Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small Scale CO_2 Injection

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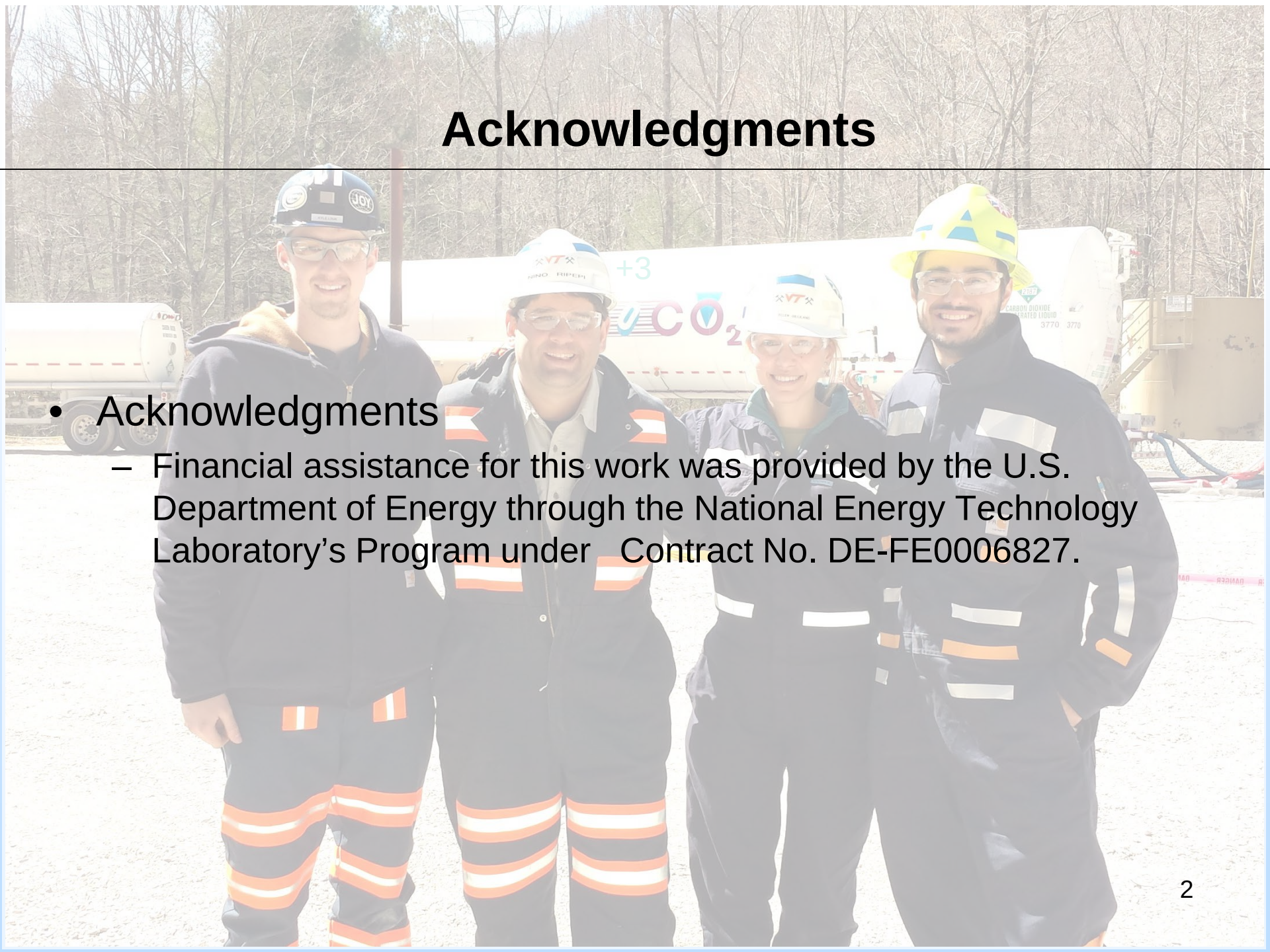
Acknowledgments



- Acknowledgments
  - Financial assistance for this work was provided by the U.S. Department of Energy through the National Energy Technology Laboratory's Program under Contract No. DE-FE0006827.

Project Overview: Goals and Objectives

- **Objectives:**
  - Inject up to 20,000 metric tons of CO2 into **3 vertical CBM wells** over a one-year period in Central Appalachia
  - Perform a small (approximately 400-500 metric tons) Huff and Puff test in a **horizontal shale gas well**
- **Goals**
  - Test the storage potential of unmineable coal seams and shale reservoirs
  - Learn about adsorption and swelling behaviors (methane vs. CO2)
  - Test the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery
- **Major tasks:**
  - Phase I: site characterization, well coring, injection design
  - Phase II: site preparation, injection operations
  - Phase III: post-injection monitoring, data analysis, reservoir modeling

Research Partners

- **Virginia Center for Coal and Energy Research (Virginia Tech)** [1,2,3,4,5]
- Cardno [2,3]
- Gerald Hill, Ph.D. [1,4]
- Southern States Energy Board [1,5]
- Virginia Dept. of Mines, Minerals and Energy [3]
- Geological Survey of Alabama [3]
- Sandia Technologies [3]
- Det Norske Veritas (DNV) [4]
- Consol Energy (Research Group) [2,3]

[1] **Project management**
[2] **Operations**
[3] **Research**
[4] **Risk management**
[5] **Outreach**

Industrial Partners

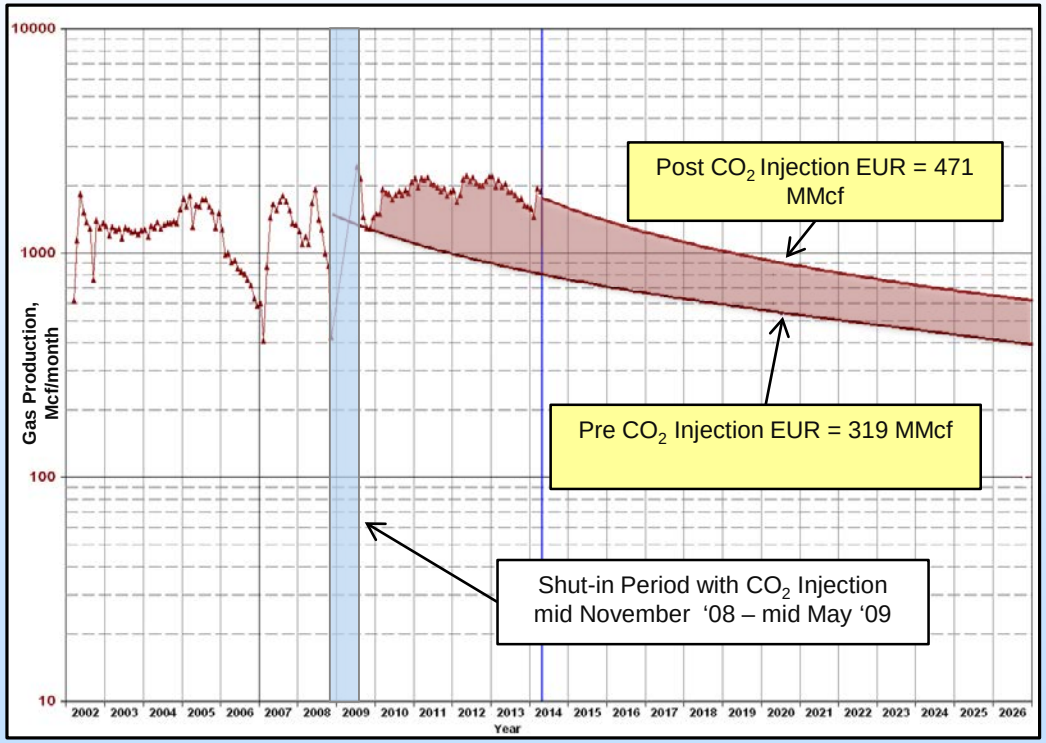
- **Consol Energy (CNX Gas)**
- Harrison-Wyatt, LLC
- Emory River, LLC
- Dominion Energy
- Alpha Natural Resources
- Flo-CO2
- Praxair

Collaborators

- Schlumberger
- Global Geophysical Services
- Oak Ridge National Laboratory
- University of Nottingham / British Geological Survey
- University of Tennessee
- University of Virginia
- Southern Illinois University
- Oklahoma State University

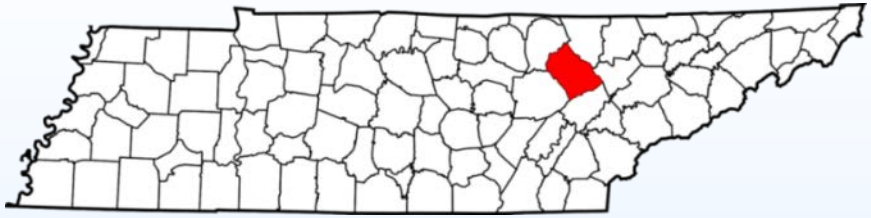
Previous Experience in Huff and Puff Test in Russell County, Virginia (2009)

Production curve for huff-and-puff test well, Russell County, Virginia, 2009

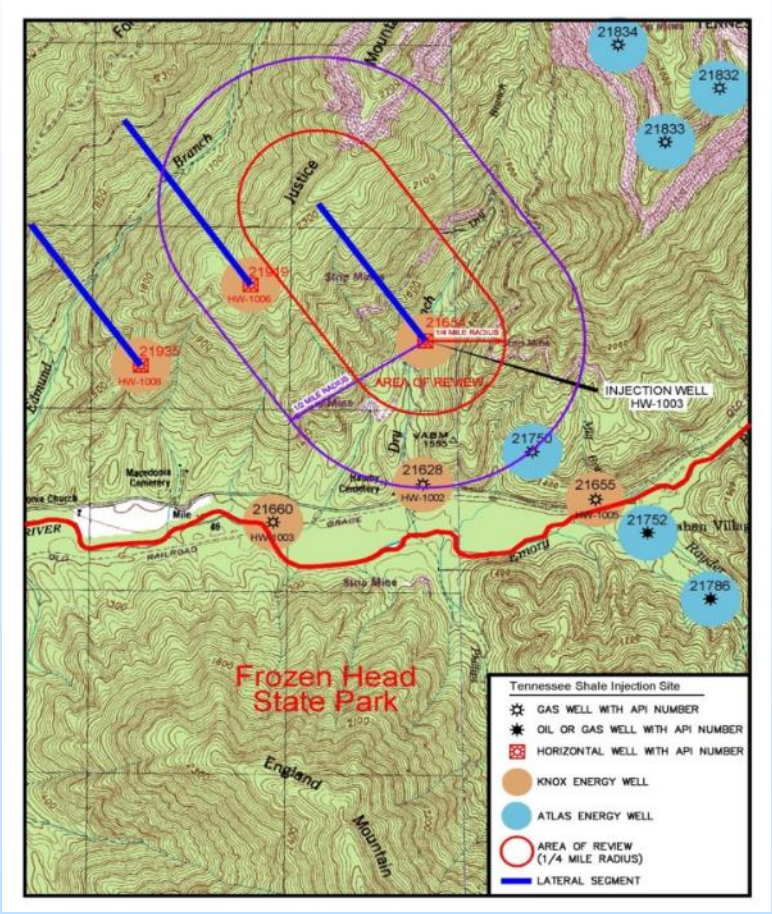


- 1000-ton CO_2 injection
- Stacked coal reservoir
- Evidence of preferential adsorption: elevated N_2 and CH_4
- Enhanced CH_4 recovery at two offset wells, no CO_2 breakthrough
- 30% CO_2 in flowback over 7 years
- **EUR of test well has increased by 48 percent**

