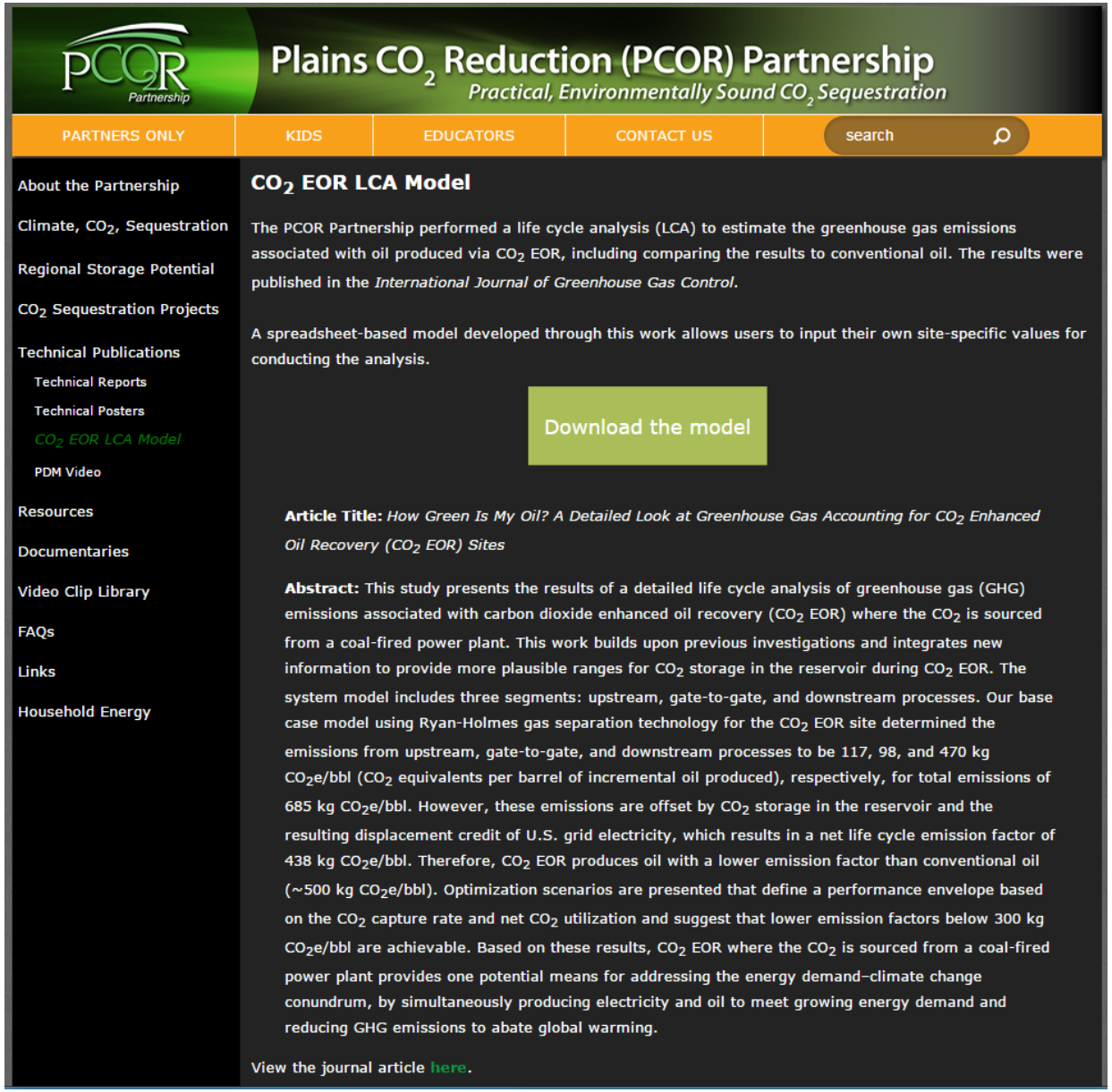
http://www.sciencedirect.com/science/article/pii/S1750583616302985

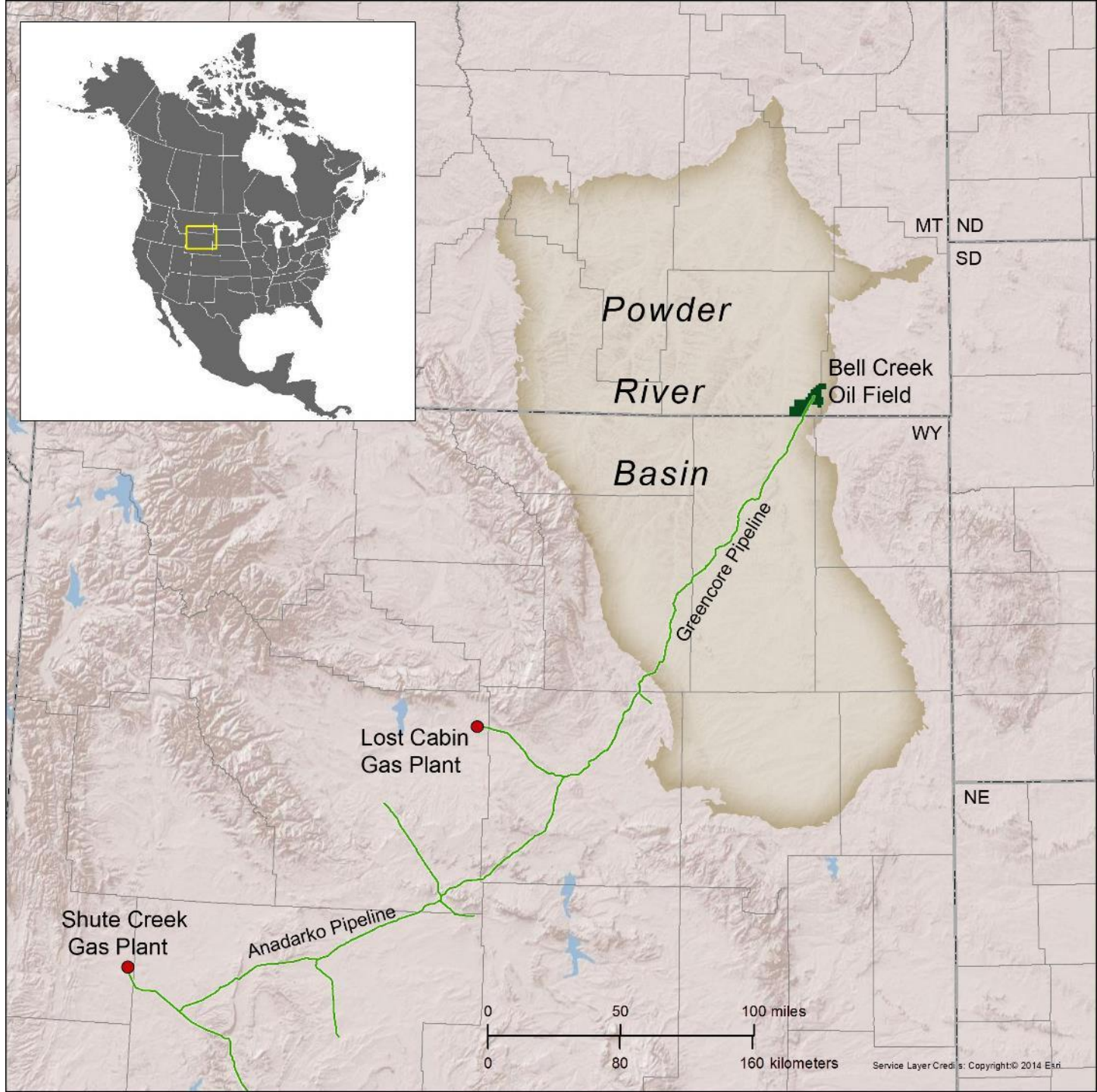
The spreadsheet $CO_2$ EOR life cycle analysis model is available on the PCOR Partnership public Web site!




http://www.undeerc.org/pcor/technicalpublications/CO2-EOR-Life-Cycle-Analysis.aspx

# BELL CREEK

- The Bell Creek oil field is operated by Denbury Onshore LLC.
- $CO_2$ is sourced from ConocoPhillips' Lost Cabin and ExxonMobil's Shute Creek gas-processing plants.
- The Energy & Environmental Research Center is studying $CO_2$ storage associated with commercial $CO_2$ EOR.

