

Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small-Scale CO₂ Injection Test

Project Number: DE-FE0006827

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Virginia Tech

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the
Infrastructure for CO₂ Storage
August 21-23, 2012

Presentation Outline

- **Project Objectives and Background**
- **Shale CO₂ Injection Test in Morgan County, Tennessee**
- **Coalbed Methane CO₂ Injection Test in Buchanan County, Virginia**
- **Conclusions**

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

Collaborators

- Schlumberger
- Global Geophysical Services
- Oak Ridge National Laboratory
- University of Tennessee
- University of Virginia
- Southern Illinois University
- Oklahoma State University

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 – 9/30/15)

- Site preparation
 - Conversion of production wells
 - Drill monitor wells
 - Install additional monitor stations
- **CO₂ injection period**
 - (3/18/14 - 3/31/14) - Shale**
 - (7/02/15 - 6/30/16) - CBM**
- Monitoring
 - Atmosphere
 - Surface
 - Reservoir

Phase III

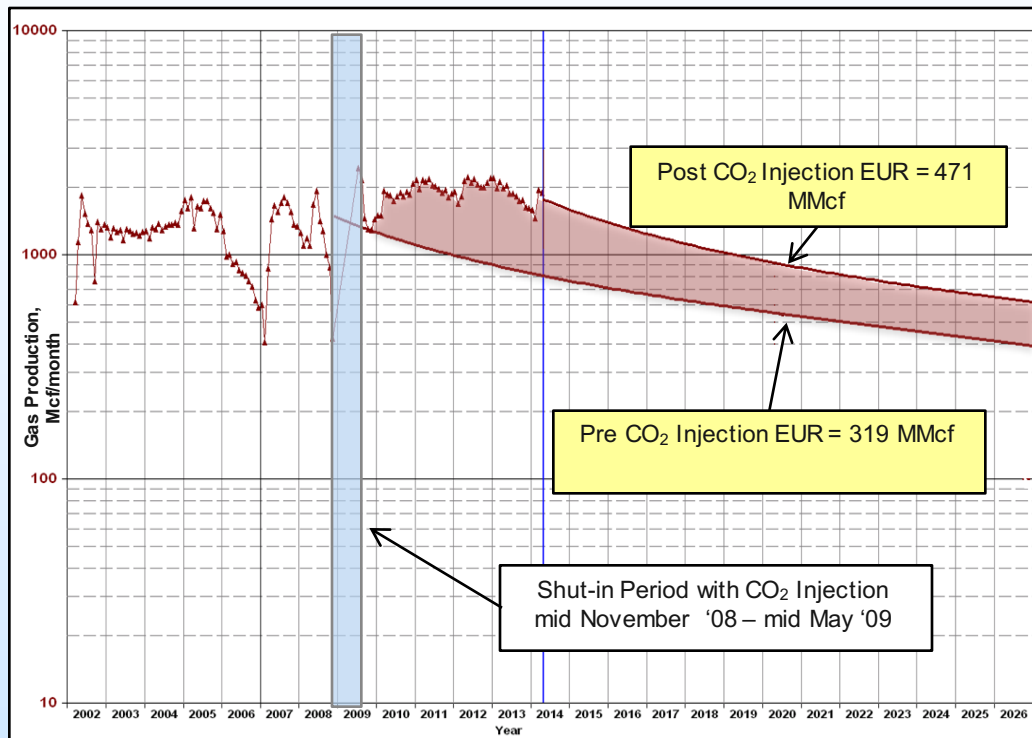
12 months (TBD)

- 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: CO₂ Injections, Reservoir Modeling, Monitoring, Education/Outreach

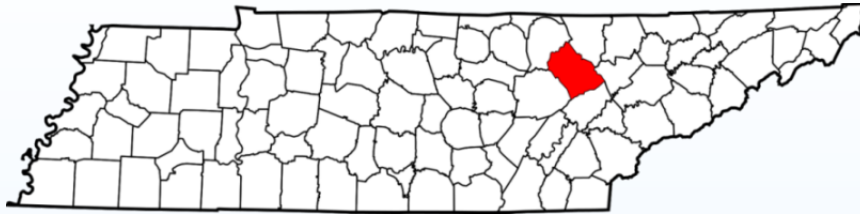
Previous Experience in Huff and Puff Test in Russell County, Virginia (2009)

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

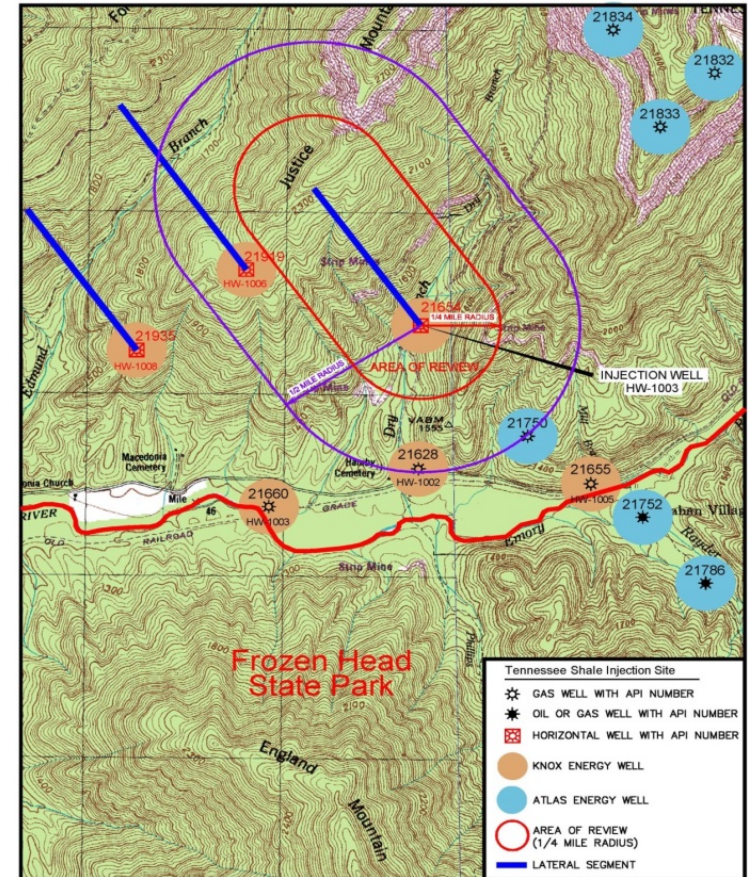


- 1000-ton CO₂ injection
- Stacked coal reservoir
- Evidence of preferential adsorption: elevated N₂ and CH₄
- Enhanced CH₄ recovery at two offset wells, no CO₂ breakthrough
- 30% CO₂ in flowback over 5 years
- **EUR of test well has increased by 48 percent**⁶

Shale CO₂ 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
- Injection period: March 18-31, 2014 (14 days)
- Shut-in period: March 31- July 29, 2014 (~4 months)
- Flowback period: July 29, 2014- present (~12 months)
- Current status: post-injection monitoring