Shale CO_2 Injection Test (510 tons) Morgan County, Tennessee



- **Horizontal well in Chattanooga Shale formation, drilled in 2009**
- **Legacy producing gas well permitted under TDEC**
- **510 tons for “huff and puff” injection test**
- **<u>Injection period</u>: March 18-31, 2014 (14 days)**
- **<u>Shut-in period</u>: March 31- July 29, 2014 (~4 months)**
- **<u>Flowback period</u>: July 29, 2014- present (~24 months)**
- **Current status: post-injection monitoring**



Shale CO_2 Injection Test in Morgan County, Tennessee

Operations Overview

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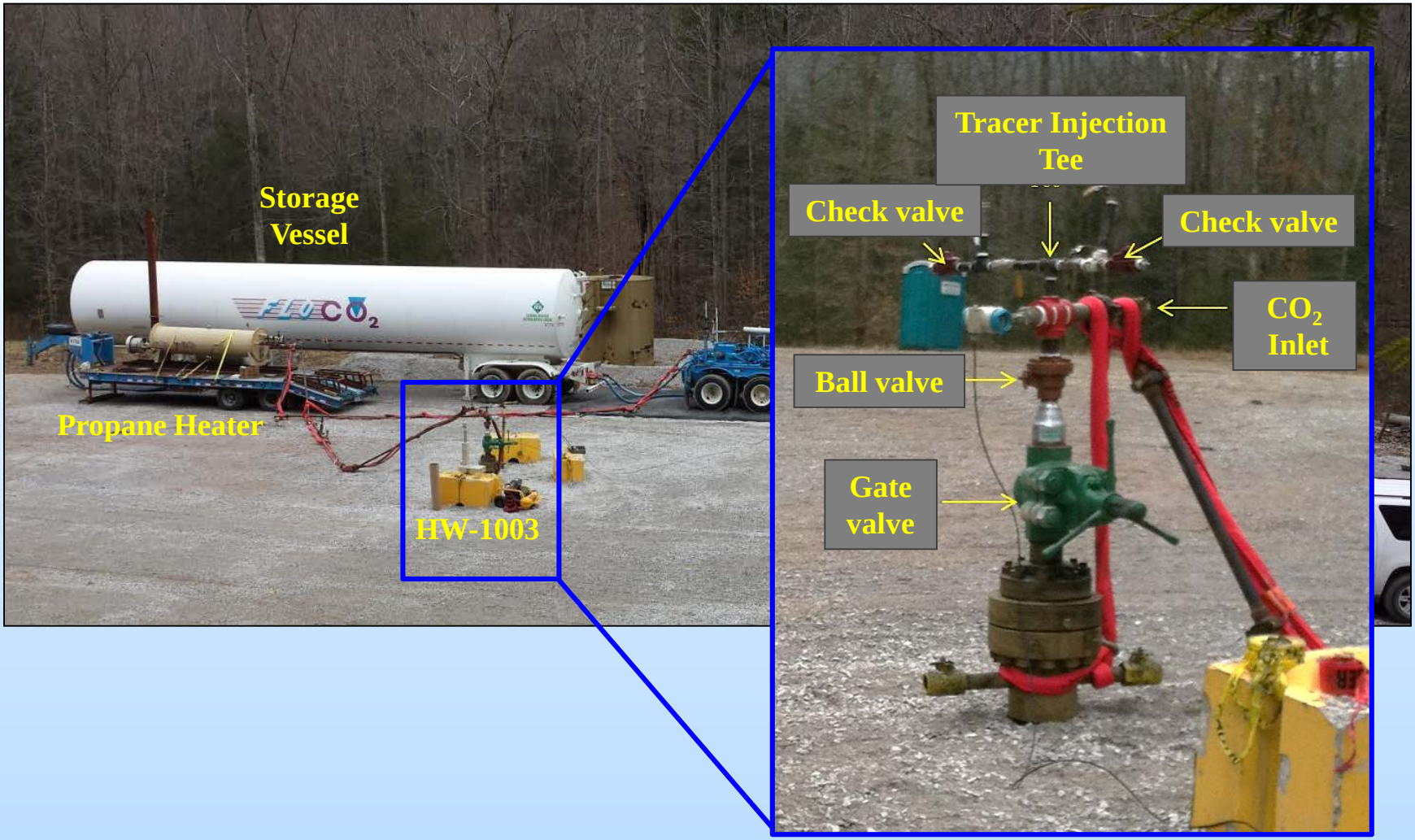
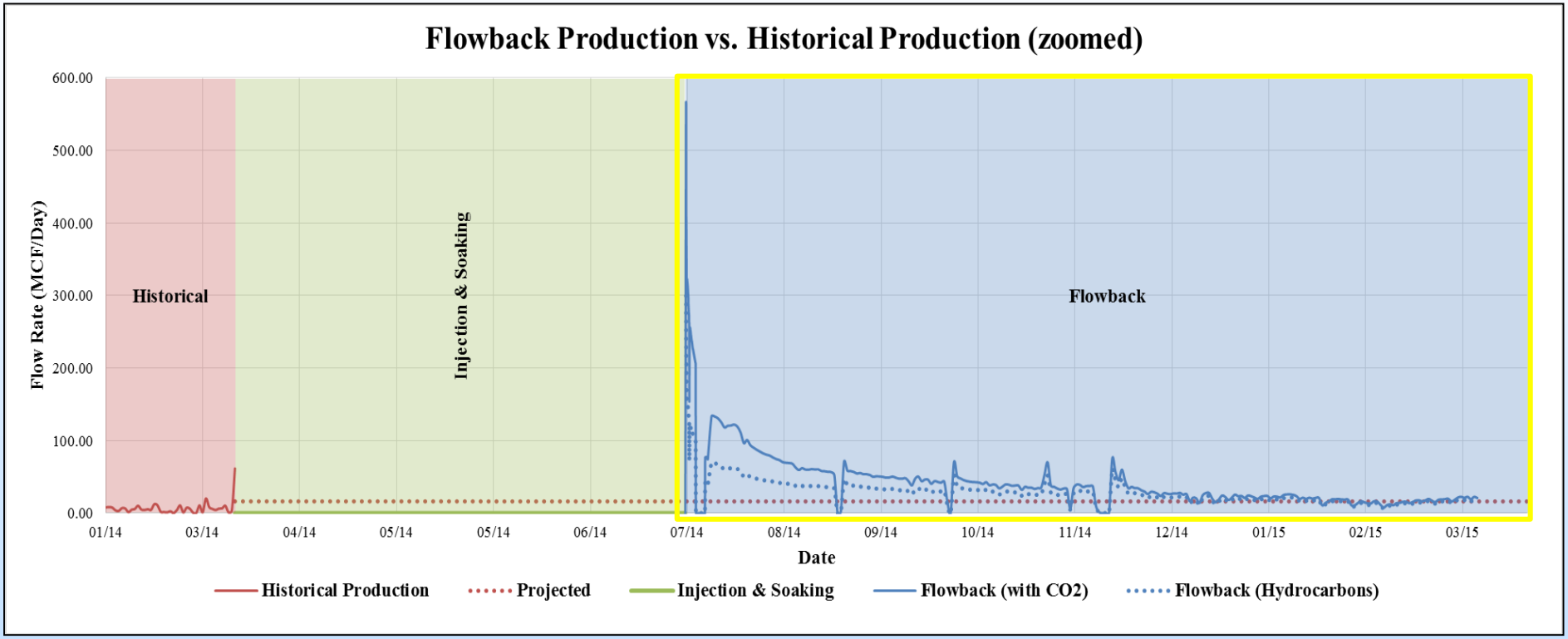


Shale CO_2 Injection Test in Morgan County, Tennessee

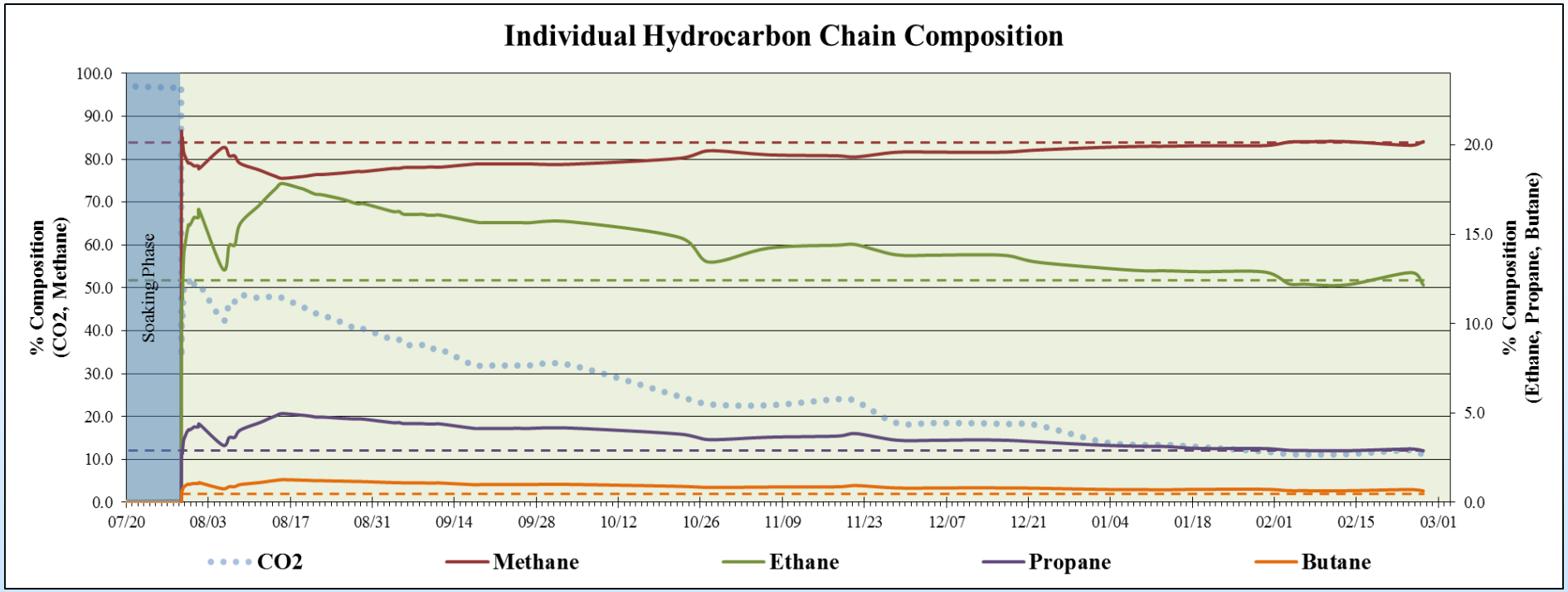
Flowback Results



- **EGR: An increase versus baseline production**
- **Correlated production of hydrocarbons and CO_2**
- **34 percent of injected CO_2 produced to date (173 tons)**