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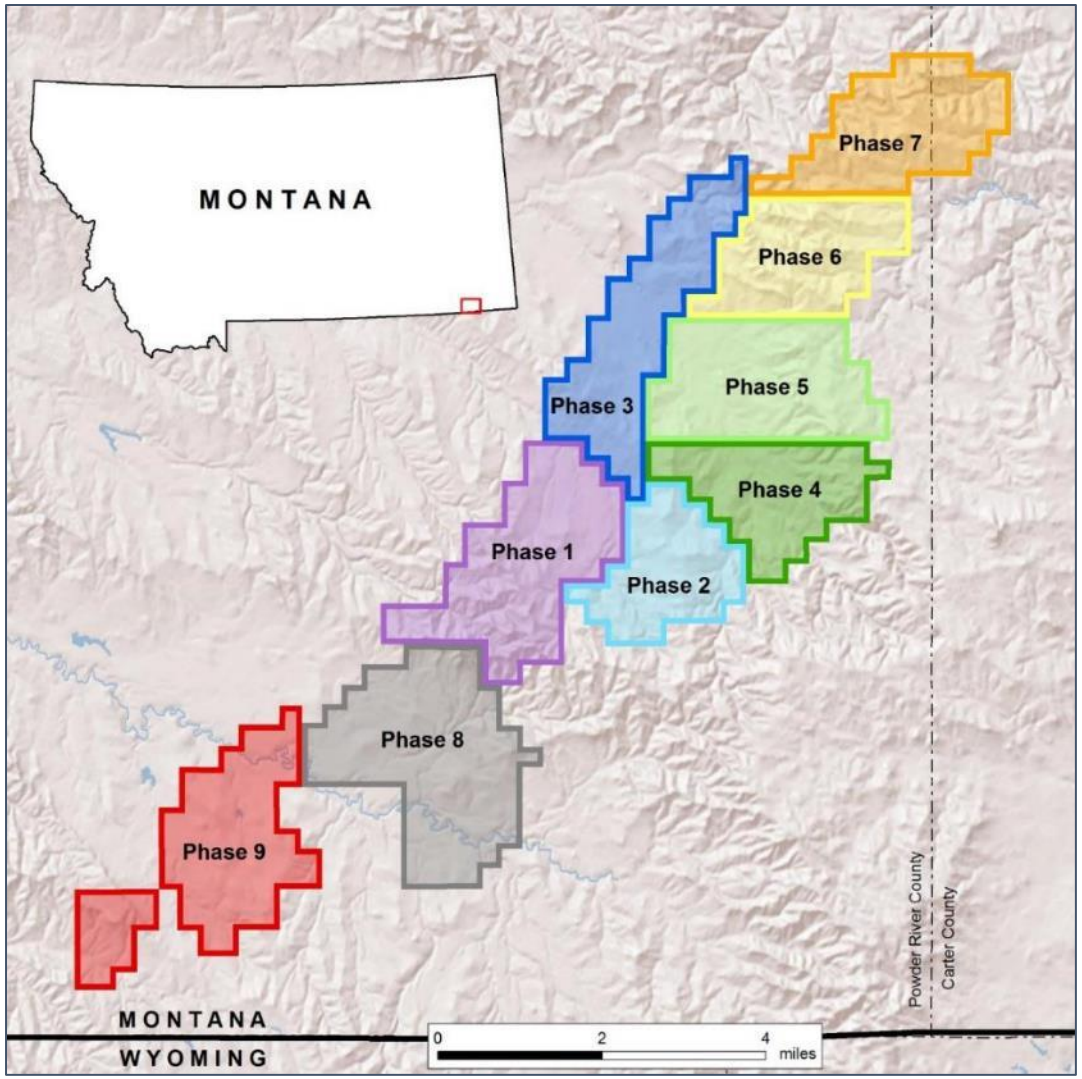
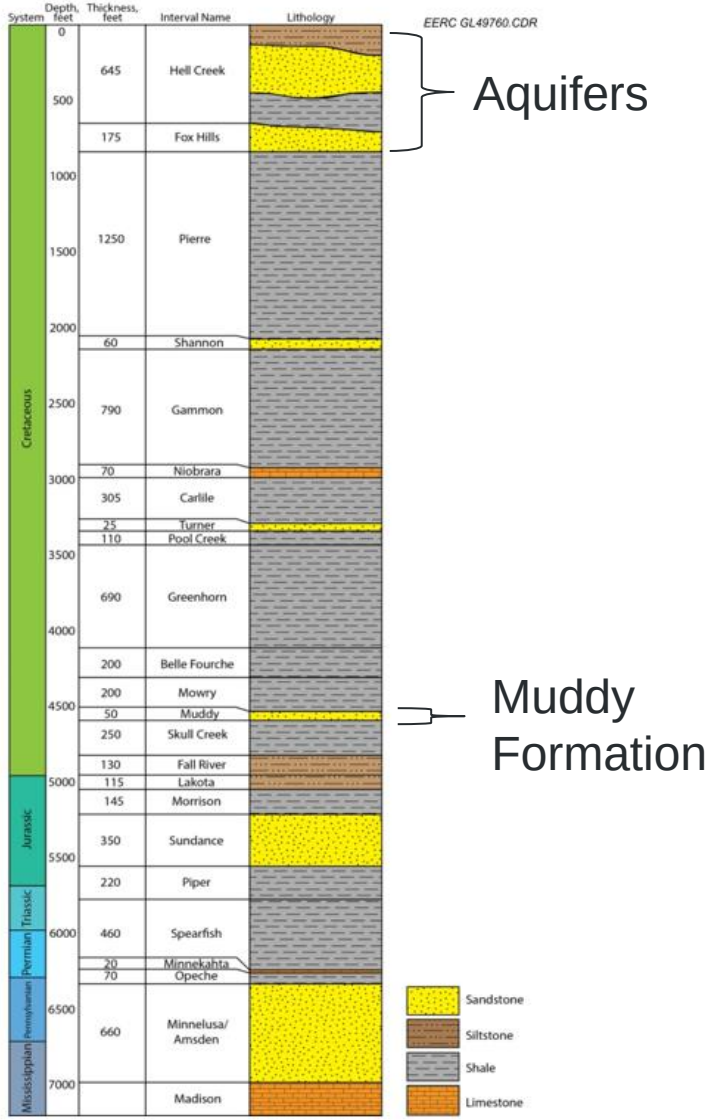
# FIELD DEVELOPMENT