Shale CO₂ Injection Test in Morgan County, Tennessee

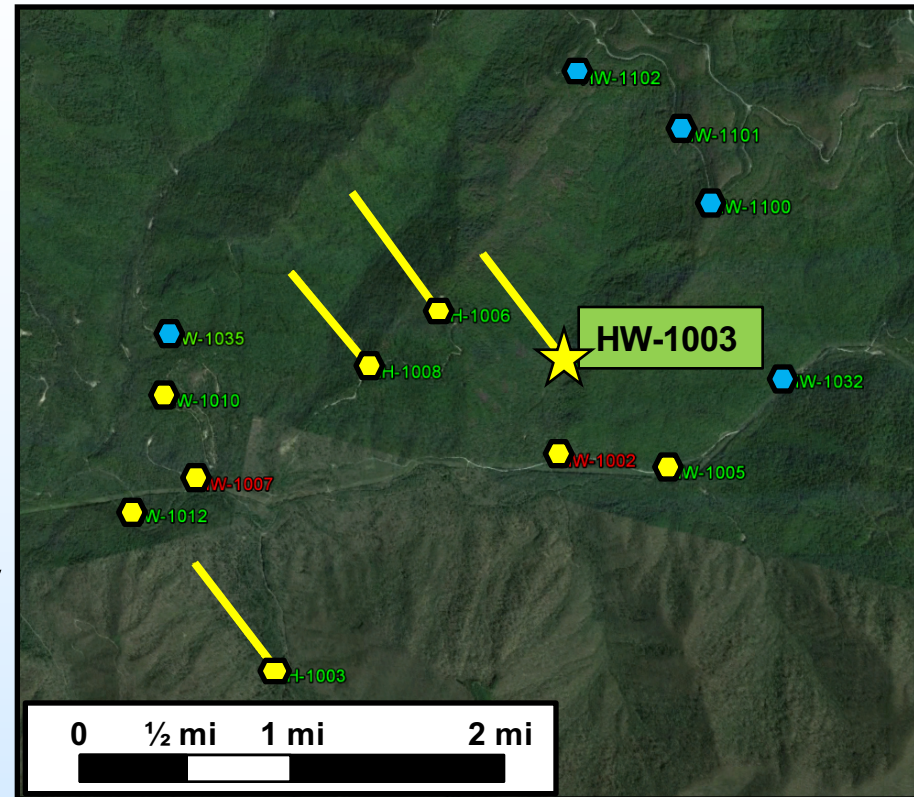
Monitoring, Verification, and Accounting (MVA)

MVA Overview:

- **Gas and water sampling**
 - Commenced: 4/2013
 - Injection Well: HW-1003
 - 13 Offset Monitoring Wells
 - 3 Horizontal / 10 Vertical
 - 11 In-zone / 2 Out-of-zone
- **Perfluorocarbon tracer study**
- **Surface water sampling**

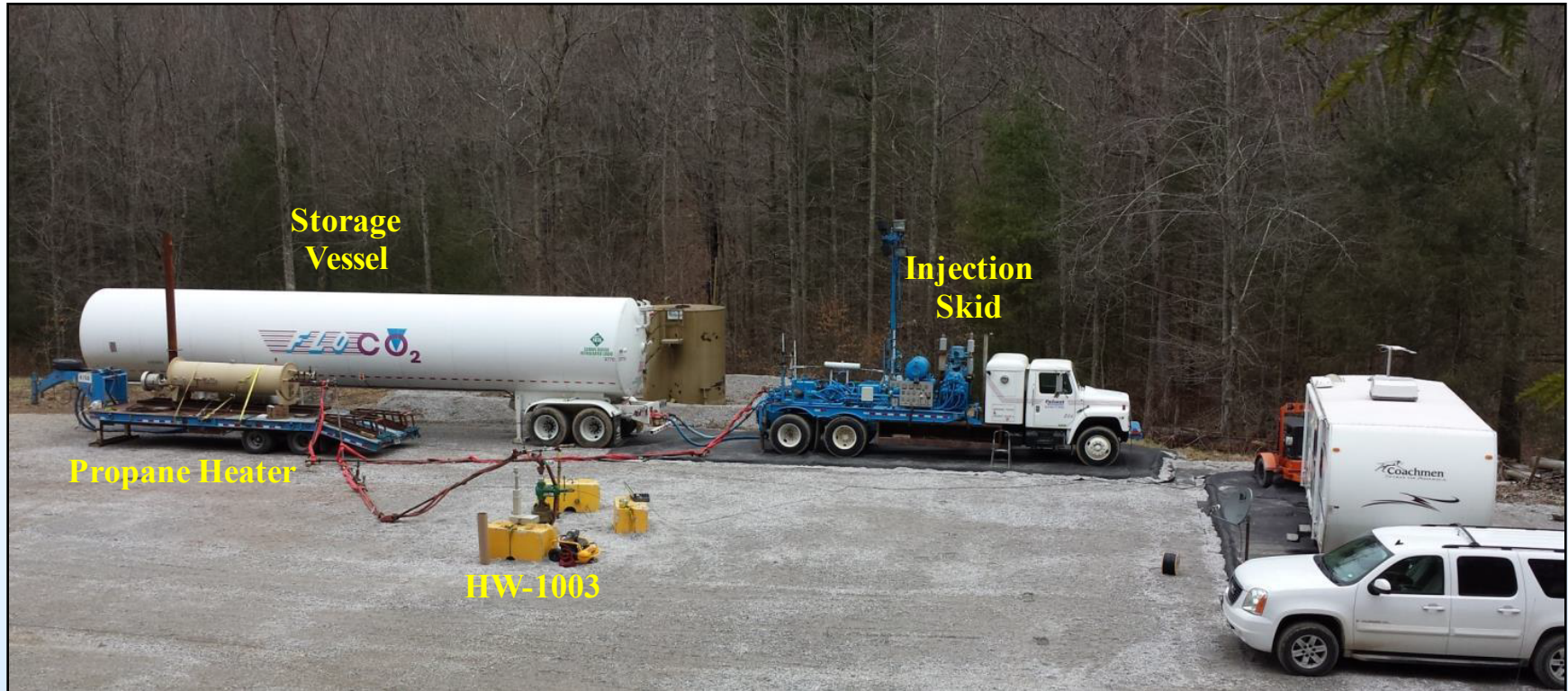
Monitor for:

- Injection Phase: % Composition, Tracer Arrival
- Soaking Phase: Pressure, % Composition
- Flowback Phase: Flowrate, % Composition, Tracers



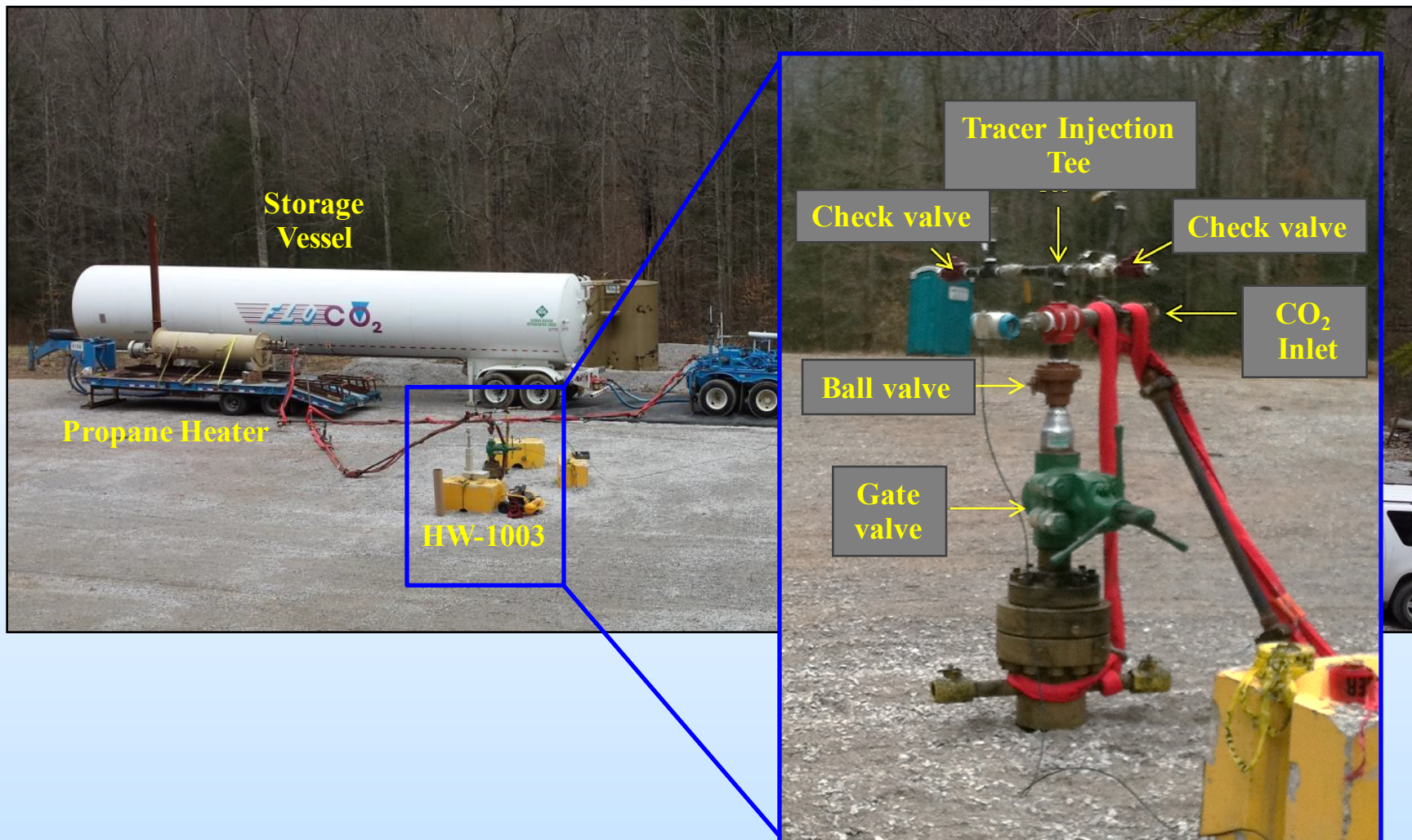
Shale CO₂ Injection Test in Morgan County, Tennessee