Shale CO_2 Injection Test in Morgan County, Tennessee

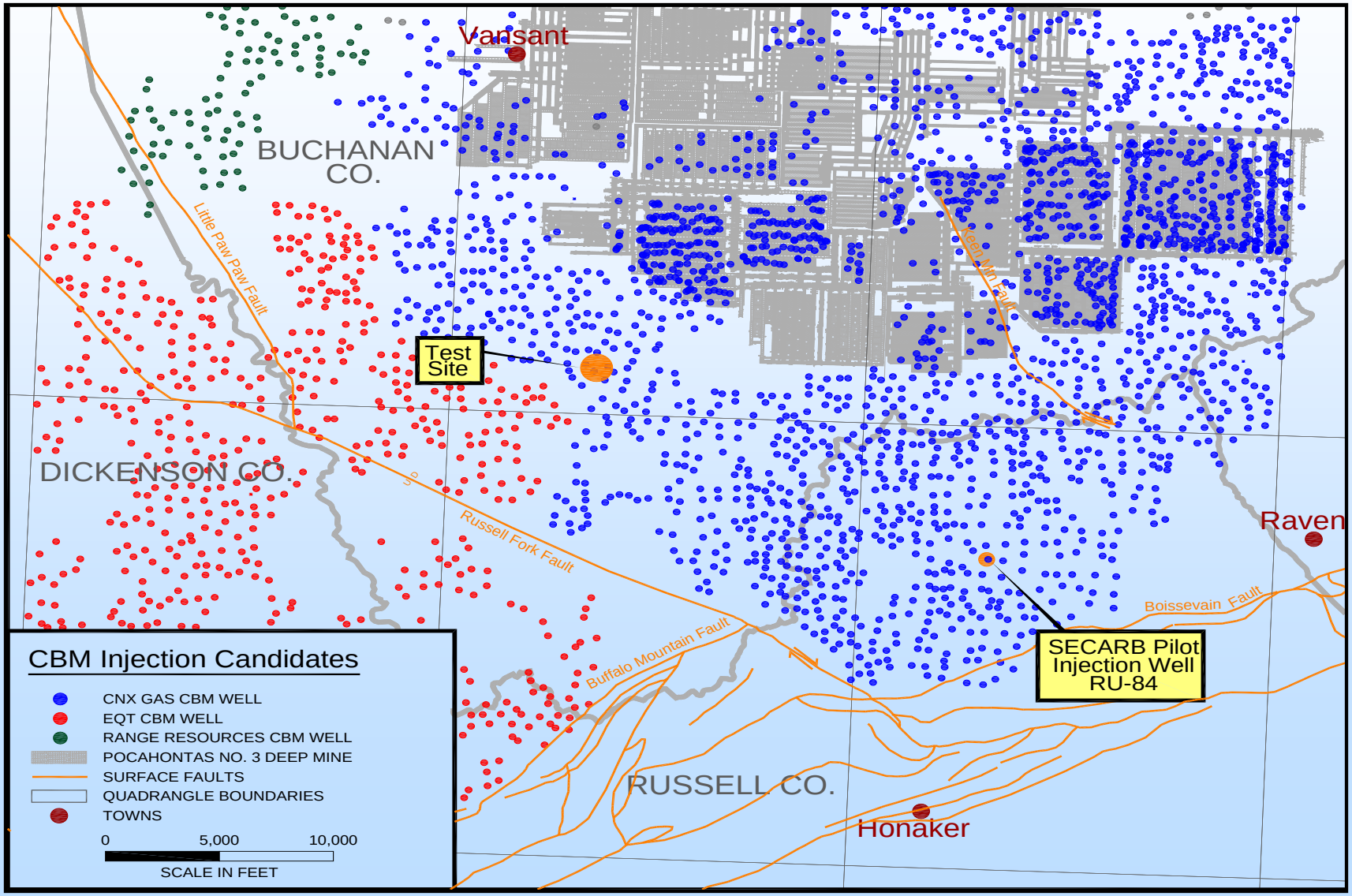
Results to Date



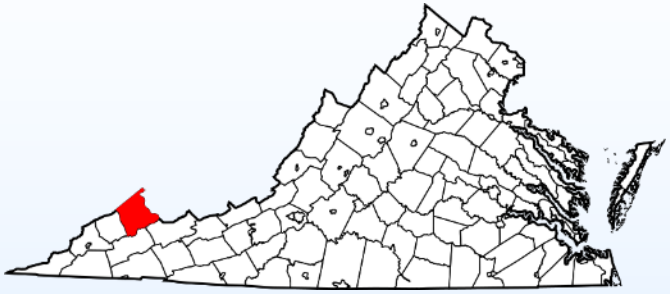
Production of heavy hydrocarbons elevated from baseline values:

- Role of pressure, viscosity and adsorption/desorption processes
- Enhanced recovery→ implications for other shale plays

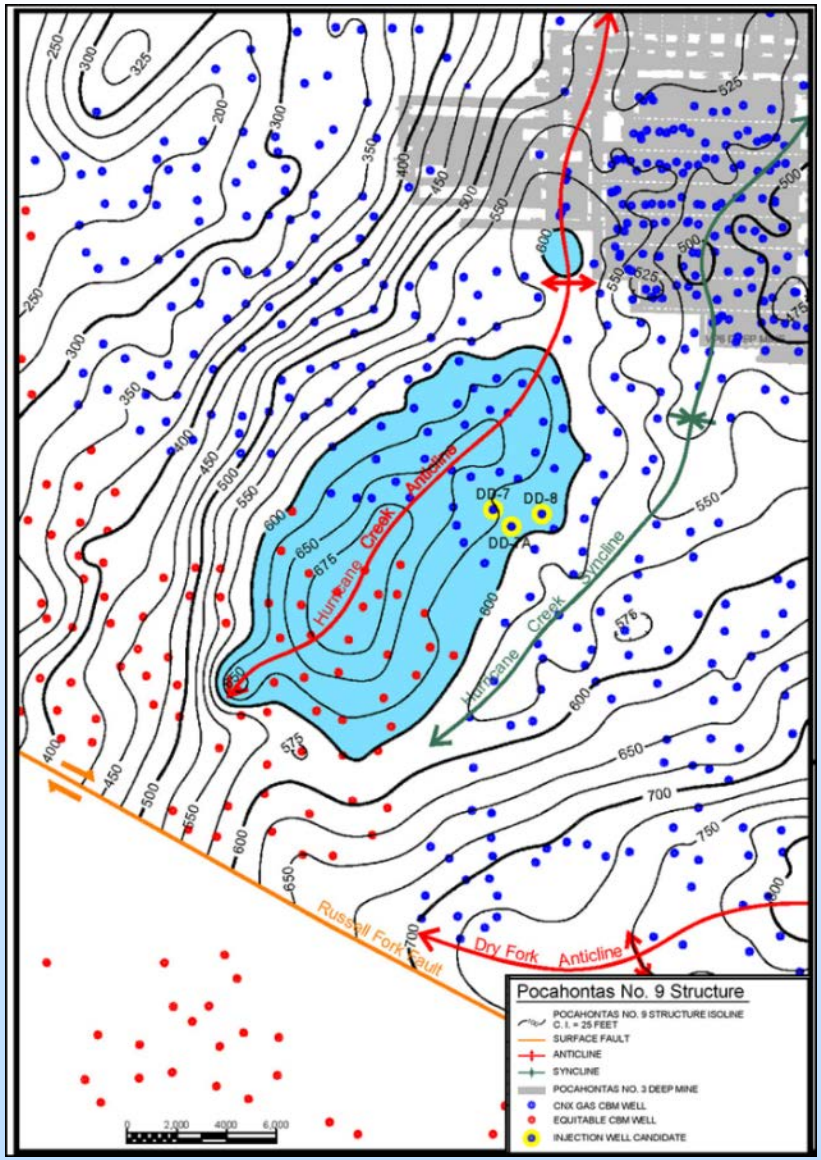
CBM Injection Test Sites
Russell and Buchanan Counties, VA



CBM CO_2 Injection Test in Buchanan County, Virginia



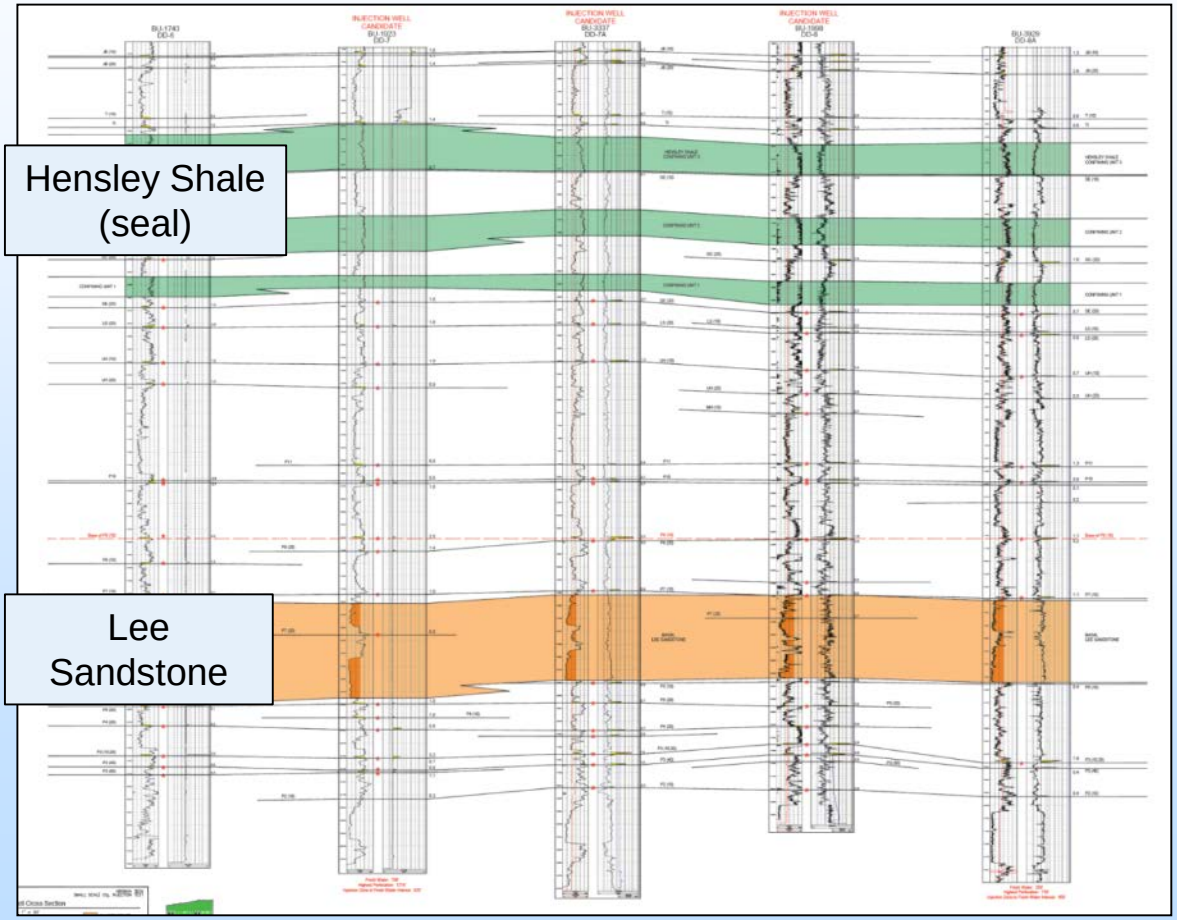
- Oakwood coalbed methane field
- Stacked coal reservoir, 15-20 seams
- Tight shale and sandstone confining units
- 14,000 tons CO_2 injected in two distinct Phases injection over 17 months in three legacy wells
- CO_2 storage + Enhanced gas recovery
- US EPA Class II UIC Permit
- Current status: Post-injection monitoring.