- **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 $CO_2$ stored.**

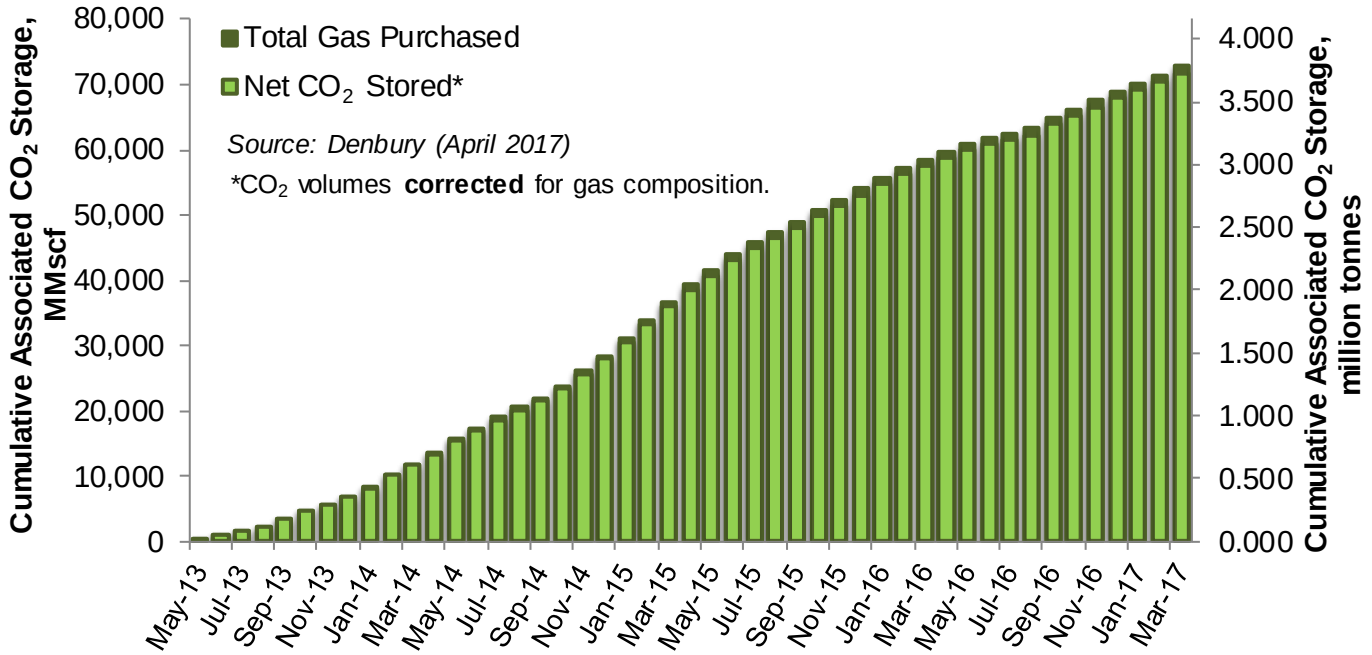


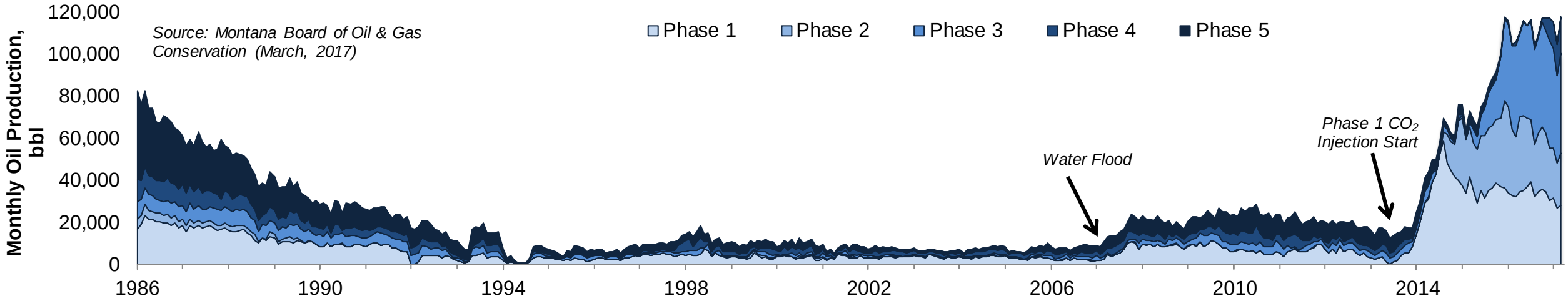



# $CO_2$ INJECTION

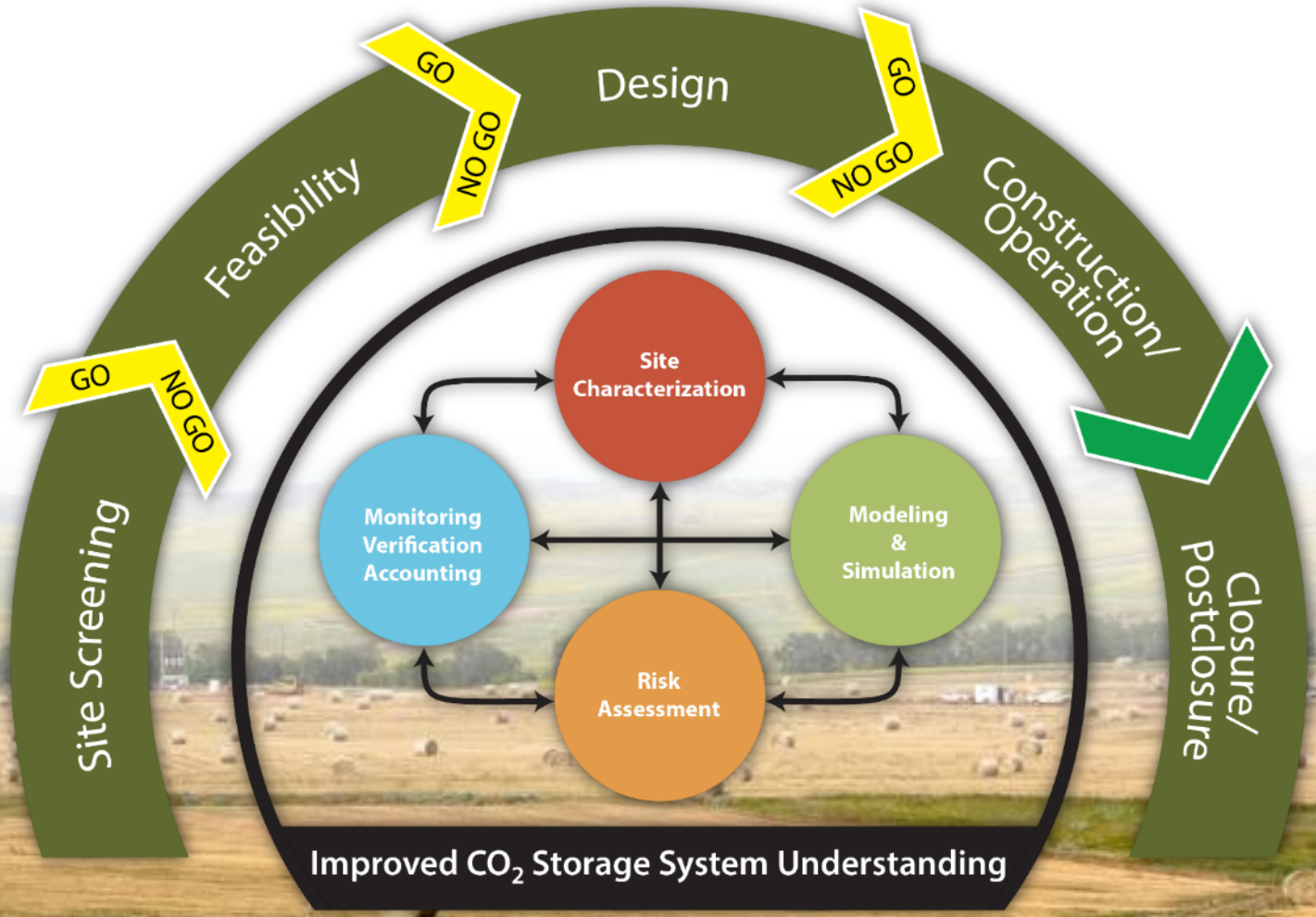
## As of March 2017

- Oil Produced: ~3.7 million barrels
*(source: Montana Board of Oil & Gas [MBOG] database)*
- $CO_2$ Stored: ~3.7 million tonnes
*(source: Denbury)*