Operations Overview



Shale CO₂ Injection Test in Morgan County, Tennessee

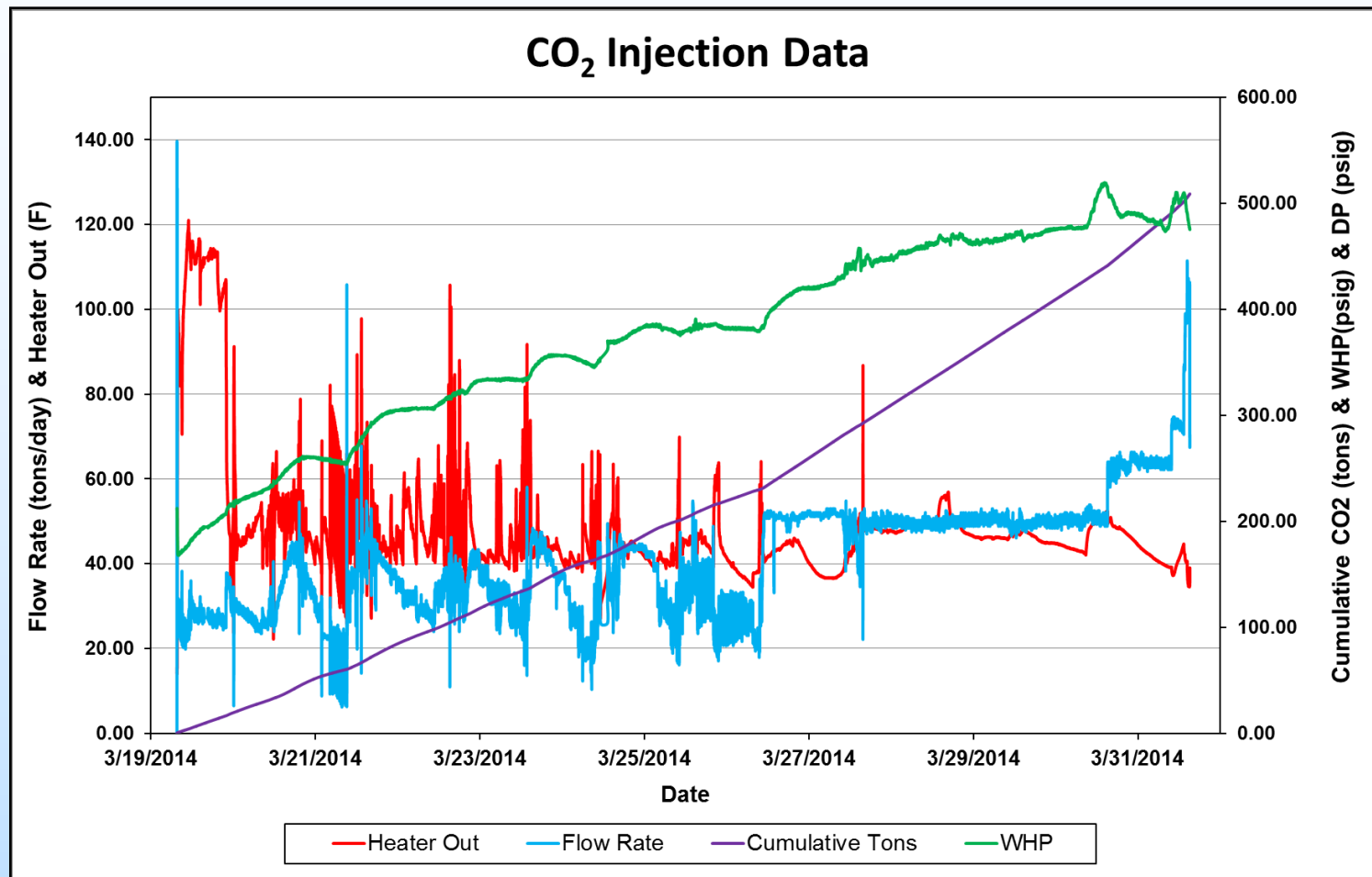
Operations Overview



Shale CO₂ Injection Test in Morgan County, Tennessee

Injection Summary

- 510 tons CO₂ injected
- Avg. Wellhead Temp: 50° F
- Avg. Flow Rate: 40 tons/day
- Max Wellhead Pressure: ~500 psi (Gas Phase)



Shale CO₂ Injection Test in Morgan County, Tennessee

Monitoring, Verification, and Accounting (MVA)



Perfluorocarbon Tracers

Injected with CO₂ stream

- **Sulfur Hexafluoride (SF₆)**
 - 0.574 kg at 50-ton mark
 - Booster Pump and Air Compressor
- **Perfluoromethylcyclopentane (PMCP)**
 - 0.854 kg at 50-ton mark
 - Syringe Pump
- **Perfluoromethylcyclohexane (PMCH)**
 - 0.894 kg at 350-ton mark
 - Syringe Pump