CBM CO_2 Injection Test in Buchanan County, Virginia

Reservoir Modeling

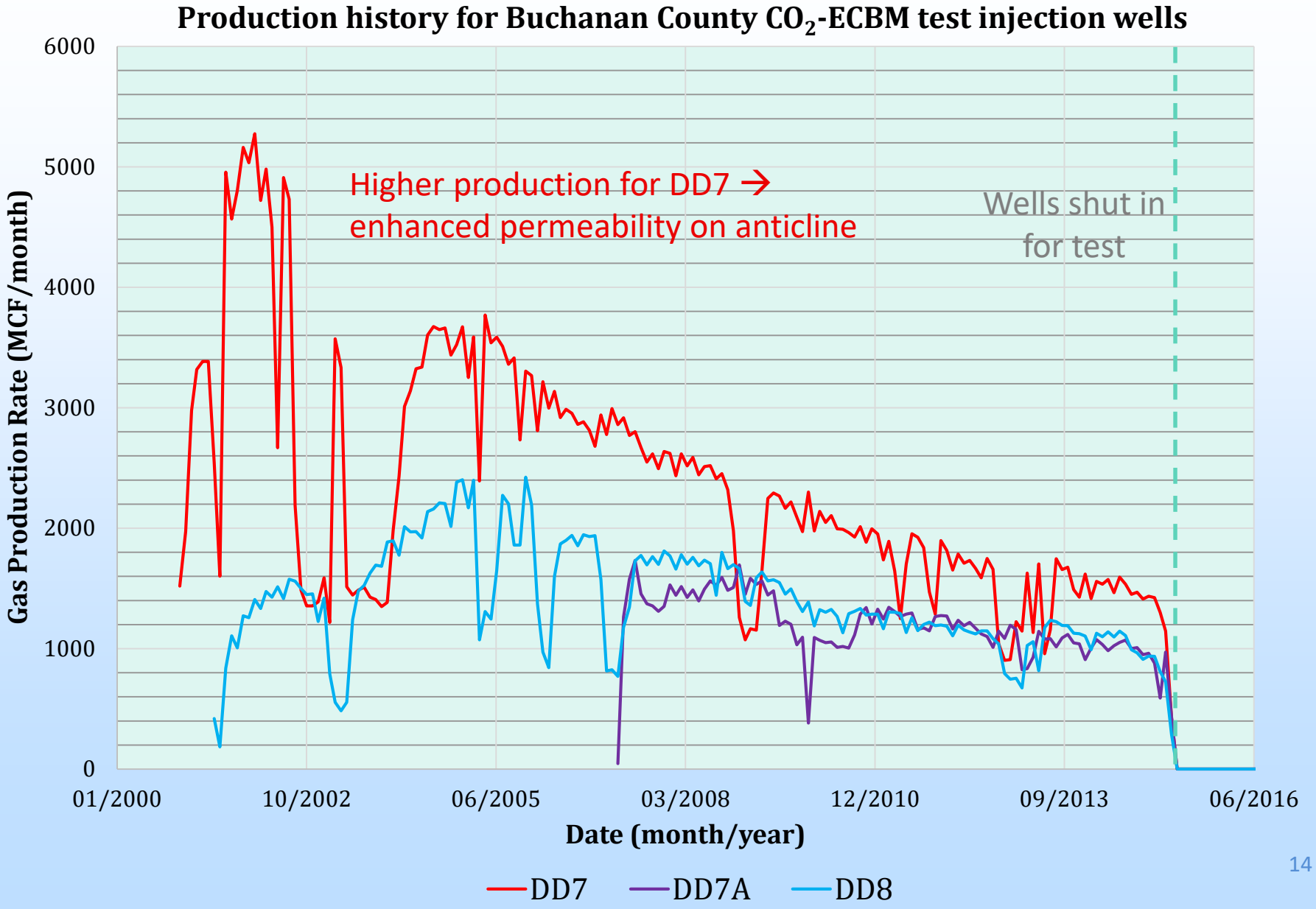
Stratigraphic cross section through injection wells



Modeling Considerations:

- 15-20 coal seams in injection zone
- Average seam thickness of 1.0 feet
- Depth range: 900-2200 feet
- Variable lateral continuity
- Intermediate and overlying seals
- Dynamic reservoir properties (active production operations)
- Multi-phase flow

Historical Monitoring: CBM Production Data



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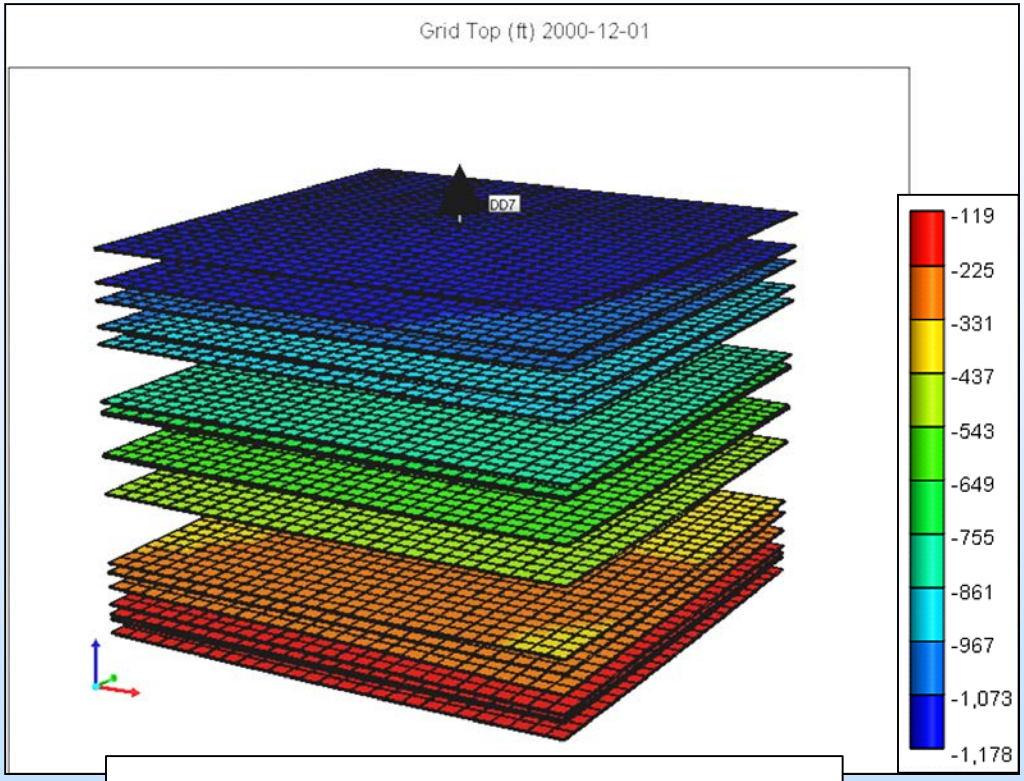
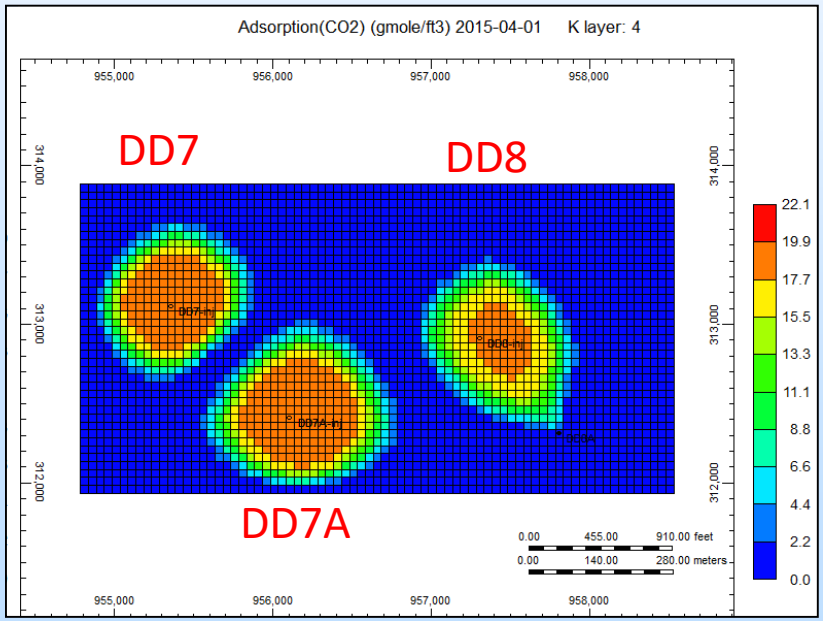