# ADAPTIVE MANAGEMENT APPROACH

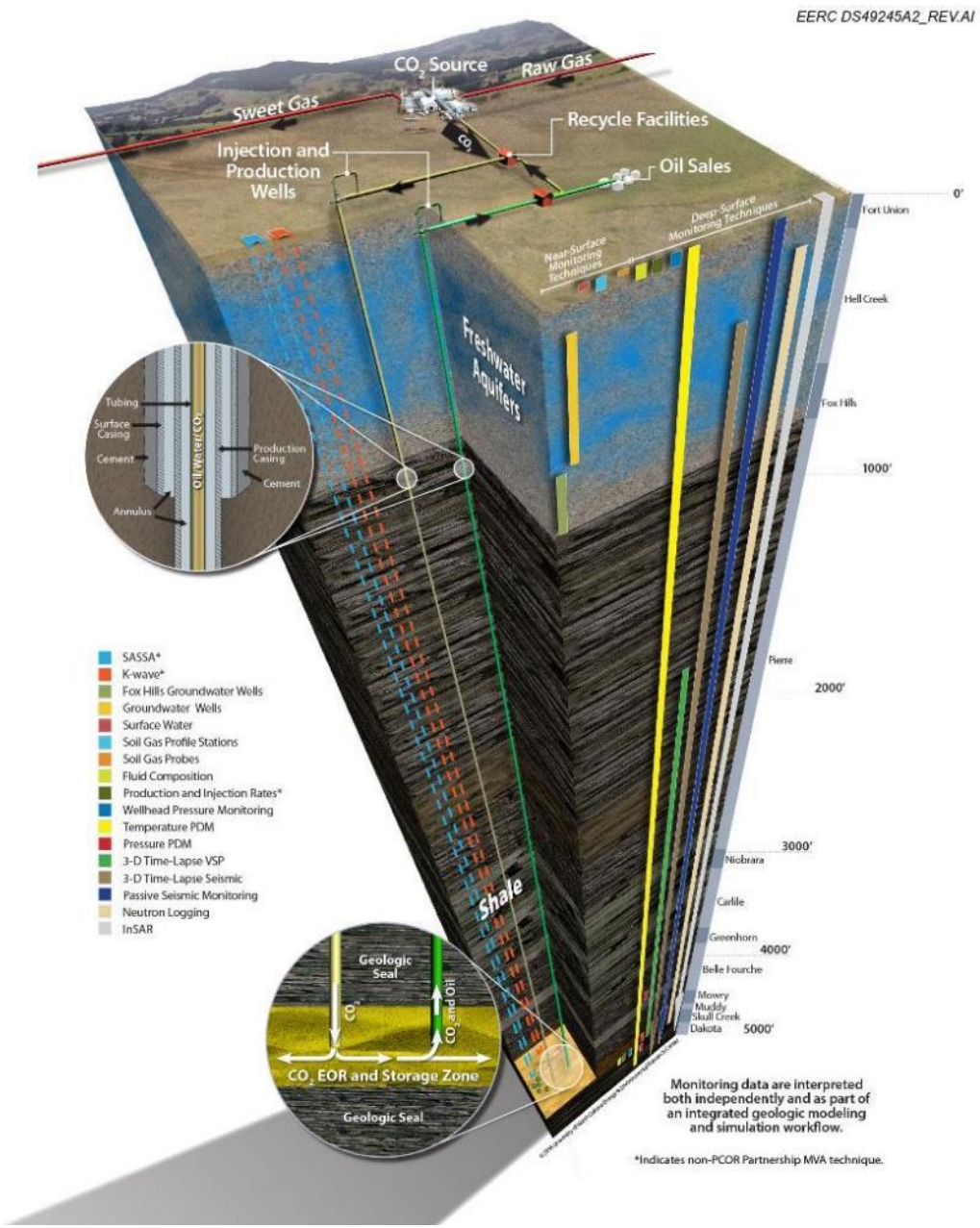


# MVA

- 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 carbon capture and storage (CCS).

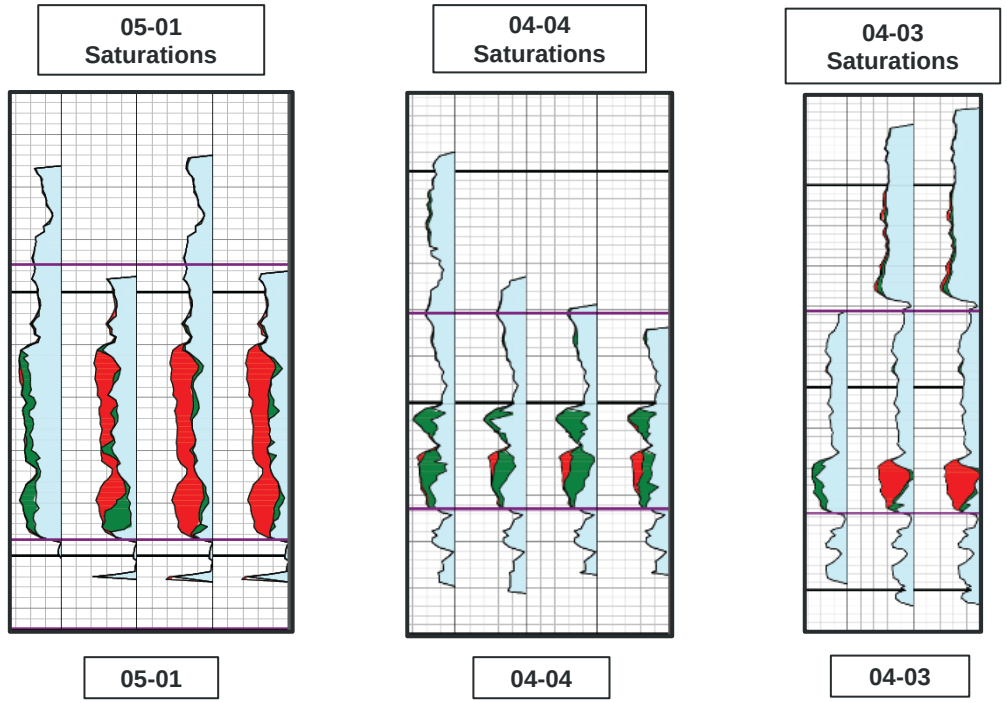
Building off of the backbone of commercial operations data.