Shale CO₂ Injection Test in Morgan County, Tennessee

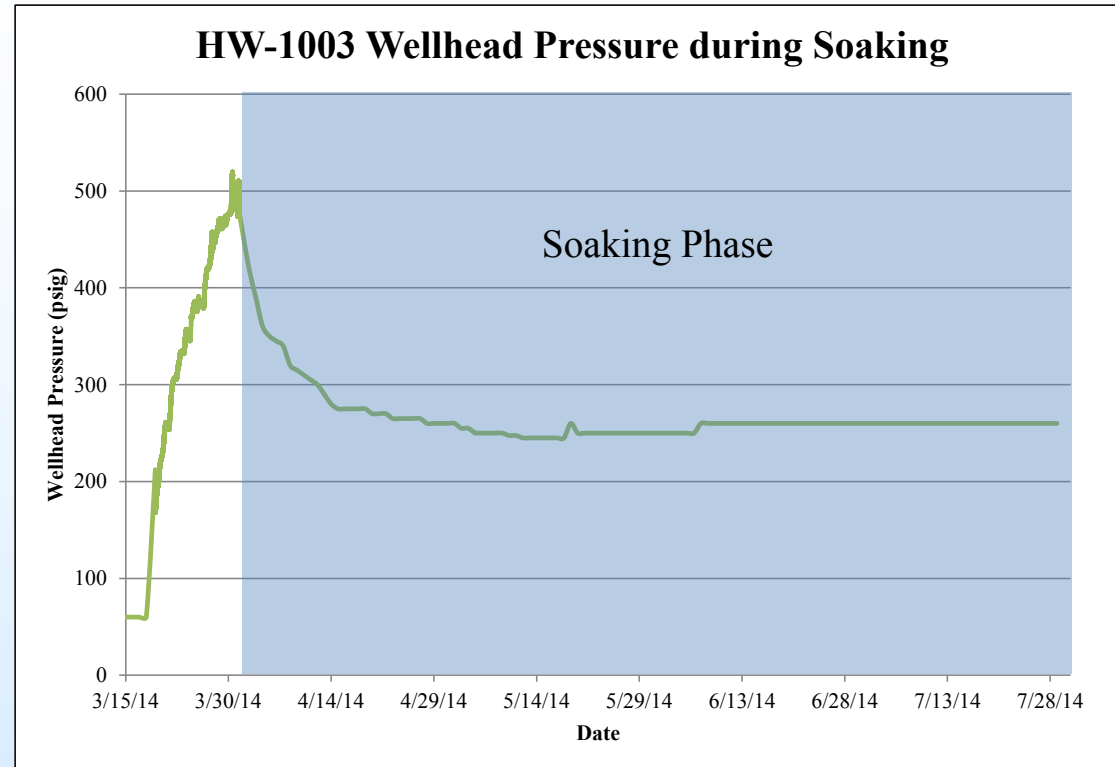
Results to Date

Injection period:

- No increased concentration of CO₂ at offset wells *
- No detection of tracers at offset wells *

Shut-in period:

- Wellhead pressure leveled out at 260 psig for 3 months *
- No liquids downhole
- All gas phase in wellbore



Shale CO₂ Injection Test in Morgan County, Tennessee

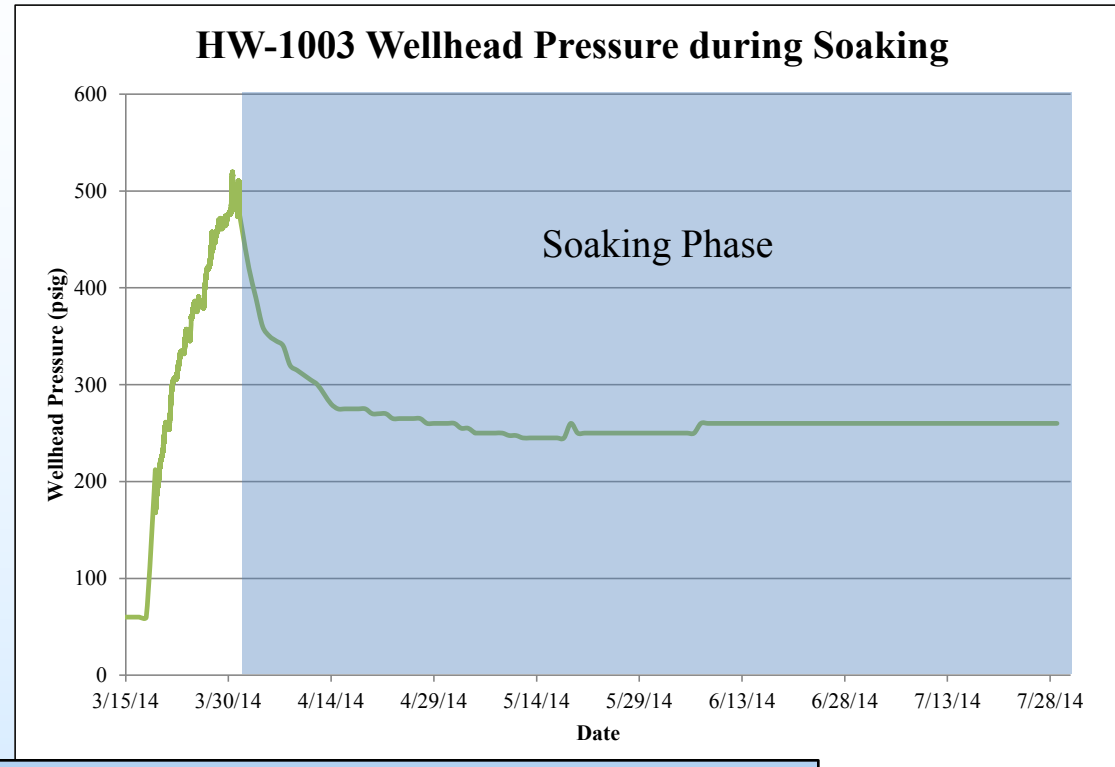
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- All gas phase