18-layer reservoir model

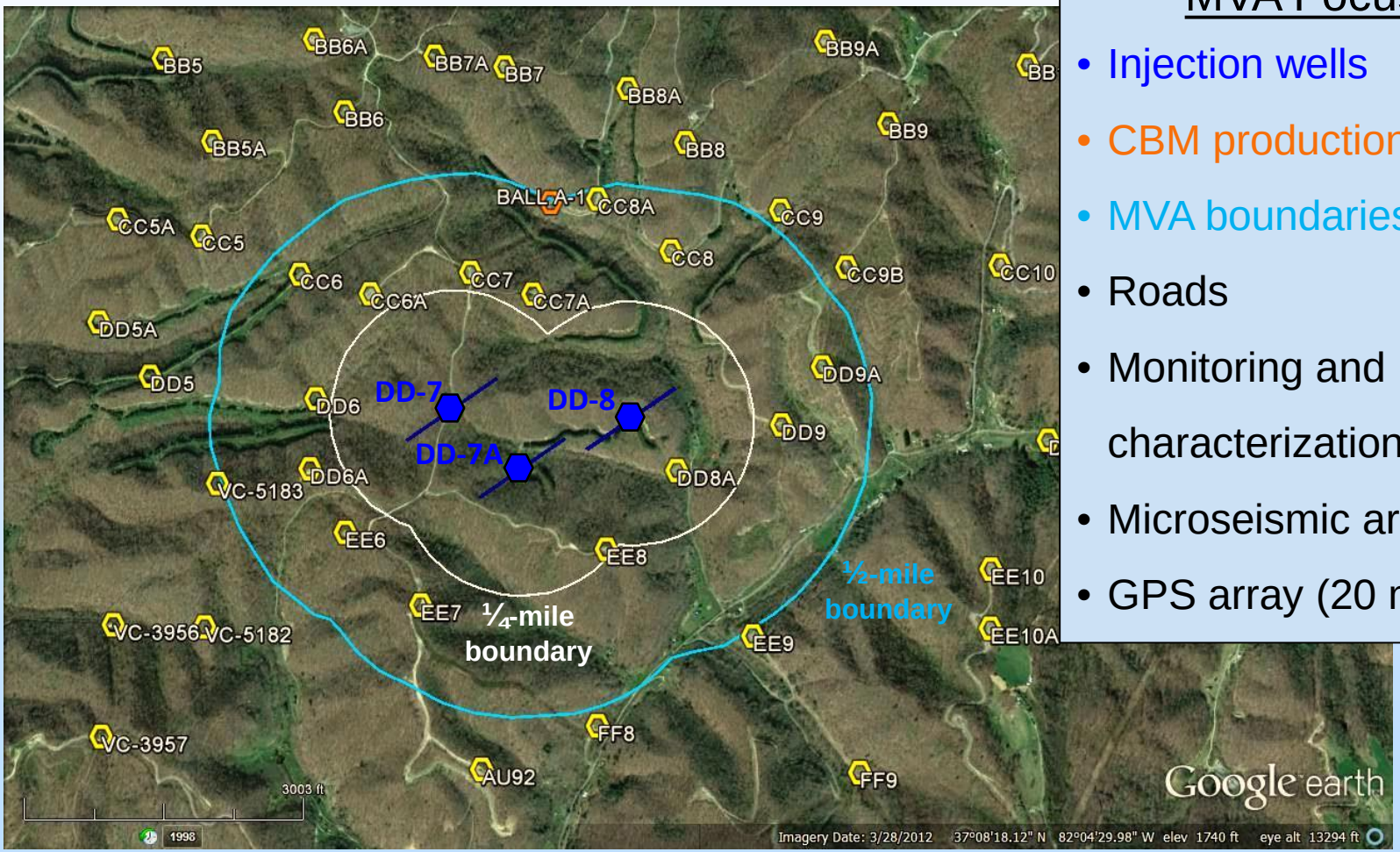
CO_2 Injection simulations used to define Area of Review (AOR) for monitoring program



CBM CO_2 Injection Test in Buchanan County, Virginia

Monitoring, Verification, and Accounting (MVA)

Oakwood Field Demonstration Site



MVA Focus Area

- Injection wells
- CBM production wells
- MVA boundaries
- Roads
- Monitoring and characterization wells
- Microseismic array (28 stns)
- GPS array (20 monuments)

CBM CO_2 Injection Test in Buchanan County, Virginia

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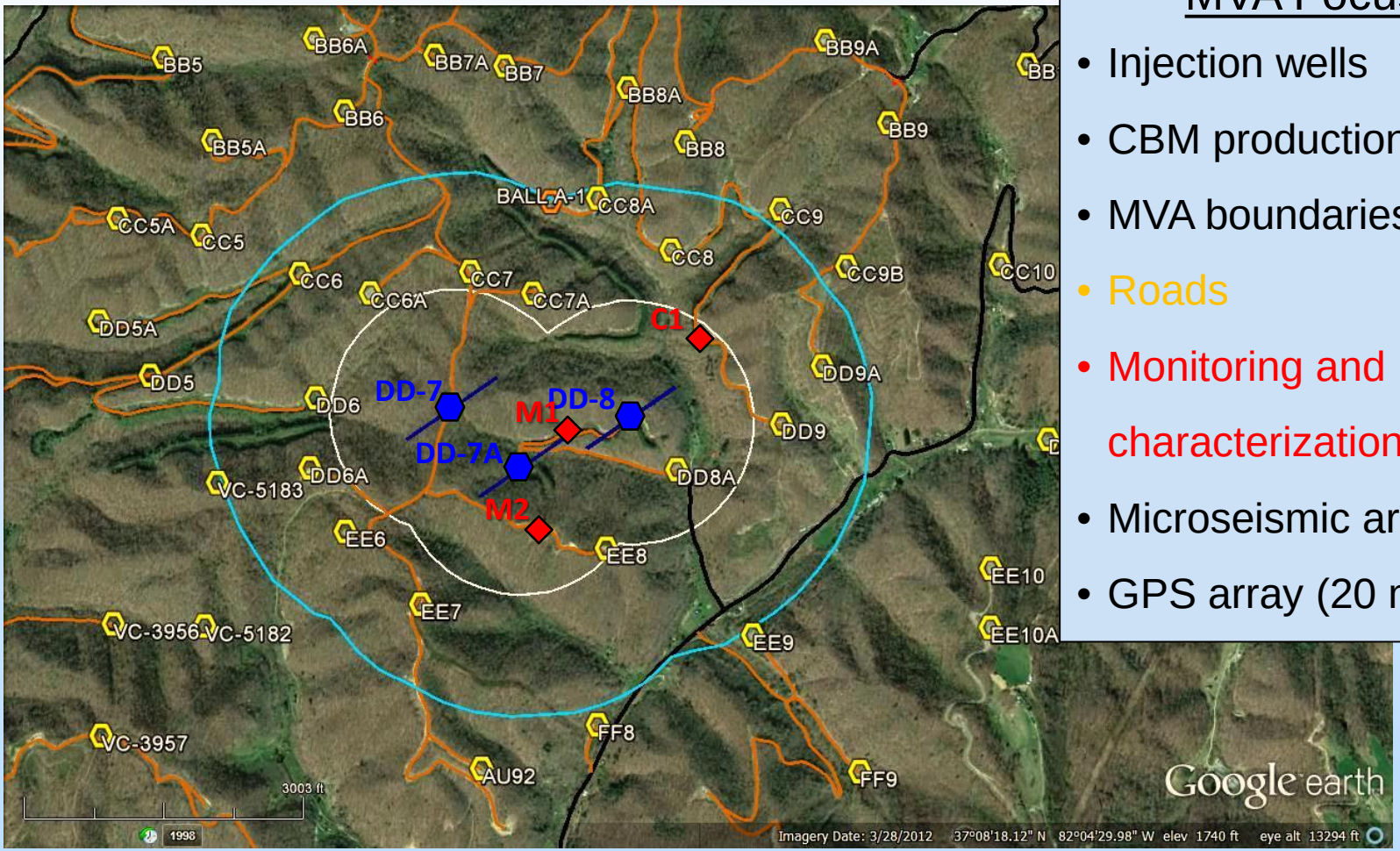

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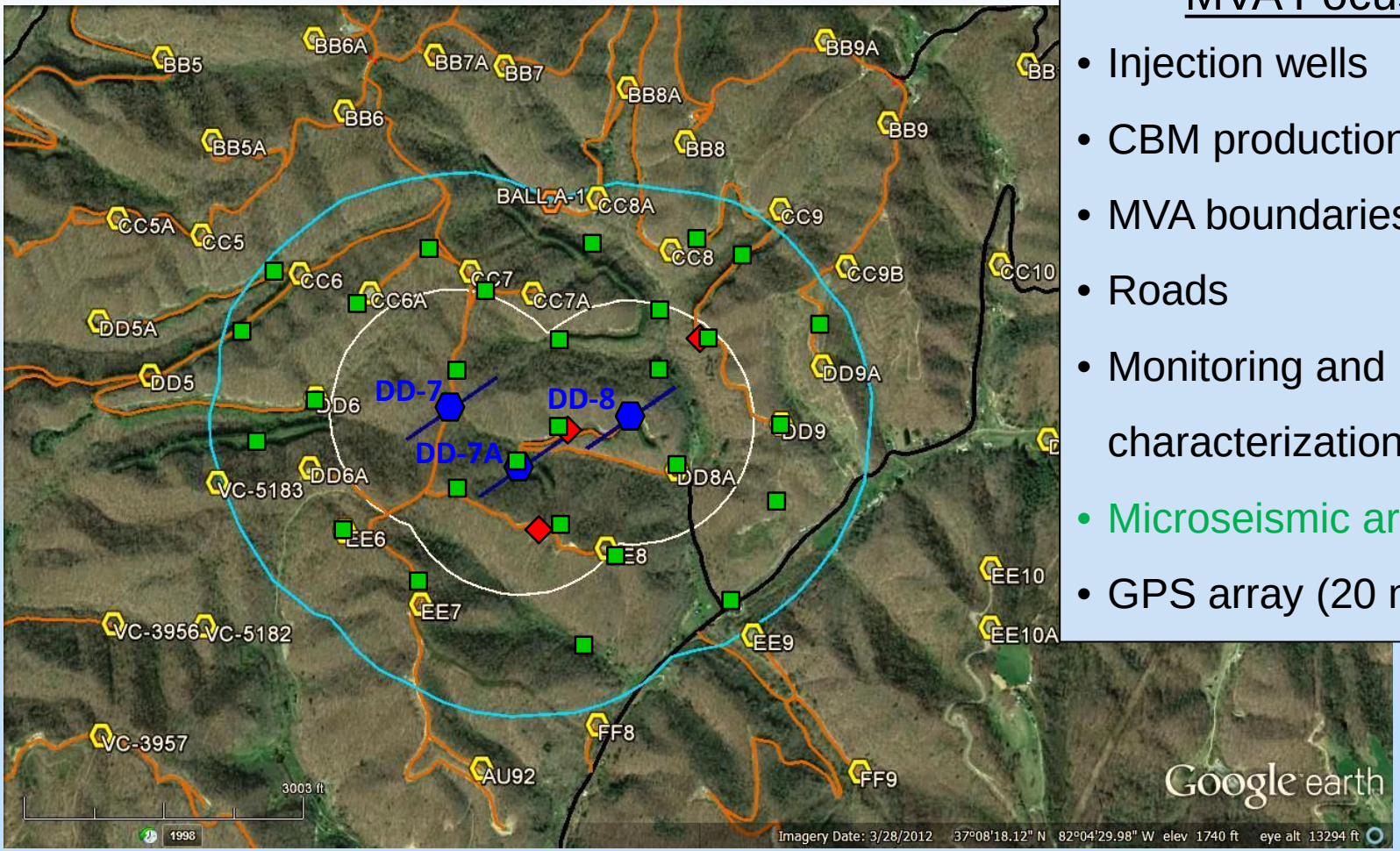