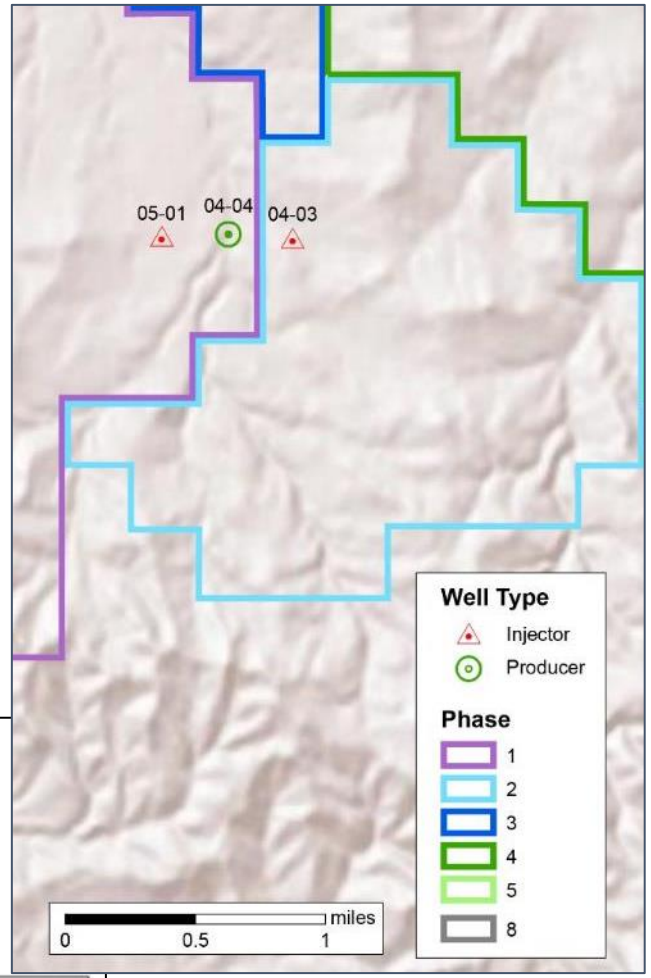


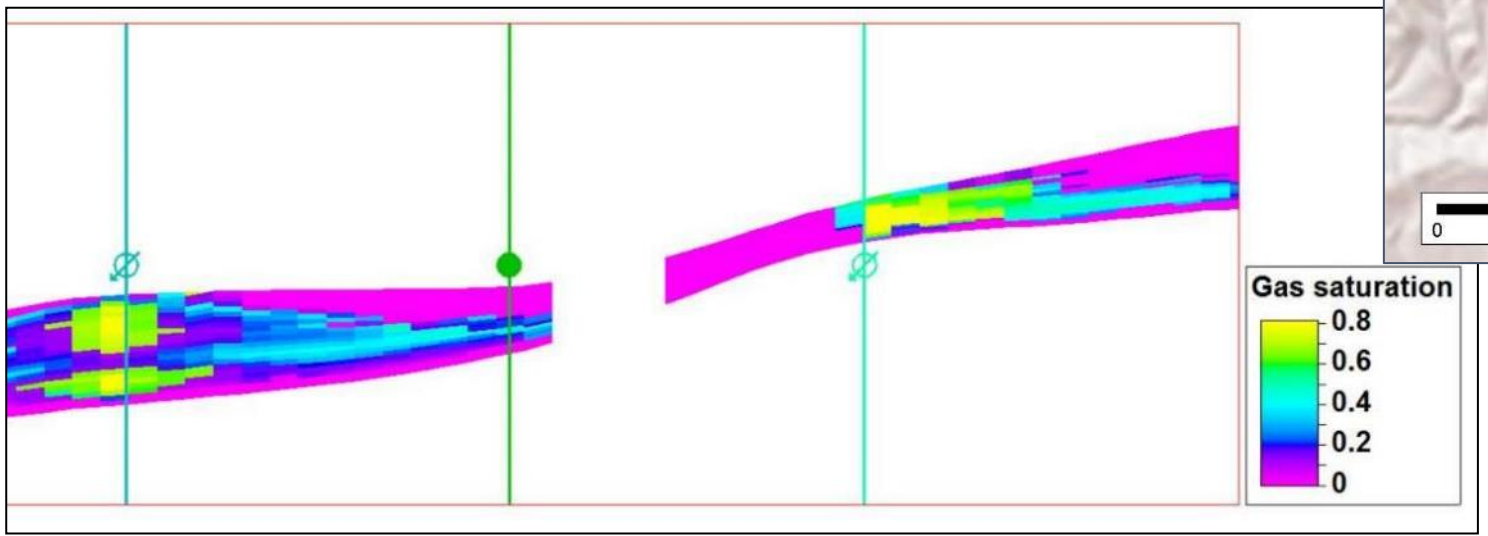
# PULSED-NEUTRON LOG (PNL) CAMPAIGN

- Seven PNL campaigns:
  - 45 wells (92 total logs) logged to date:
    - ♦ 45 baseline
    - ♦ 47 repeat

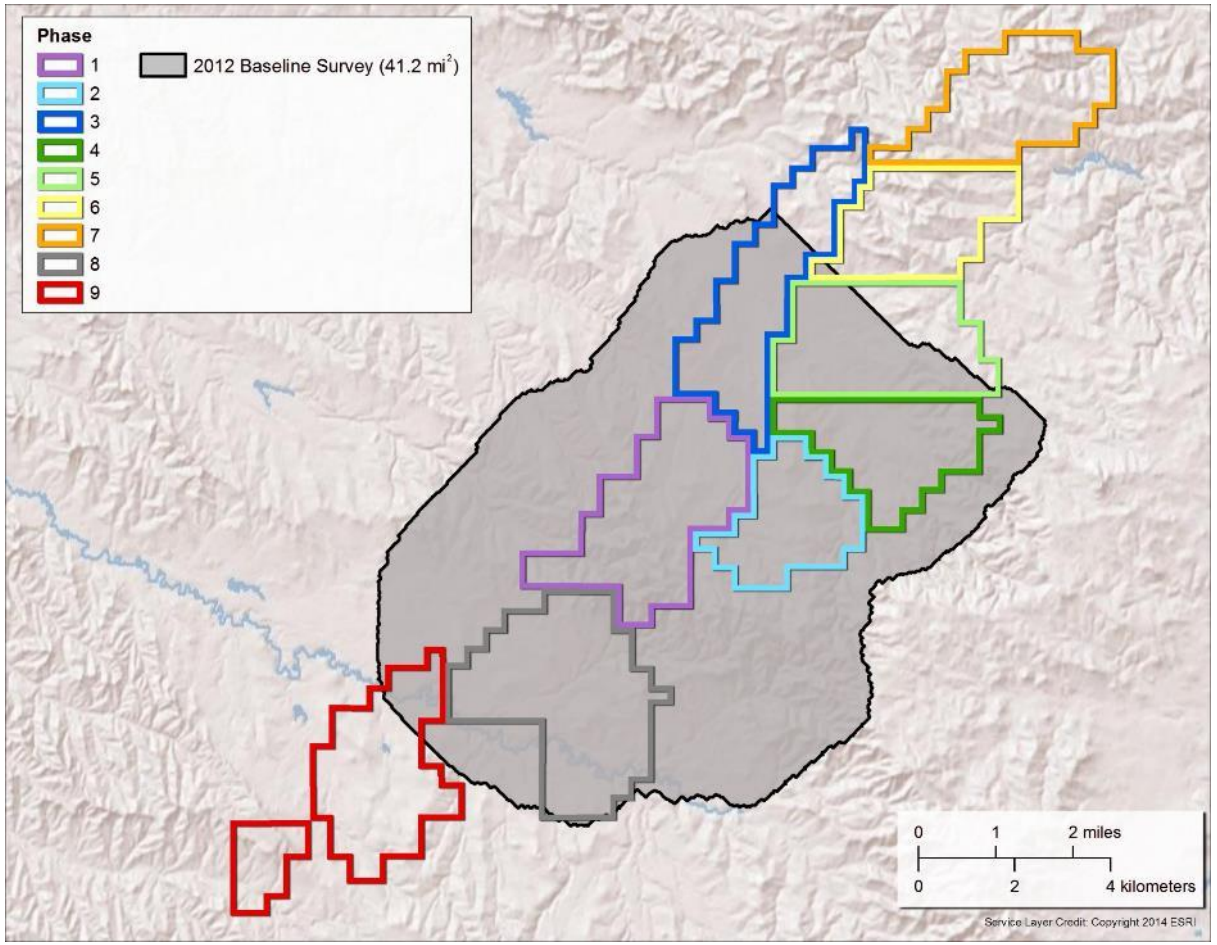
# MVA FOR MODEL VALIDATION – PULSED-NEUTRON LOGGING