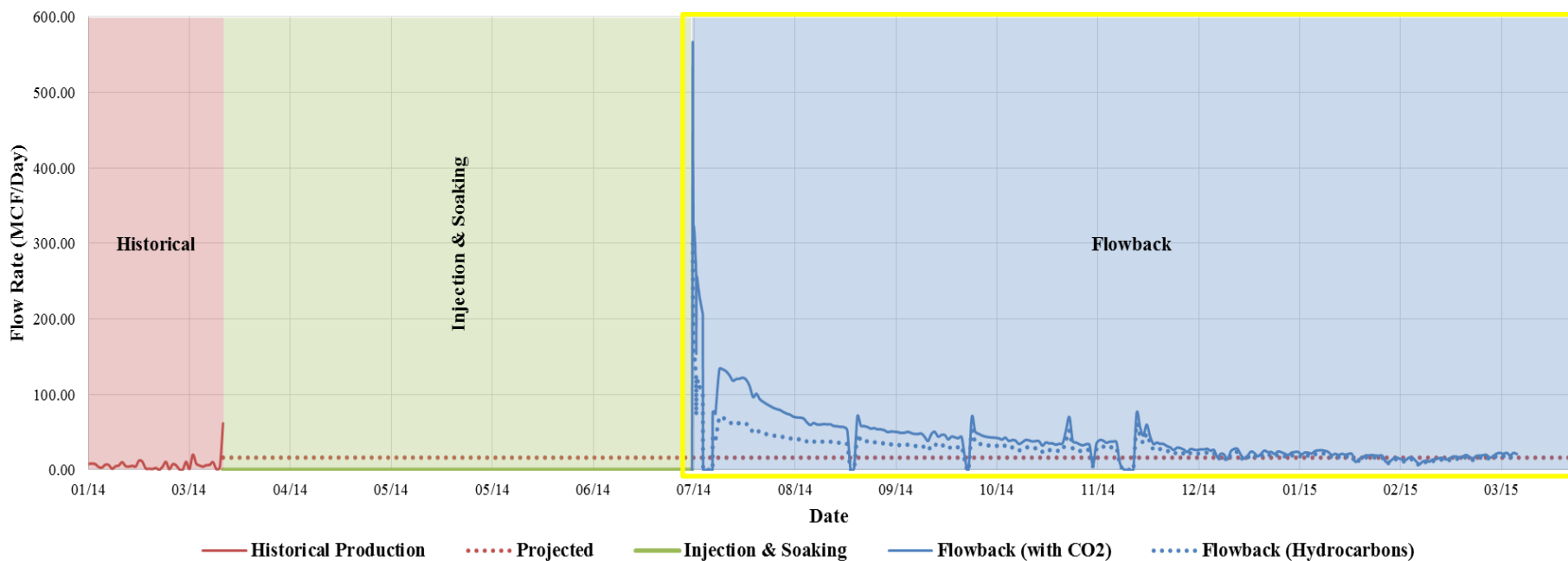
*Indications of closed system behavior

- Consistent with modeled predictions
- CO₂ confinement → storage option

Shale CO₂ Injection Test in Morgan County, Tennessee

Flowback Results

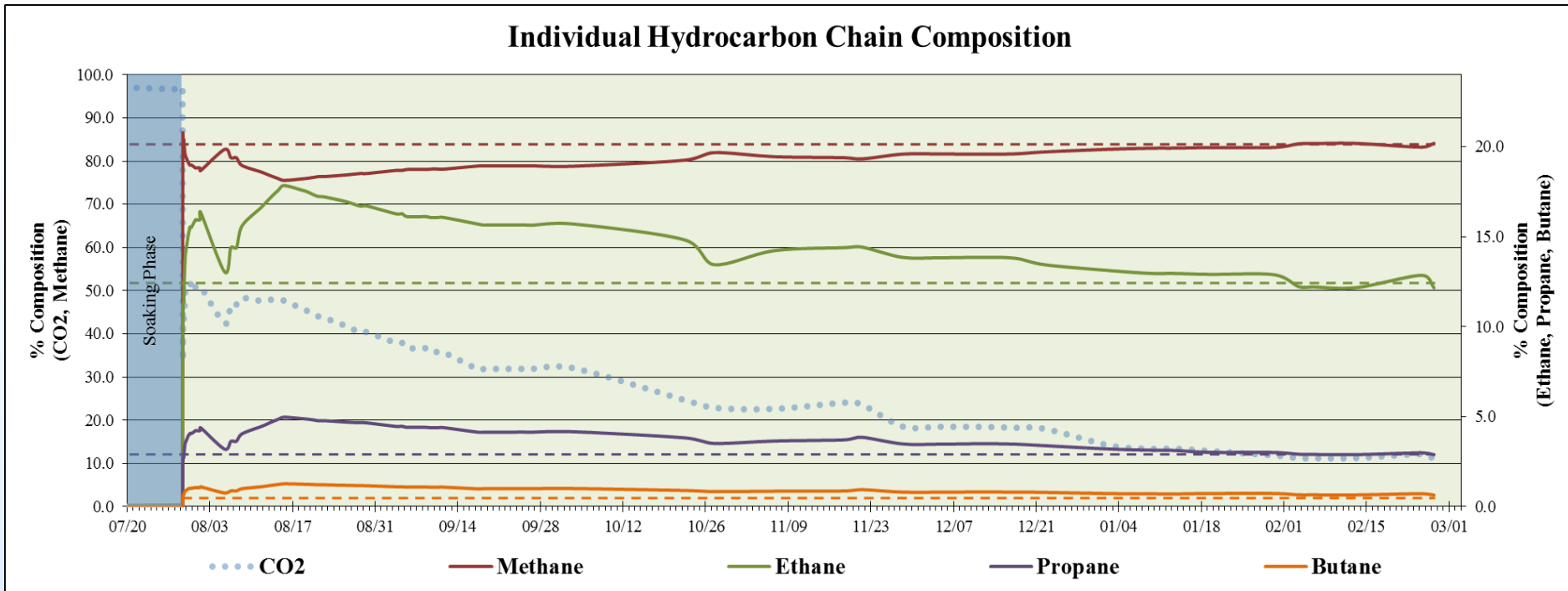
Flowback Production vs. Historical Production (zoomed)



- EGR: An increase versus baseline production
- Correlated production of hydrocarbons and CO₂
- 34 percent of injected CO₂ produced to date (173 tons)
- Current CO₂ production rate of 0.22 tons/day
- \$60 per ton of CO₂ Injected for EGR (including NGLs)

Shale CO₂ Injection Test in Morgan County, Tennessee

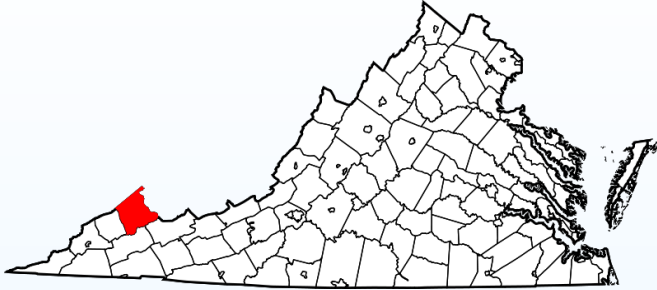
Results to Date



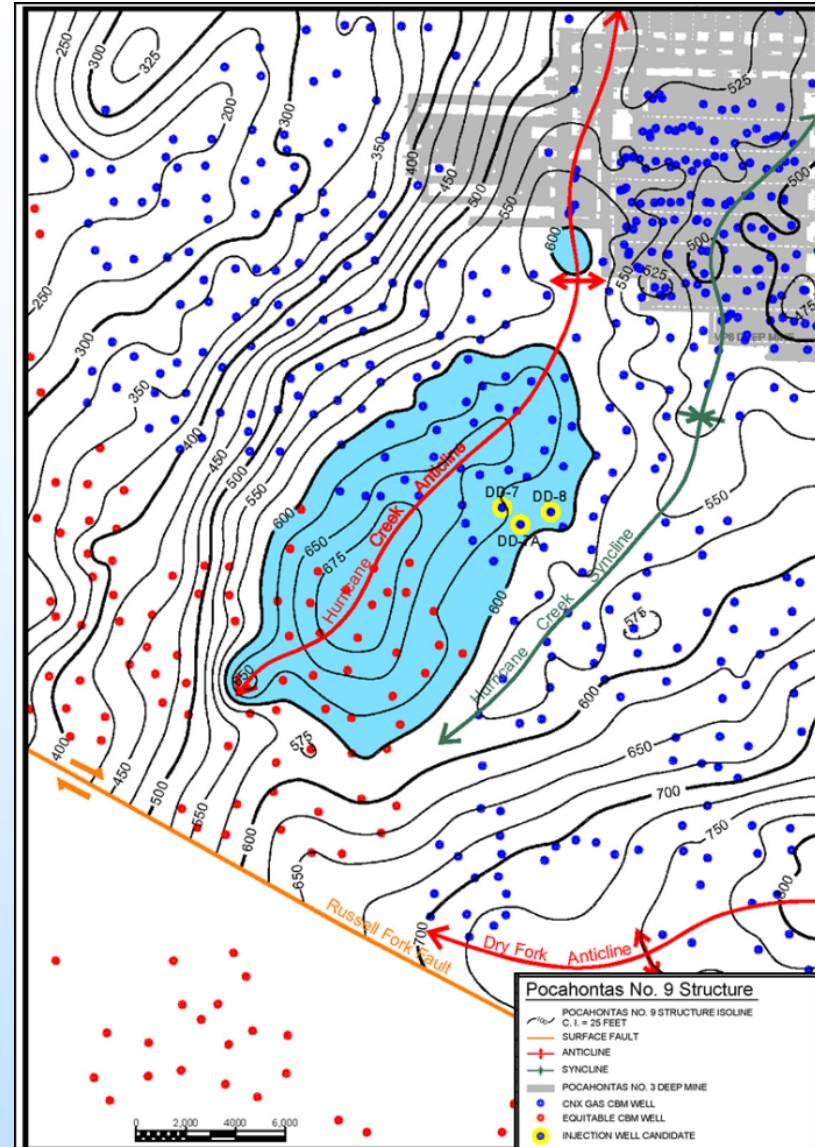
Production of heavy hydrocarbons elevated from baseline values:

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

CBM CO₂ Injection Test in Buchanan County, Virginia



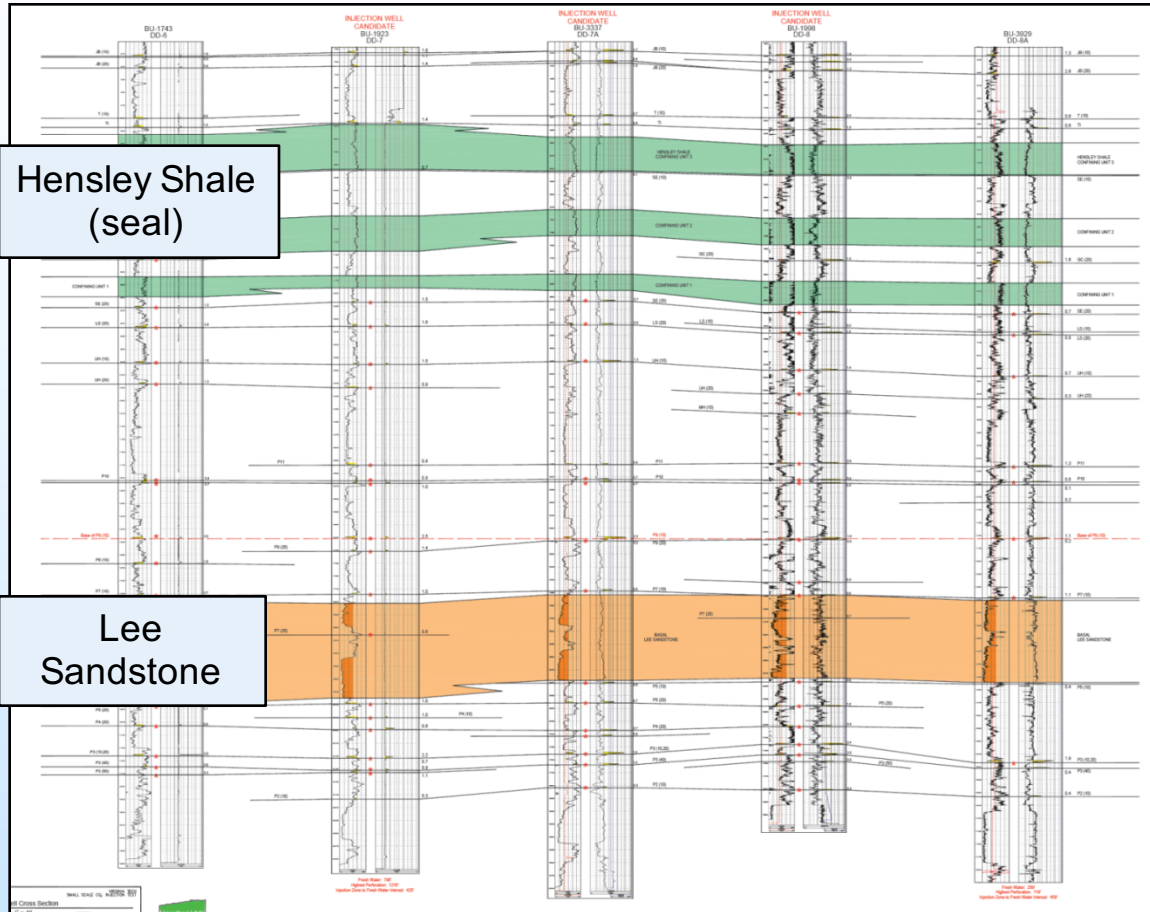
- Oakwood coalbed methane field
- Stacked coal reservoir, 15-20 seams
- Tight shale and sandstone confining units
- 20,000-tonne CO₂ injection over one year in three legacy production wells
- CO₂ storage + Enhanced gas recovery (EGR)
- **US EPA Class II UIC Permit**
- **Current status: Injection on-going.**



CBM CO₂ Injection Test in Buchanan County, Virginia

Reservoir Modeling

Stratigraphic cross section through injection wells

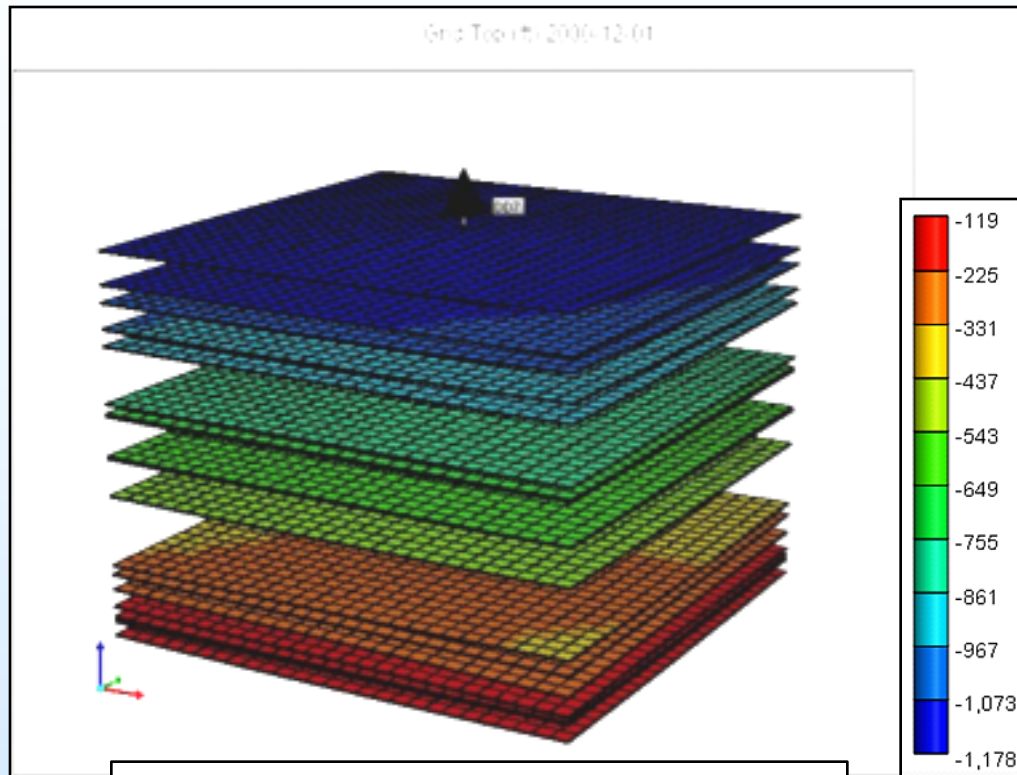


Modeling Considerations:

- 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

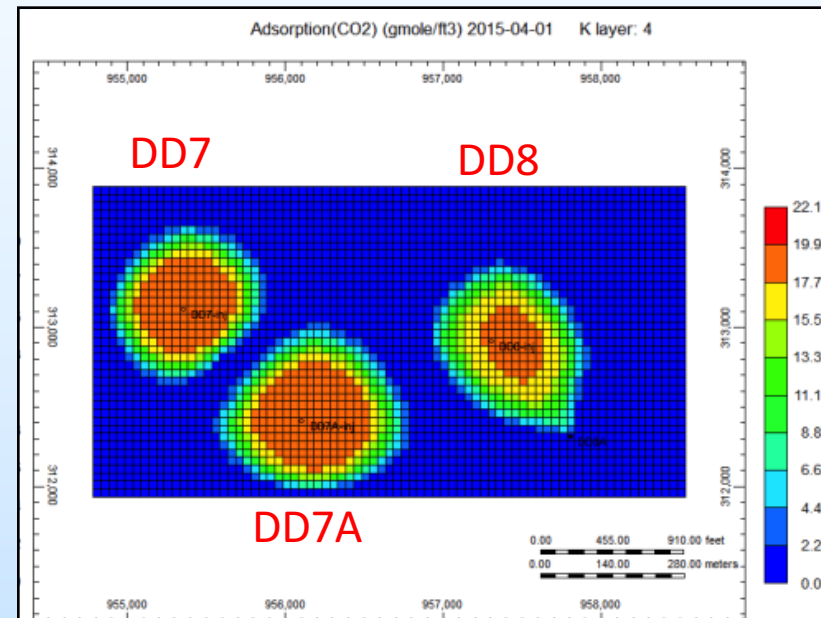
CBM CO₂ Injection Test in Buchanan County, Virginia

Reservoir Modeling



18-layer reservoir model

CO₂ Injection simulations used to define Area of Review (AOR) for monitoring program