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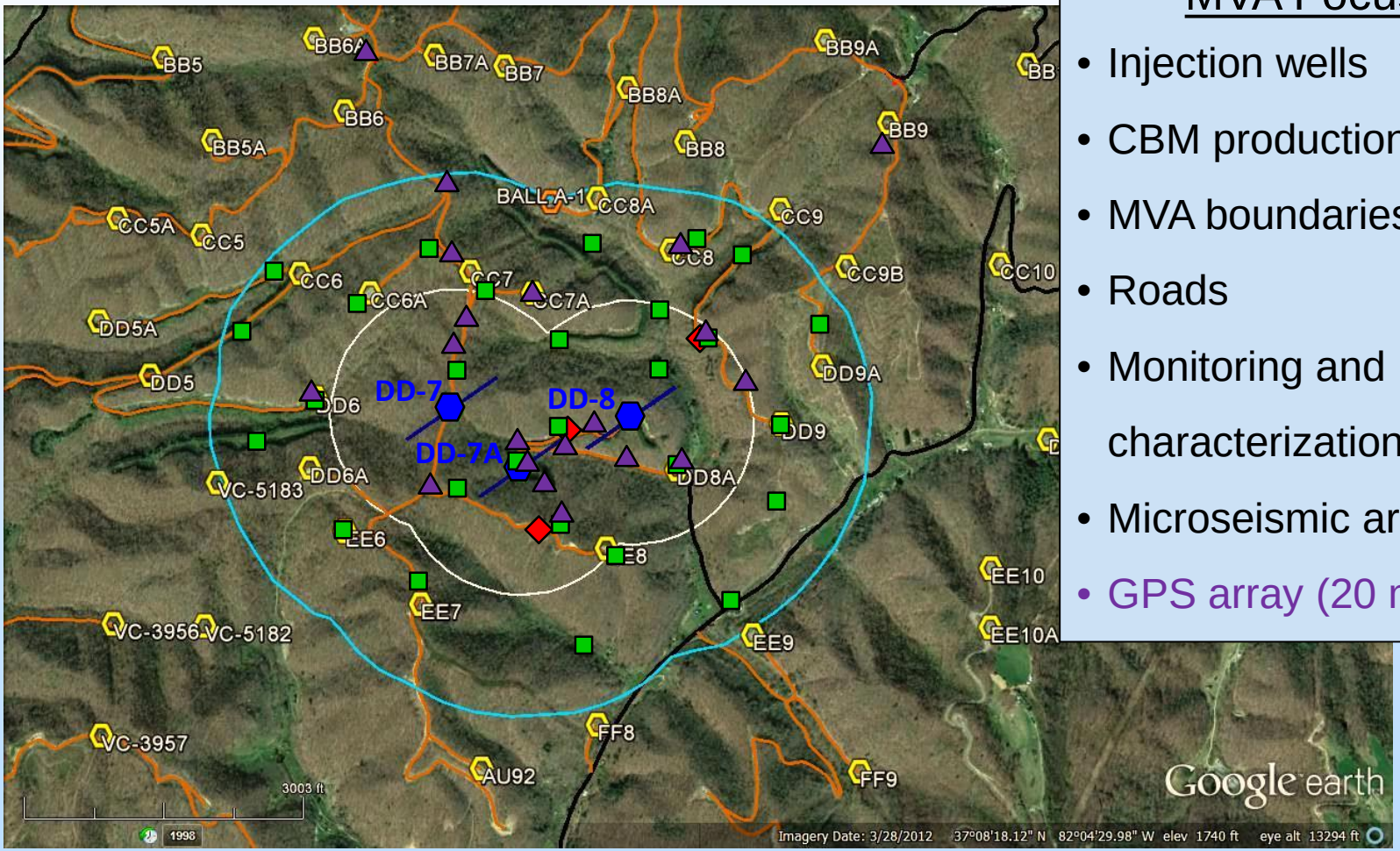

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CBM CO_2 Injection Test in Buchanan County, Virginia

Monitoring, Verification, and Accounting (MVA)

MVA Approach

Borehole-scale technologies:

- Pressure/Temperature
- Gas/H2O composition
- Tracers/Isotopes
- Formation logging

Technologies deployed over large areal extents:

- Microseismic/TFI
- Surface deformation measurement (GPS + InSAR)

- Combination of technologies will provide data sets with overlapping spatial and temporal scales.
  - Data will help distinguish signals from CO_2 operations vs. active CBM operations
  - Data sets will cross validate each other
- Selected technologies to address/overcome challenges of reservoir geometry and terrain

CO2 Storage and Delivery and Injection Skid

Injection Skid for 3 wells w/ Coriolis Flowmeters, Valves and Radio/Cell Communication

CO_2 Injection Parameters

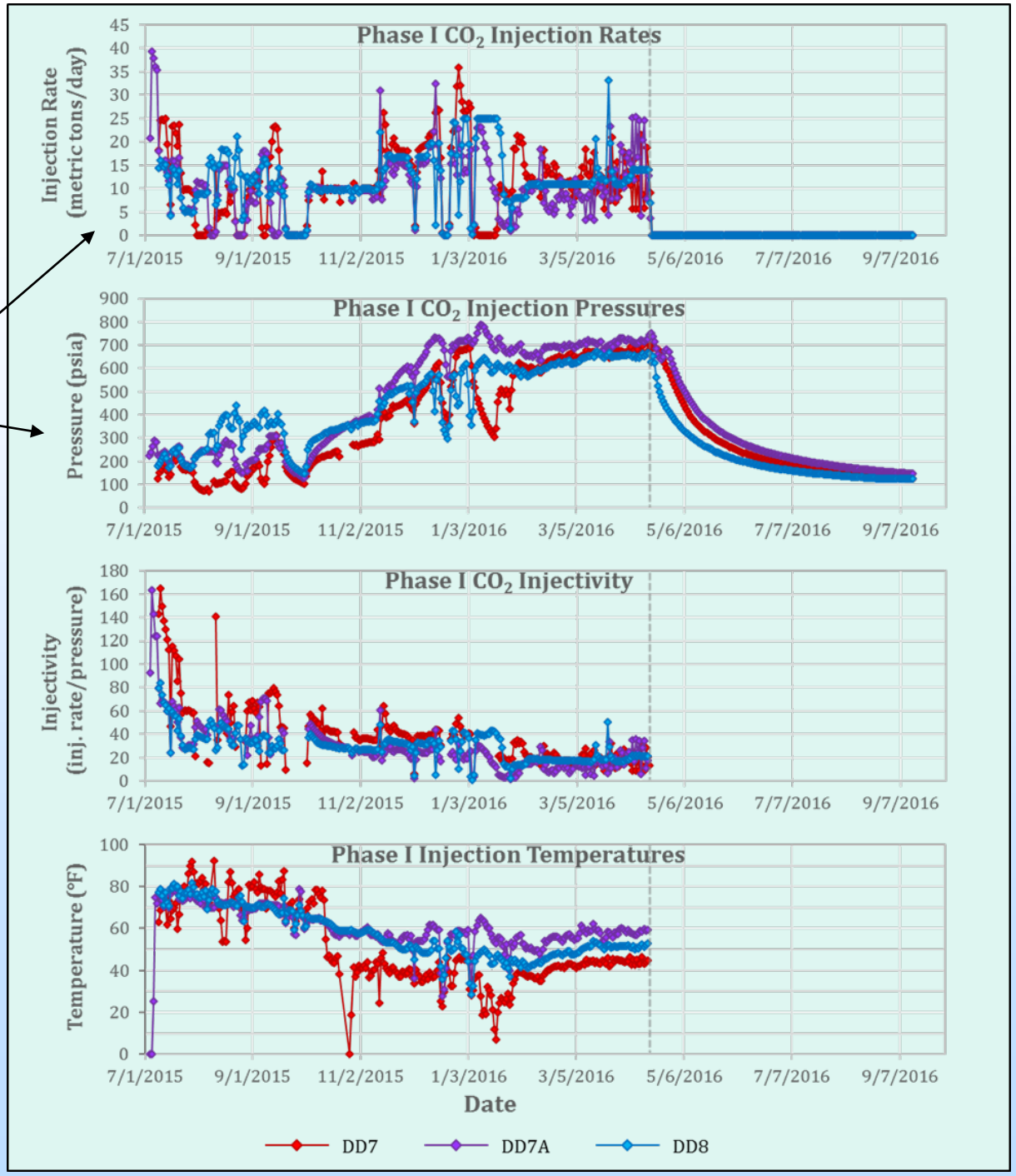
SCADA system:

- ~Continuous recording
- Remote access for monitoring and adjustments

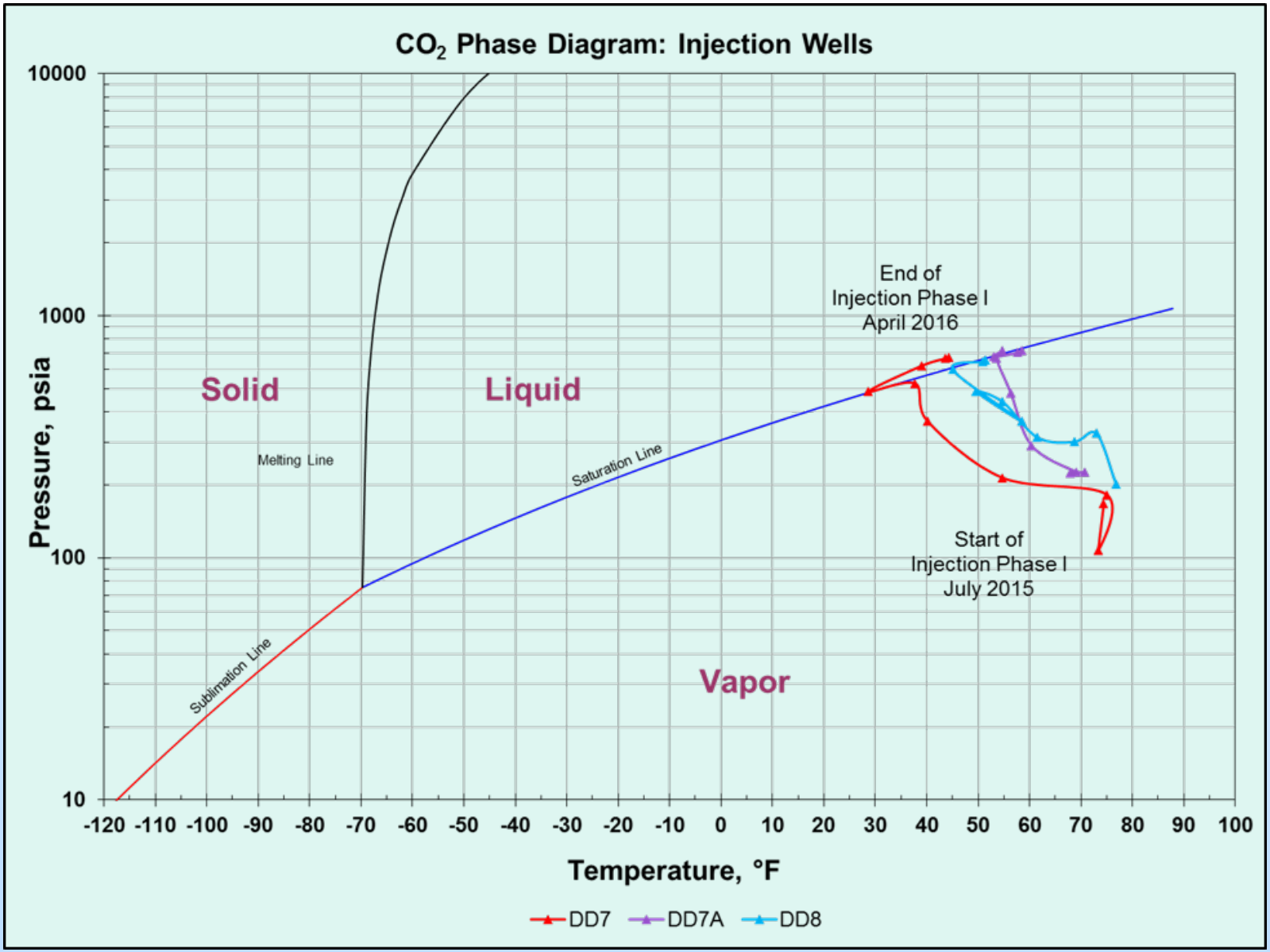
Expected correlation

CO_2 Injectivity= injection rate/pressure

- **Decreases w/ incr. pressure**
- **Levels out before zero**
- **Restored**

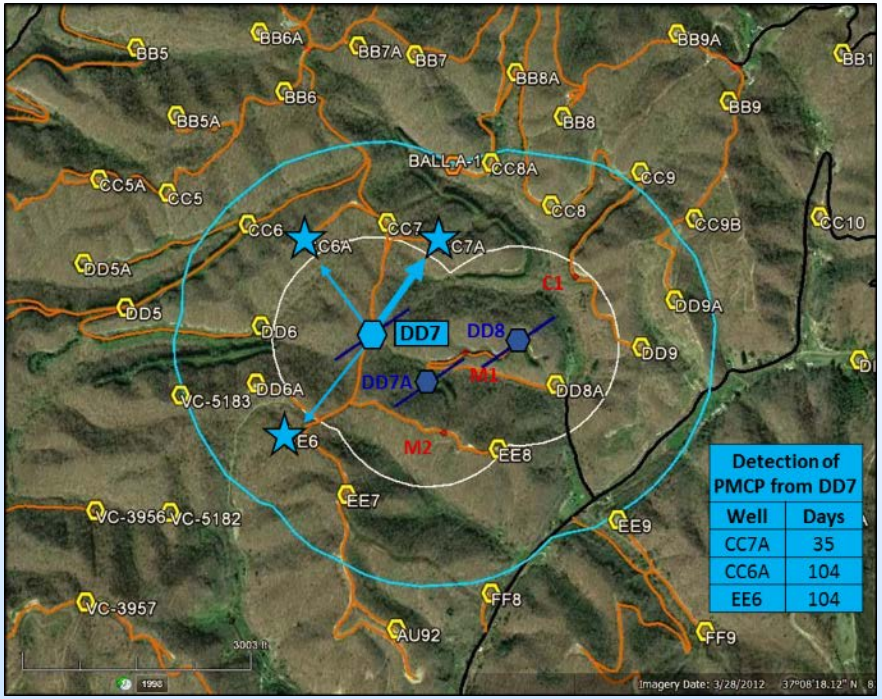


Transition from Gas → Liquid CO_2



Gas composition: Tracer Detection at Offset Wells

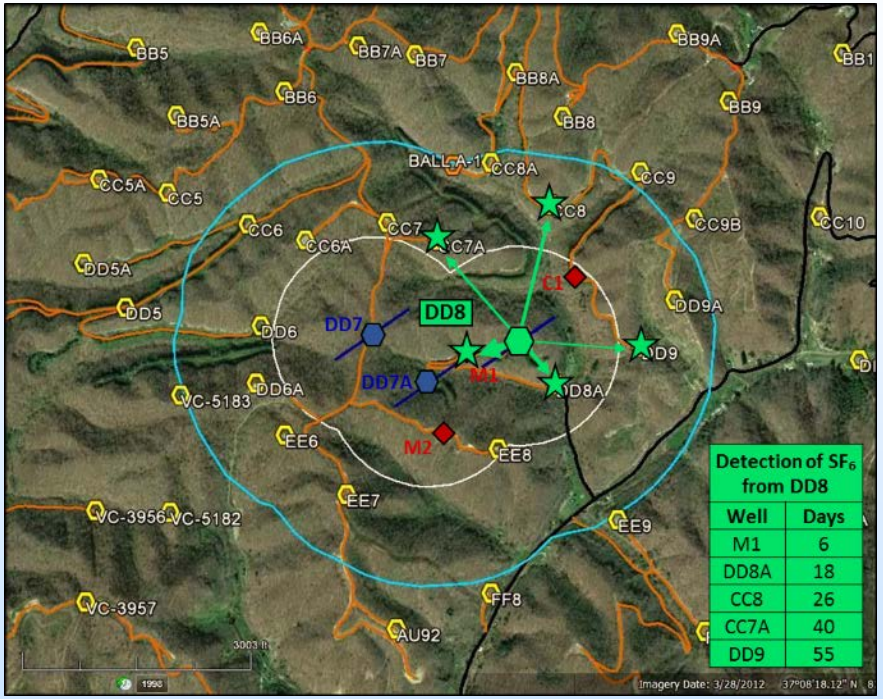
PMCP in DD7 water



Detection of PMCP from DD7

Well	Days
CC7A	35
CC6A	104
EE6	104

SF_6 in DD8 CO_2 stream

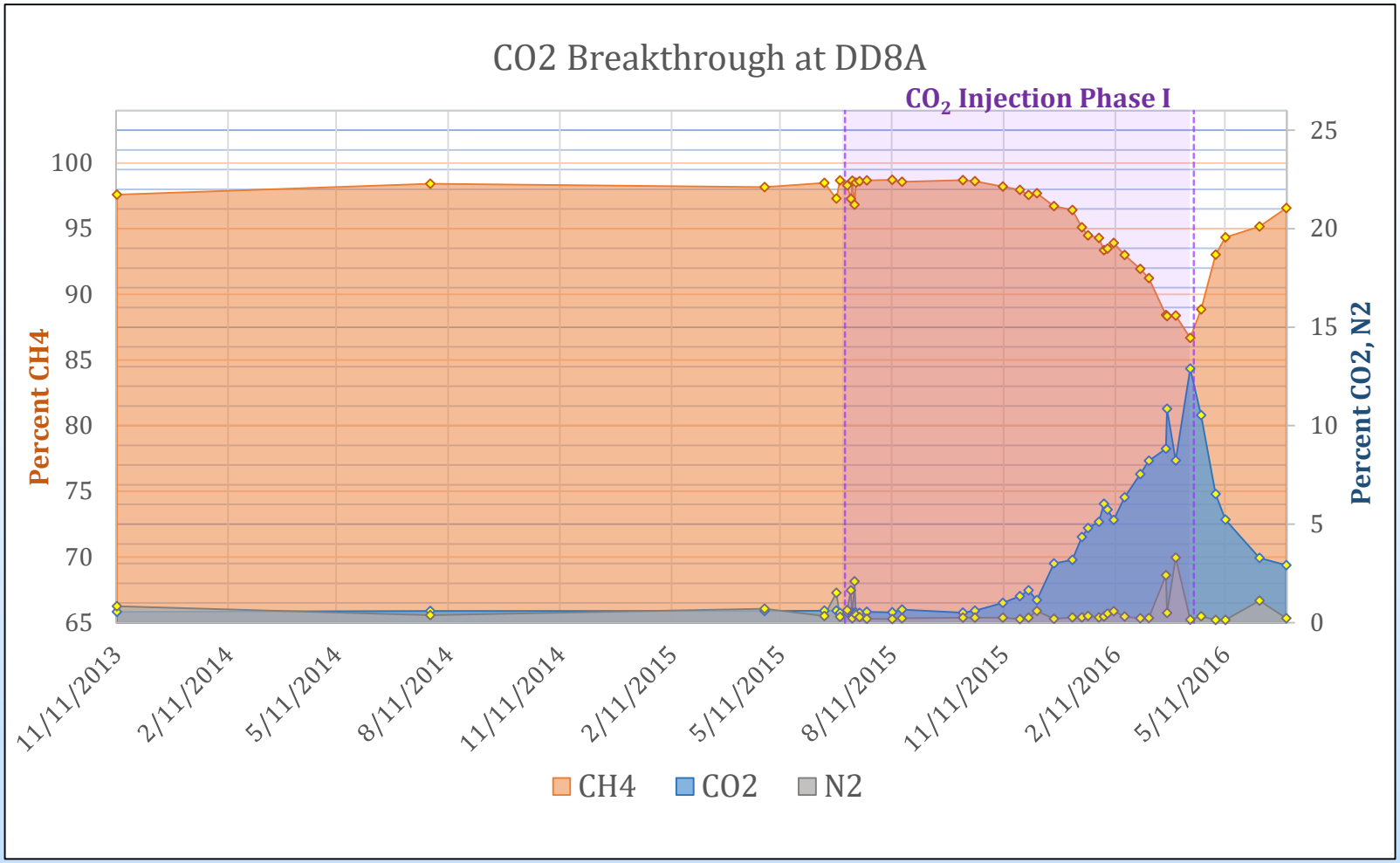


Detection of SF_6 from DD8

Well	Days
M1	6
DD8A	18
CC8	26
CC7A	40
DD9	55

- Three rounds of tracers:
  Start of injection, 15% of CO_2 target volume, 40% of CO_2 target volume
- Only tracers from start of injection detected
- For DD7, all detecting wells located west (up-dip); could encounter pressure interference from other injection wells