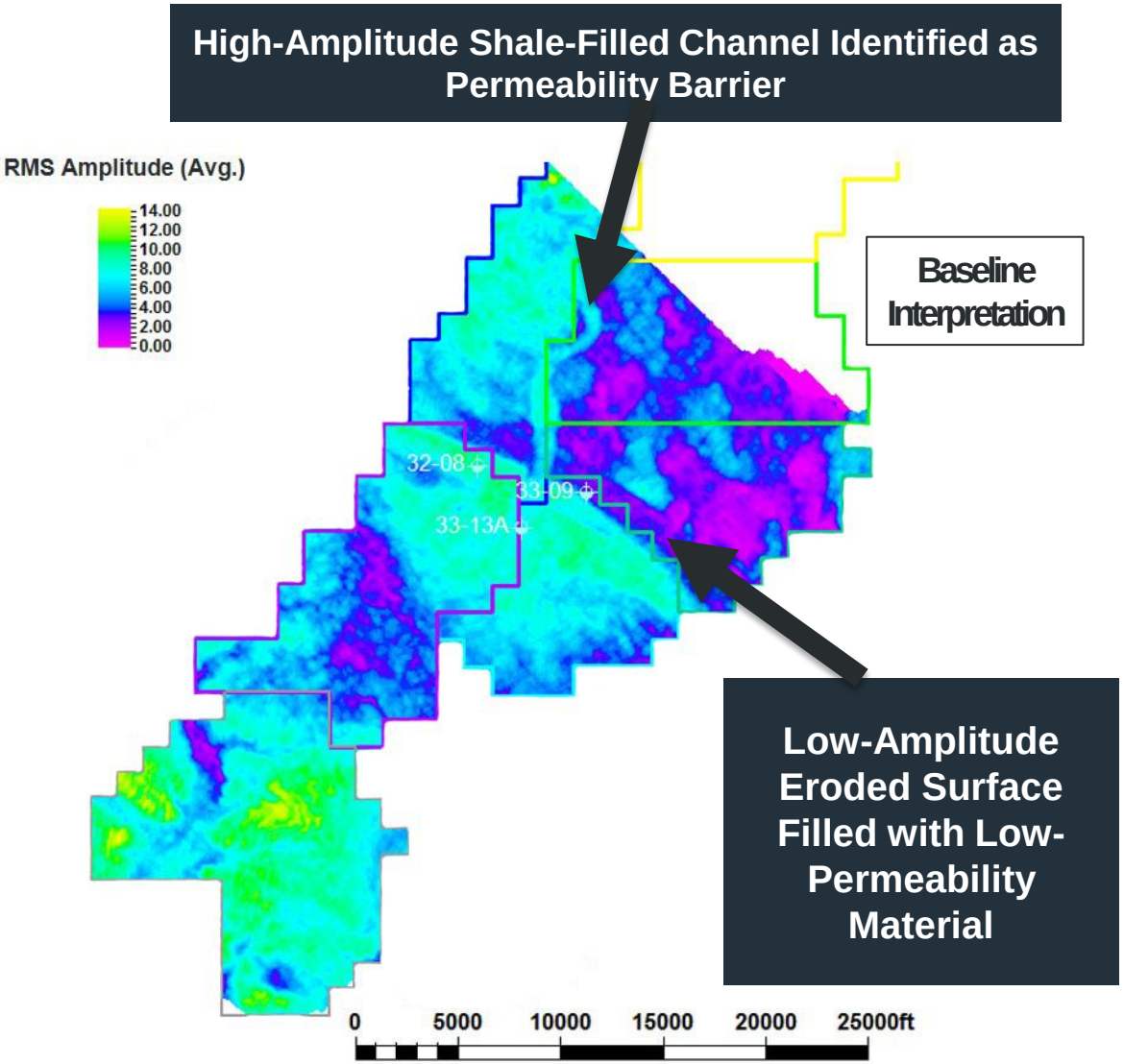



# BASELINE 3-D SEISMIC SURVEY

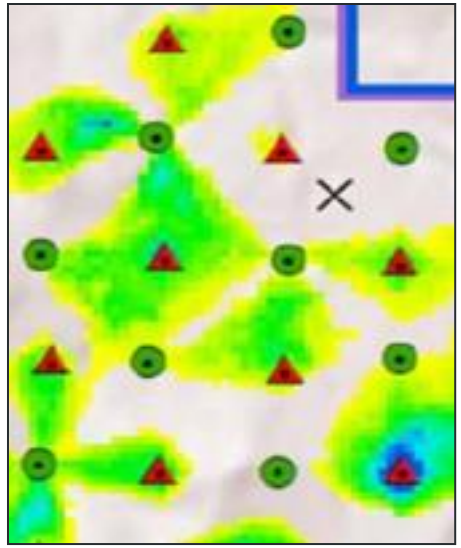



- 104-km Baseline Survey (August 2012)

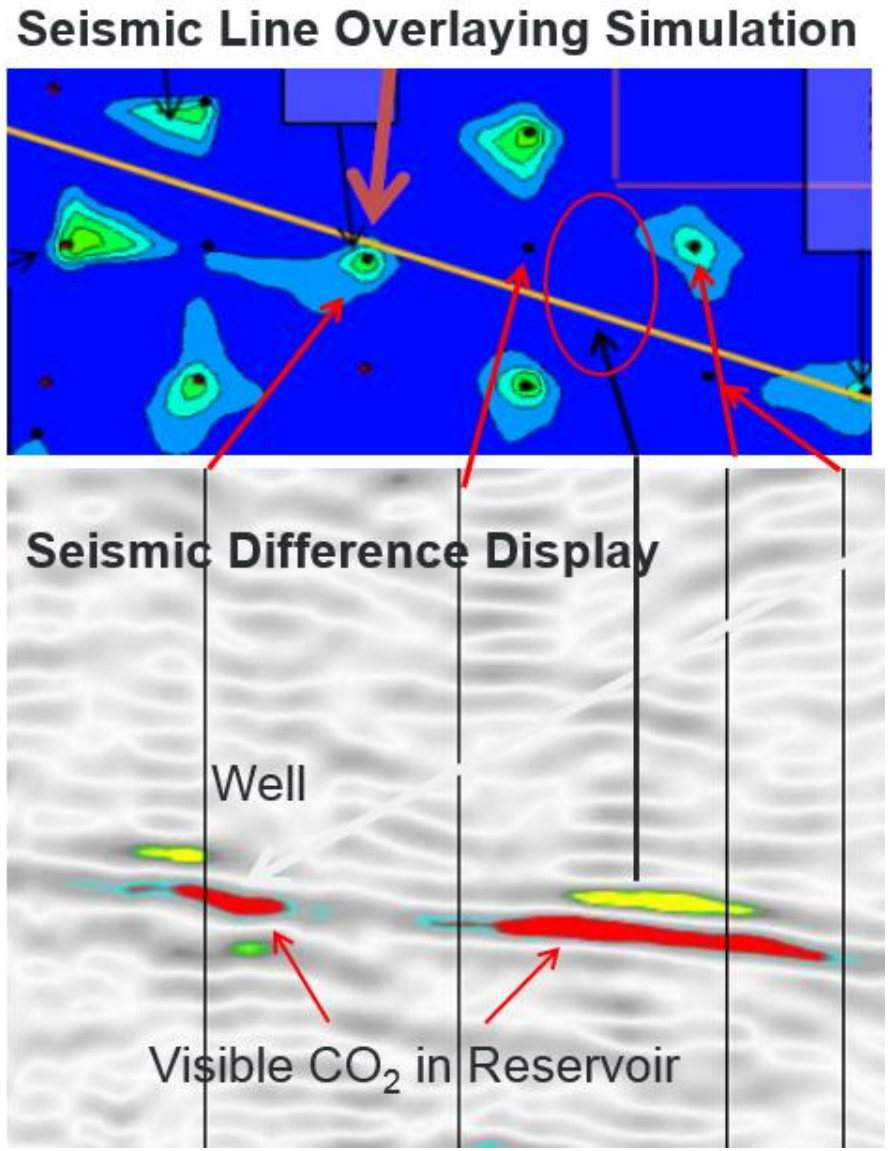


# SIMULATION-GUIDED MVA

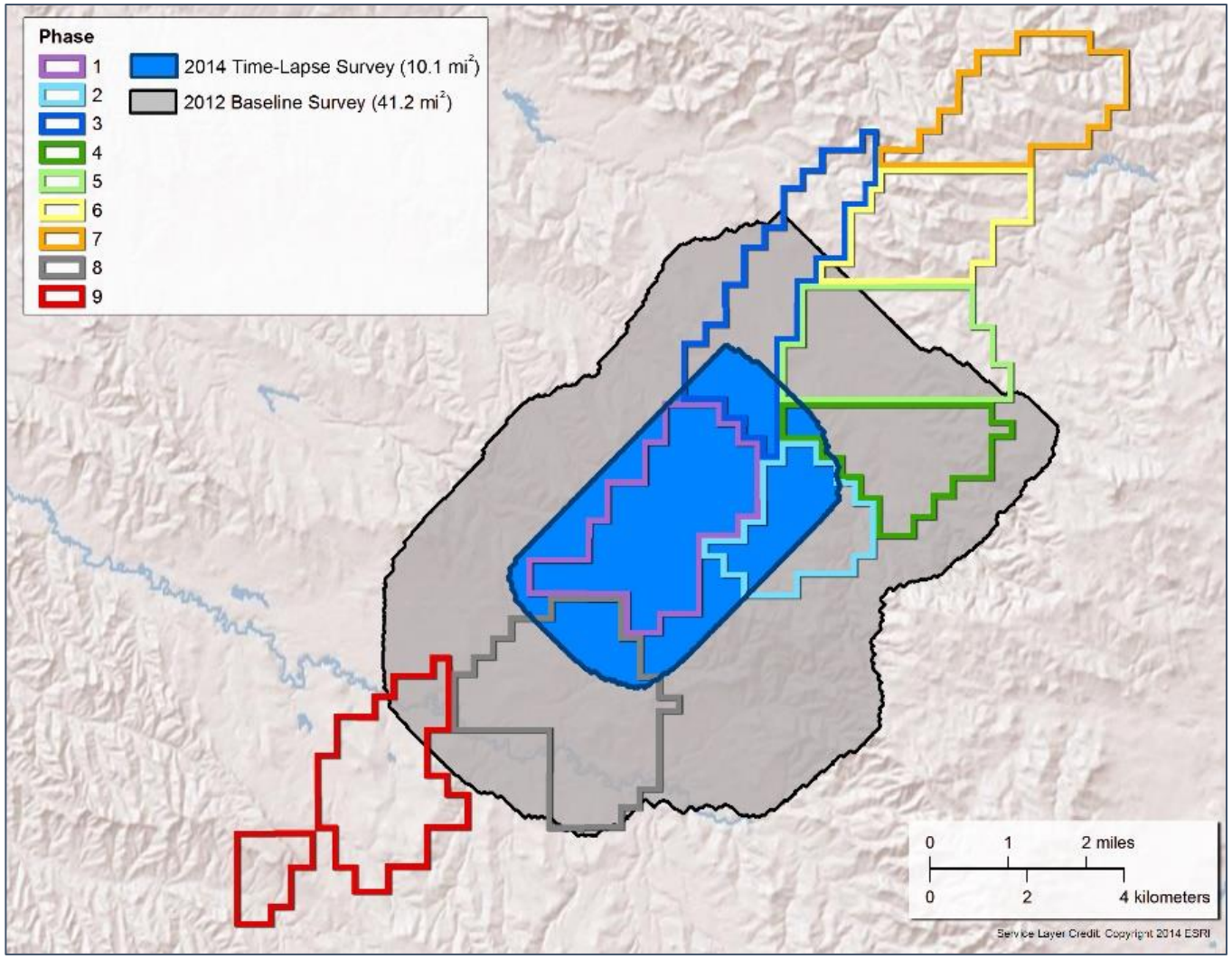
- Simulation was used to predict location and saturation of $CO_2$.
- 2-D seismic line used to confirm ability of seismic to detect $CO_2$ in the reservoir.
- Results supported decision to conduct large 3-D survey.