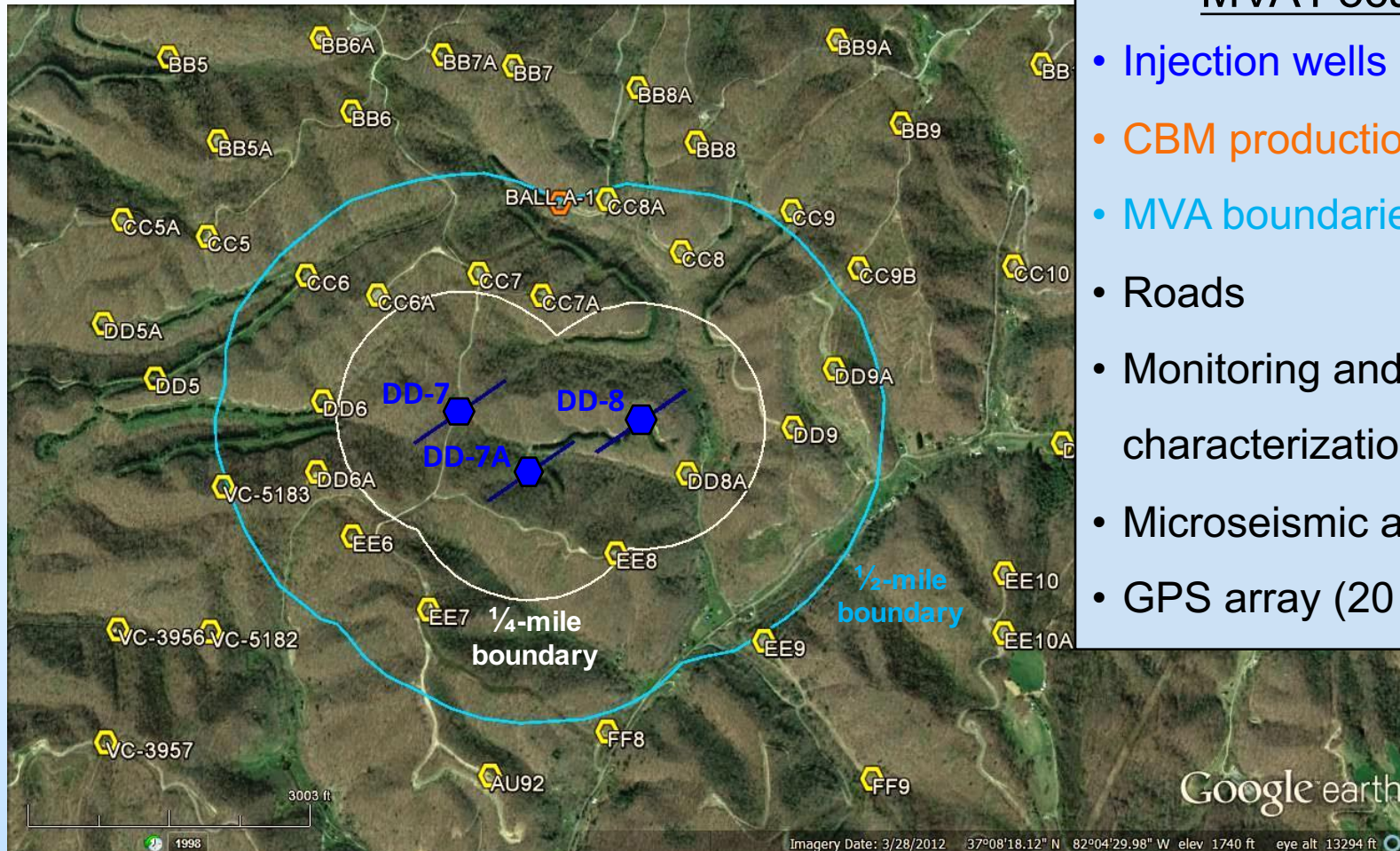
CBM CO₂ Injection Test in Buchanan County, Virginia

Monitoring, Verification, and Accounting (MVA)

Oakwood Field Demonstration Site

MVA Focus Area

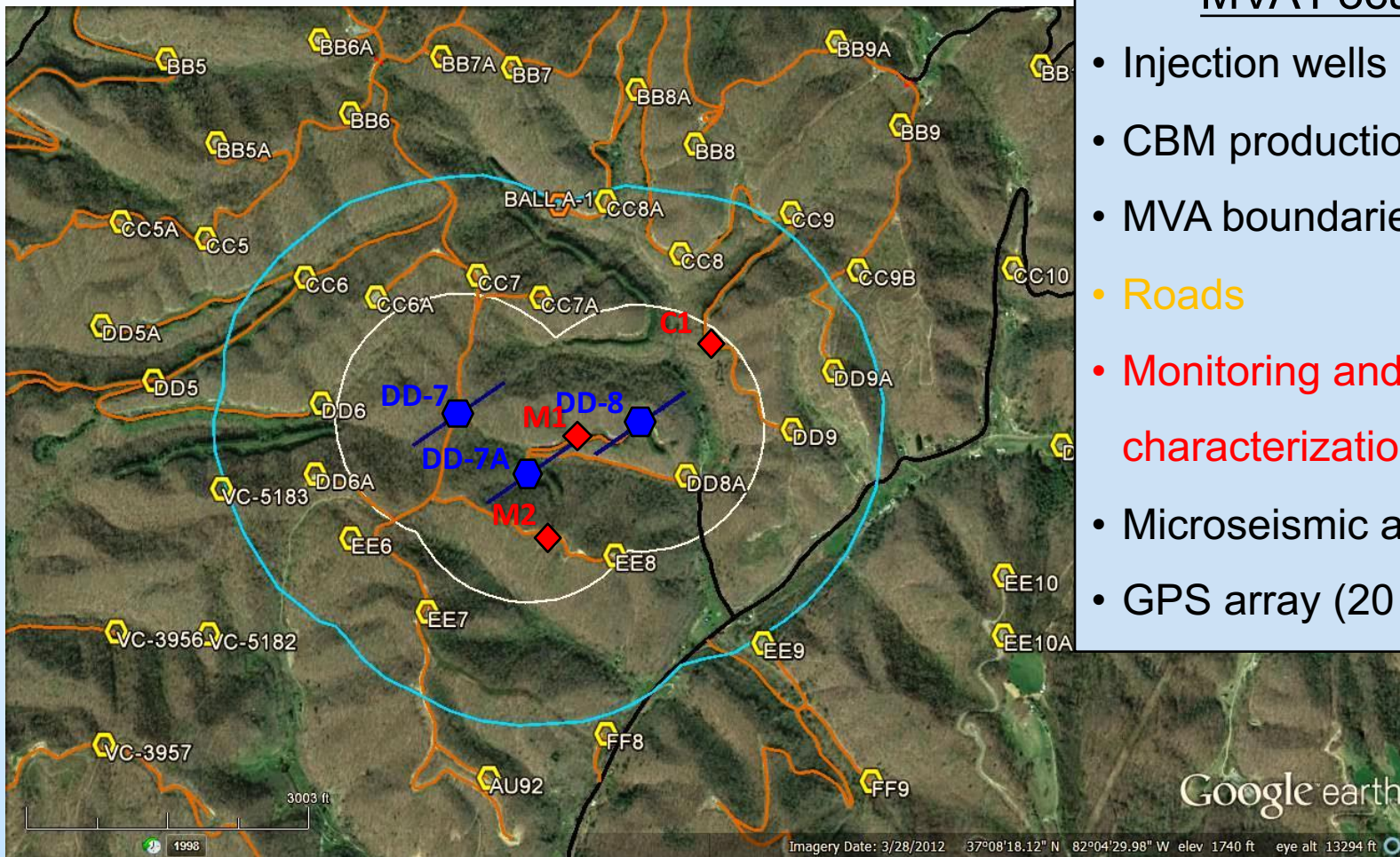
- Injection wells
- CBM production wells
- MVA boundaries
- Roads
- Monitoring and characterization wells
- Microseismic array (28 stns)
- GPS array (20 monuments)