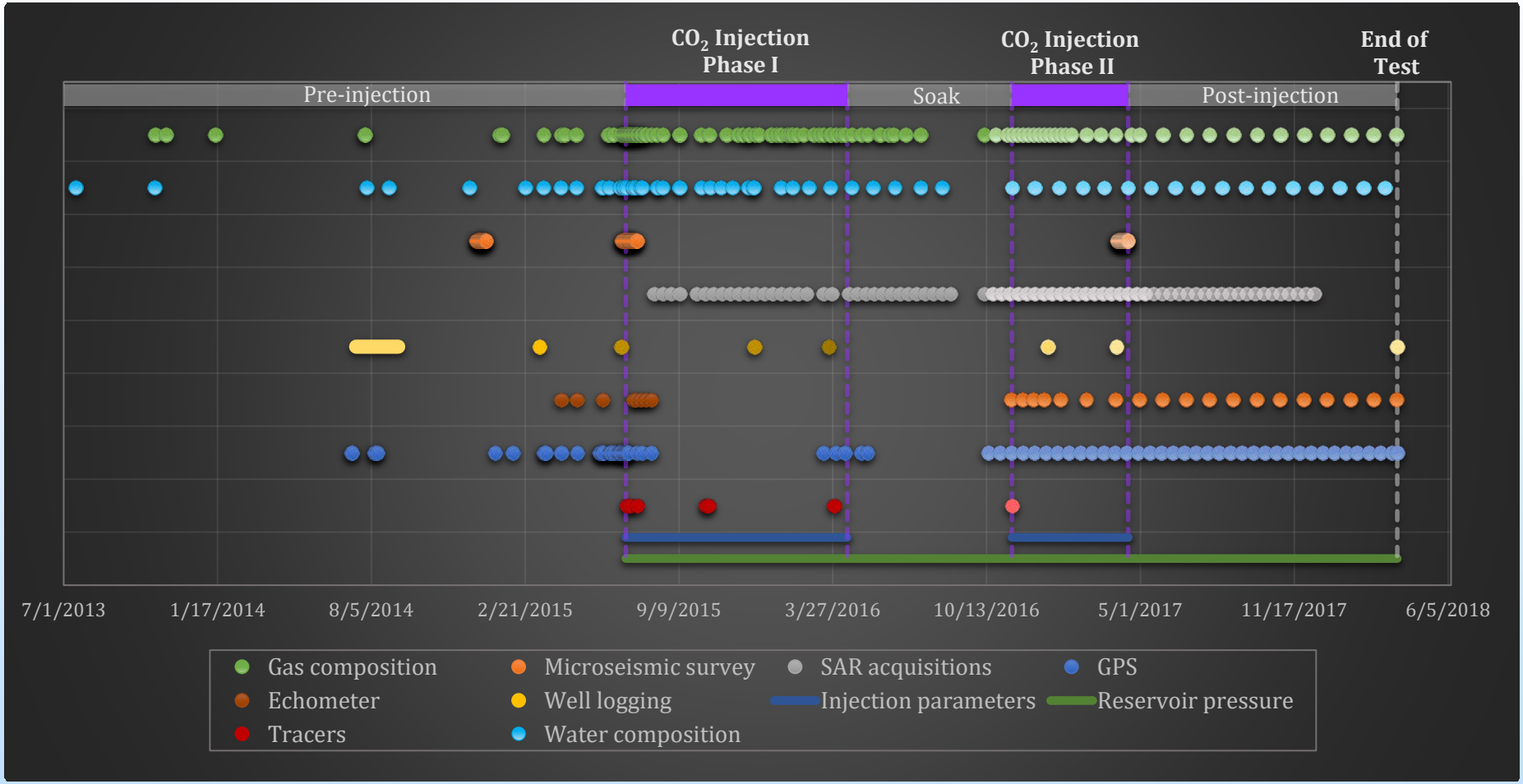
Gas composition: CO_2 Breakthrough at DD8A



- Increase in CO_2 from < 1% to 12.9%
- Outcome: no change to operations; did not compromise test objectives or CBM operations

Project Timeline

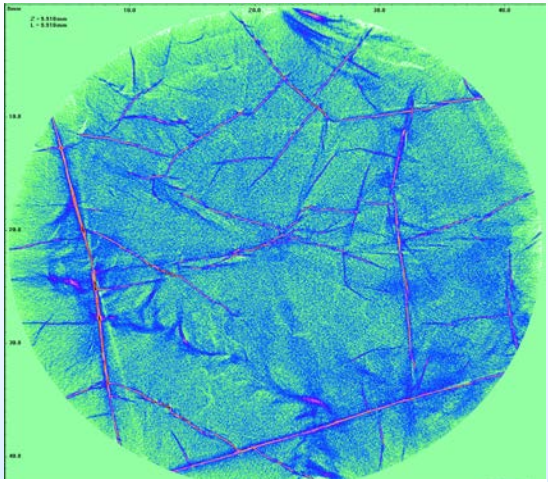
Two Injection Phases

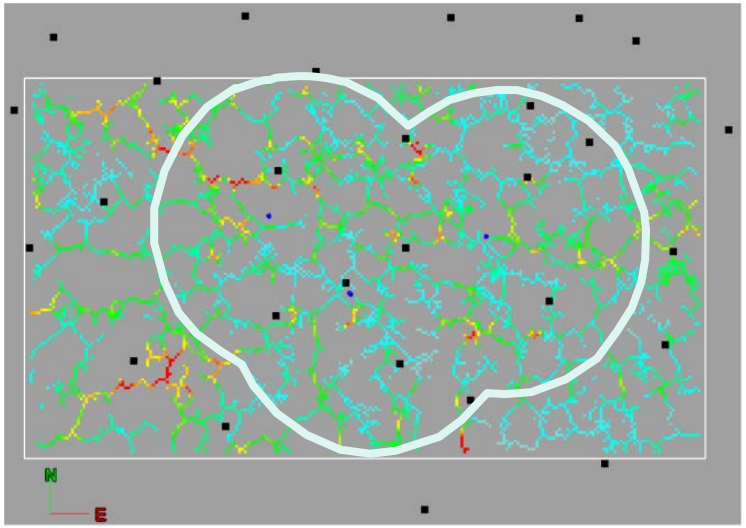


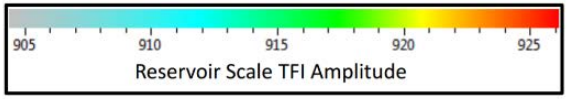
Currently in Post-injection Monitoring

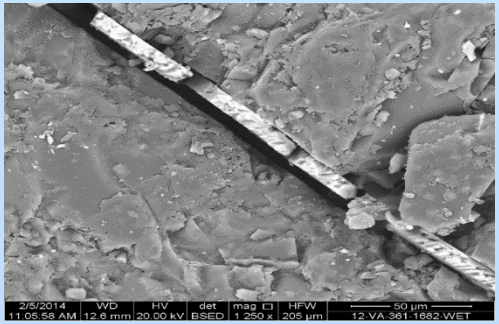
Reservoir Modeling –
History Match Monitoring Results

- Coal swelling effects?
  - Geomechanical effects from laboratory testing
- What seams take the CO2?
  - Spinner Surveys on Injection Wells as inputs
  - Water Kill Test on Production Wells as inputs
- Why does SF6 breakthrough prior to CO2?
  - Adsorption Isotherms run on SF6/CO2/CH4 inputs
- How far do the hydraulic fractures go?
  - Fracture length in coalmines
  - TFI's from Microseismic Monitoring





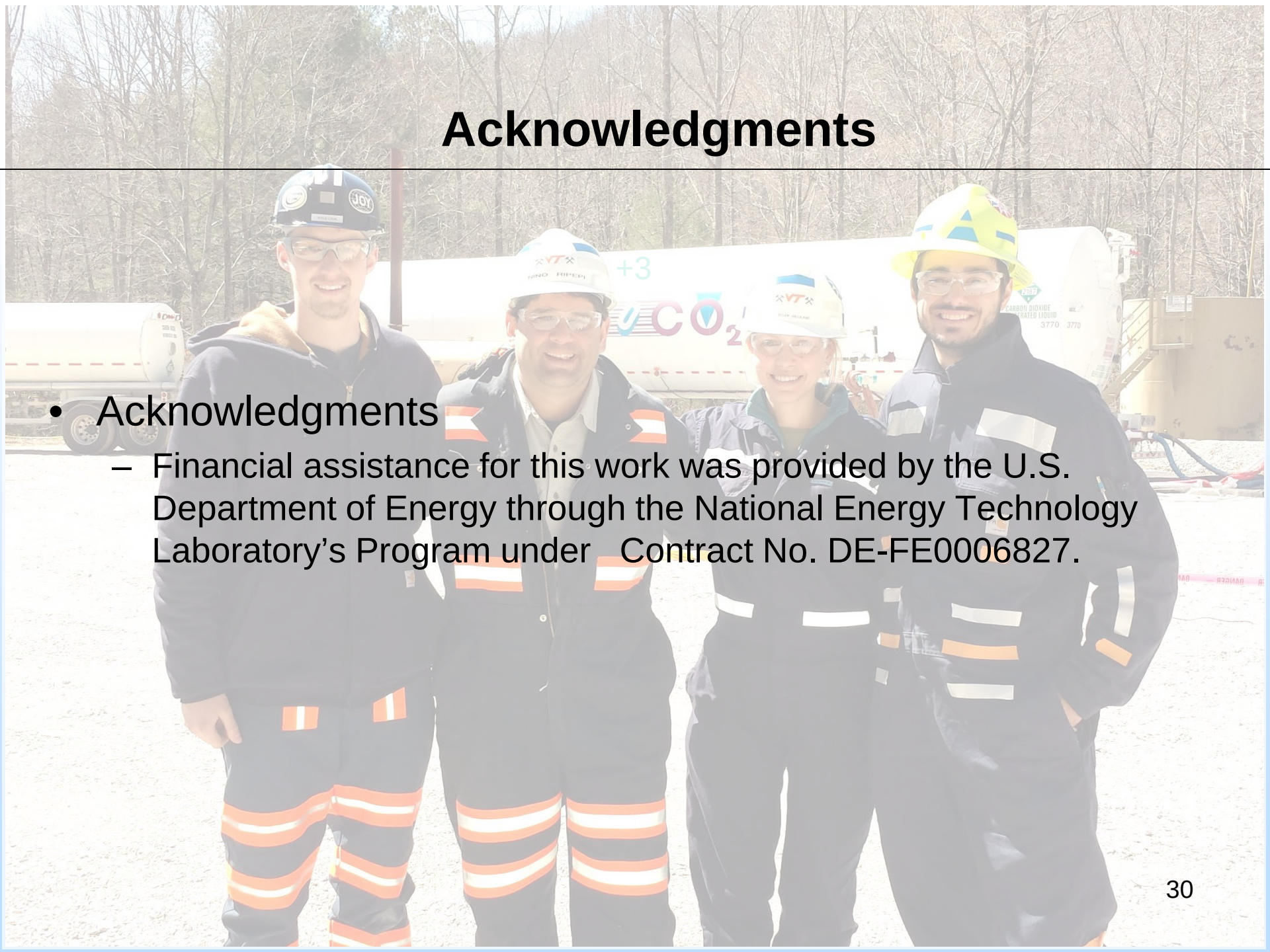




Summary

- Shale Test Injection successful
  - Flowback showed EGR and specifically NGLs
- CBM Test Injection
  - 14,000 tons injected in two Phases
  - Multiple wells allow for varied injection rates and pressures as well as fall-off testing
  - Breakthrough of CO2 at 1 offset well
  - Pressure has nearly stabilized
  - Expect to **flowback** injection wells during final quarter as an extended huff and puff.

Acknowledgments



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Project Schedule

Phase I

(10/1/11 – 3/31/13)

- Characterization
  - Drill char. Well
  - Core sample analysis
  - Modeling
  - Baselines for monitoring
- Injection design
- Monitoring design
  - Well locations
  - Geophysical surveys

- **Go/no go 1: permits, access (12 months)**
- **Go/no go 2: characterization (18 months)**

Phase II

(4/1/13 – 1/31/17)

- Site preparation
  - Conversion of production wells
  - Drill monitor wells
  - Install additional monitor stations
- **CO_2 injection period**

(3/18/14 - 3/31/14) - Shale

(7/02/15 – 1/31/17) - CBM

- Monitoring
  - Atmosphere
  - Surface
  - Reservoir

Phase III

(2/1/17 – 12/31/17)

- Site closure
  - Conversion of injection and monitor wells
  - Site restoration
- Post-injection characterization
  - Data analysis and interpretation
  - Post-injection monitoring
  - Reservoir modeling
  - Assessing enhanced recovery for commercialization

Ongoing: Post-Injection Monitoring, Reservoir Modeling, Education/Outreach