**Predictive Simulation Results ($CO_2$ plumes)**



# FIRST REPEAT 3-D SURVEY

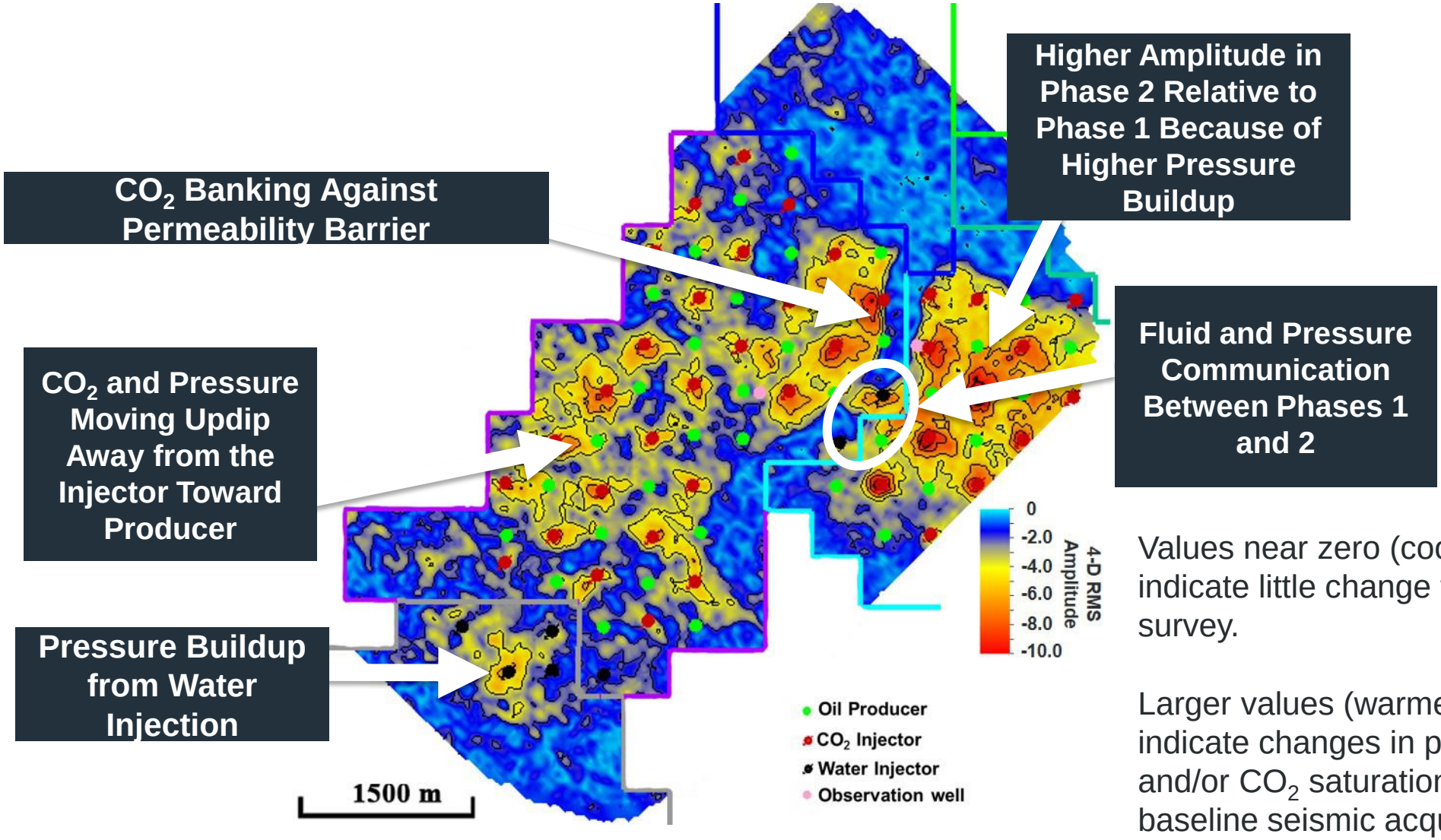



| Phase | Start of $CO_2$ Injection | Estimated Associated $CO_2$ Storage (Oct 2014), Mt |
|---|---|---|
| 1 | May 2013 | 1.04 |
| 2 | Dec 2013 | .166 |

Calculated using MBOG data.

- 26-km$^2$ repeat (October 2014).
- ~1.2 Mt $CO_2$ stored in monitored area at the time of survey.

# FIRST REPEAT 4-D DIFFERENCE INTERPRETATION (2012–2014)

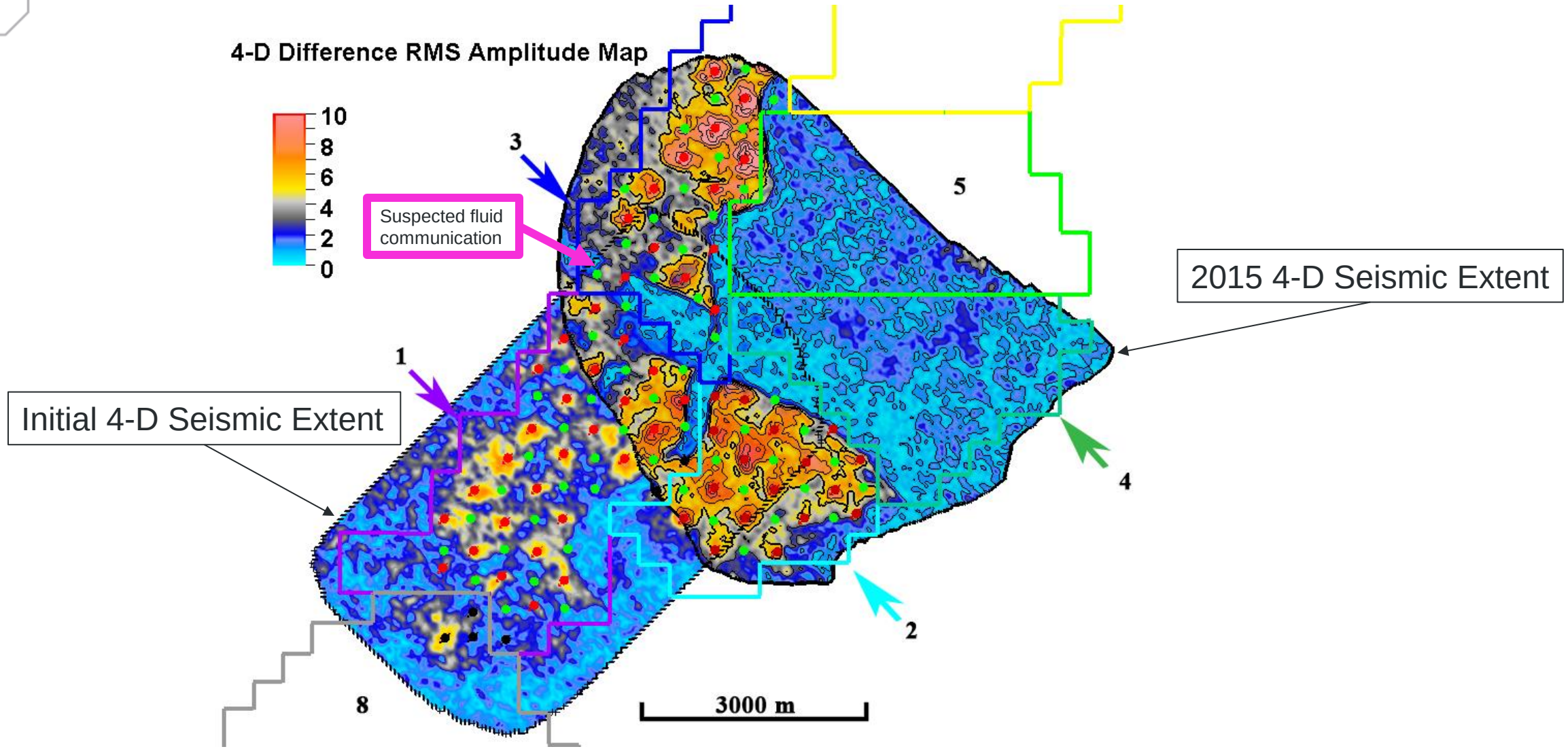



Values near zero (cooler colors) indicate little change from baseline survey.

Larger values (warmer colors) indicate changes in pressure and/or $CO_2$ saturation since baseline seismic acquisition.

# ADDITIONAL OBSERVATIONS

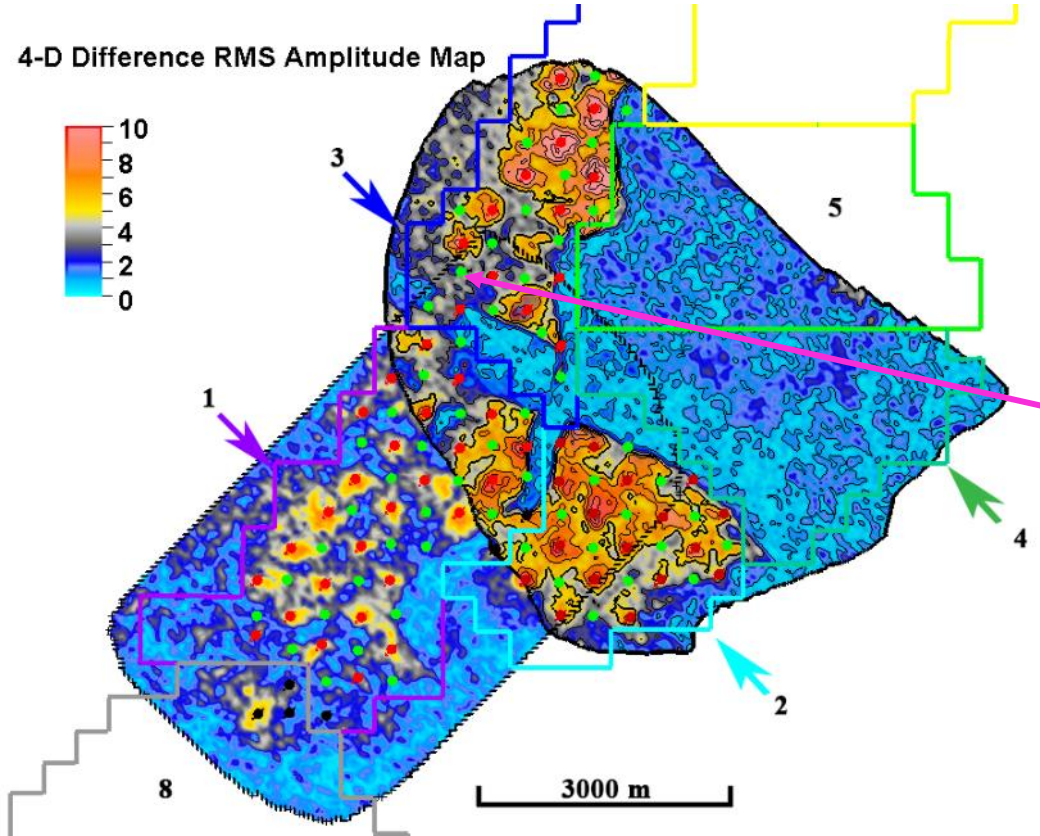
An additional 4-D seismic analysis (survey acquired in 2015) shows suspected fluid communication between the Phase 1 and 3 areas…

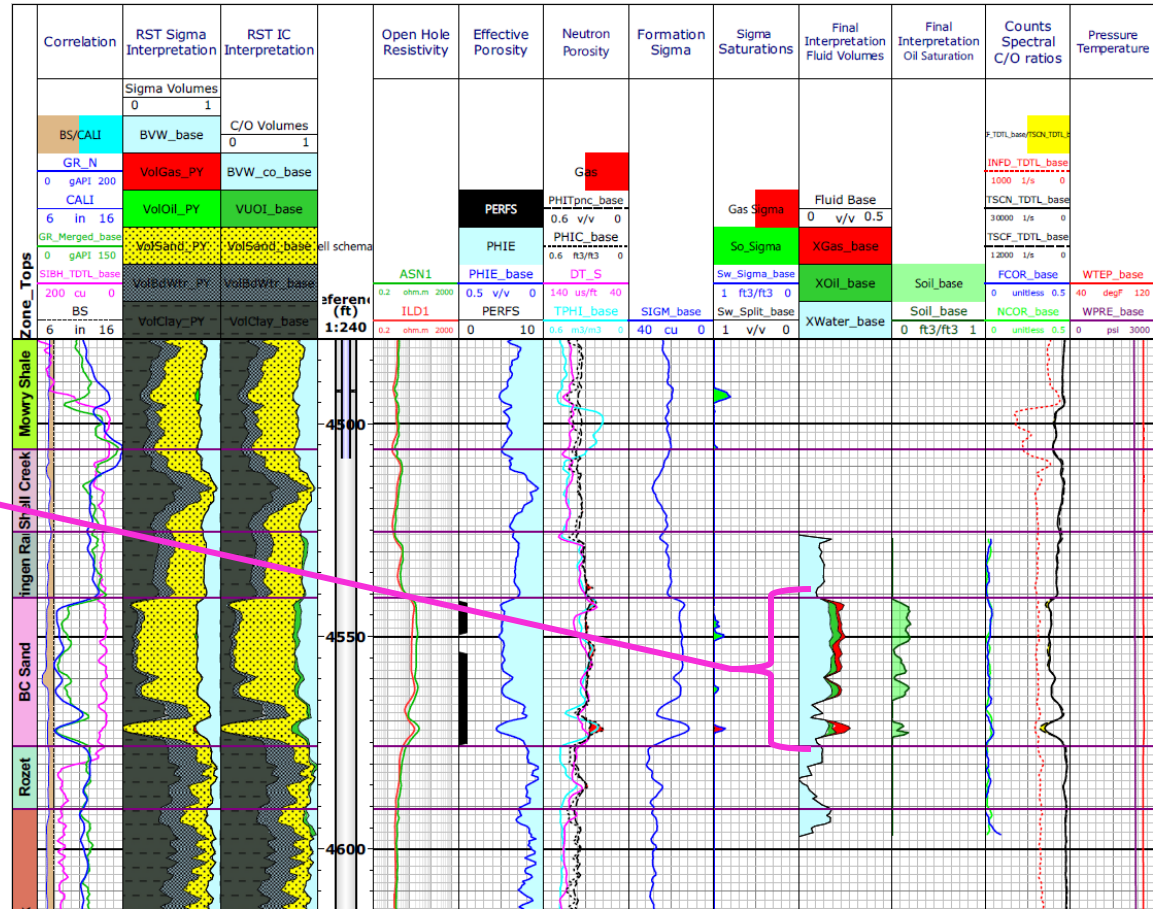


# WHAT DOES IT MEAN?

What does the change in amplitude response in 4-D investigations mean?

- The difference is due to comingled effects of changes in pressure and $CO_2$ saturation, which are difficult to distinguish from one another.
- However, initial investigation of pulsed-neutron logs acquired contemporaneously with the 2015 seismic survey indicate an average $S_{CO2}$ of 3%–4% over an interval of 20 feet is detectable (at a minimum) in Bell Creek 4-D seismic.



# IMPORTANT LEARNINGS FROM THE 4-D SEISMIC INVESTIGATION

- Permeability barriers (preventing fluid communication and pressure dissipation) have been illuminated where they were masked previously in the baseline seismic.
- Cross-phase fluid communication has been identified.
- $CO_2$ accumulating updip along the western edge of the N–S permeability barrier is visible.
- $CO_2$ and pressure plumes associated with injection wells are clearly shown.
- Improved insight into the reservoir's interwell heterogeneity.
  - Yielded important details necessary to adapt static models, enable better history matching, and increase accuracy in predictive simulations.
- Provided actionable information for the engineers operating the field while demonstrating associated CO2 storage incidental to EOR.

# CONTACT INFORMATION

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# THANK YOU!

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