CBM CO₂ Injection Test in Buchanan County, Virginia

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- **Roads**
- **Monitoring and characterization wells**
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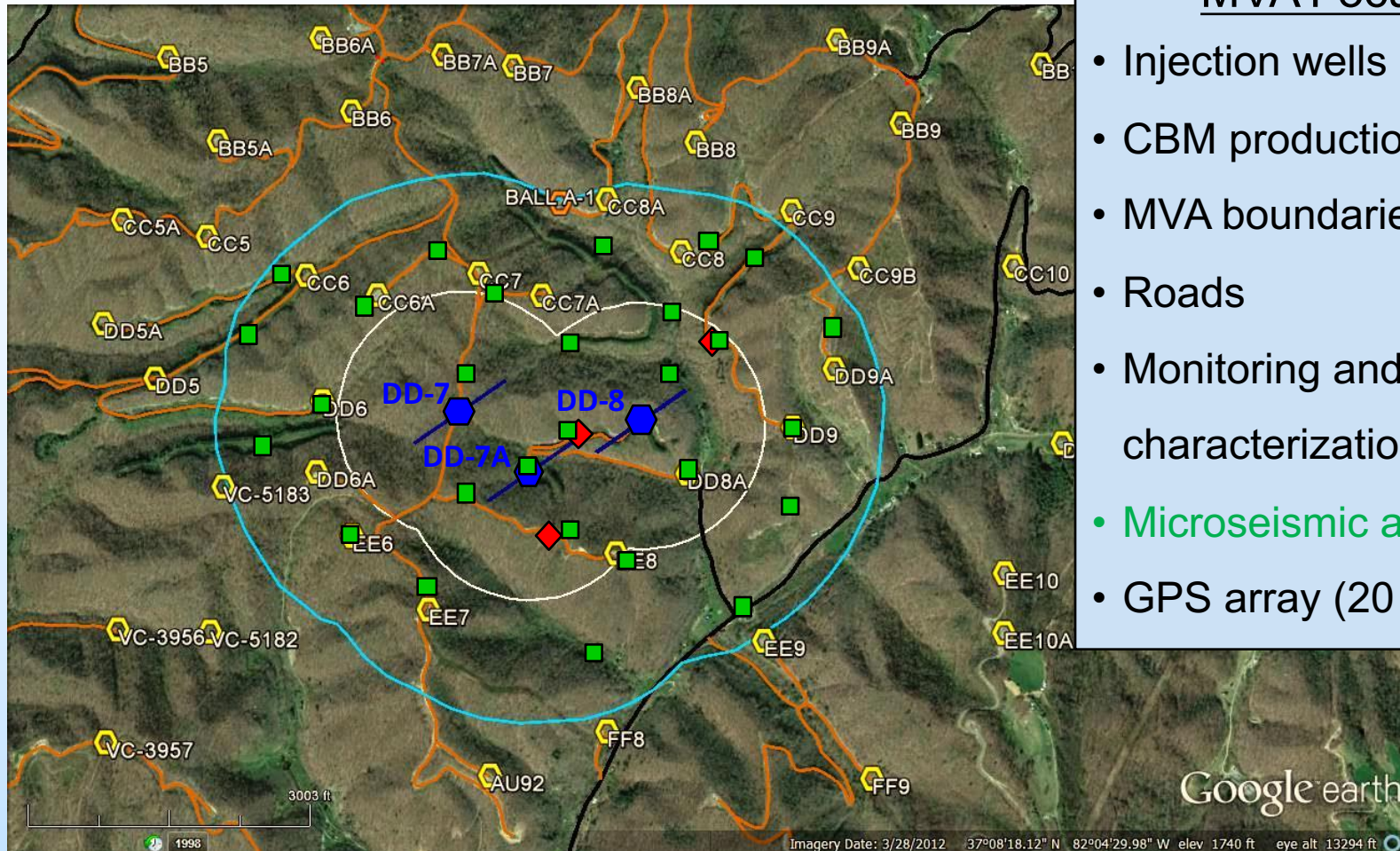
CBM CO₂ Injection Test in Buchanan County, Virginia

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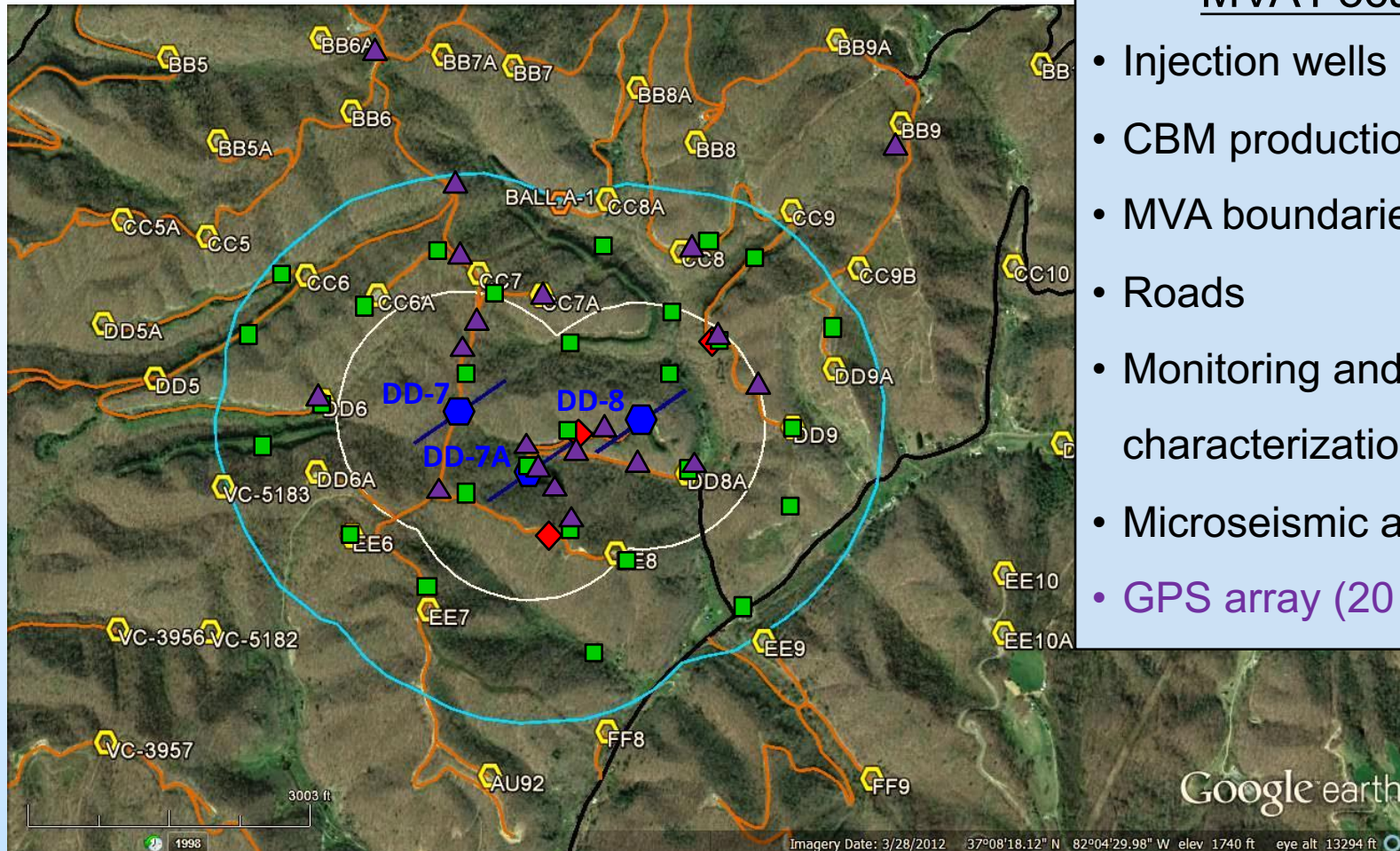
CBM CO₂ Injection Test in Buchanan County, Virginia

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CBM CO₂ 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 CO₂ operations vs. active CBM operations
 - Data sets will cross validate each other
- Selected technologies to address/overcome challenges of reservoir geometry and terrain

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



SCADA (supervisory control and data acquisition) system

← → ↻ scada.eagleresearchcorp.com/SelectStation.aspx



EAGLE RESEARCH CORPORATION

LOG OFF **STATION LIST** **ADMIN**

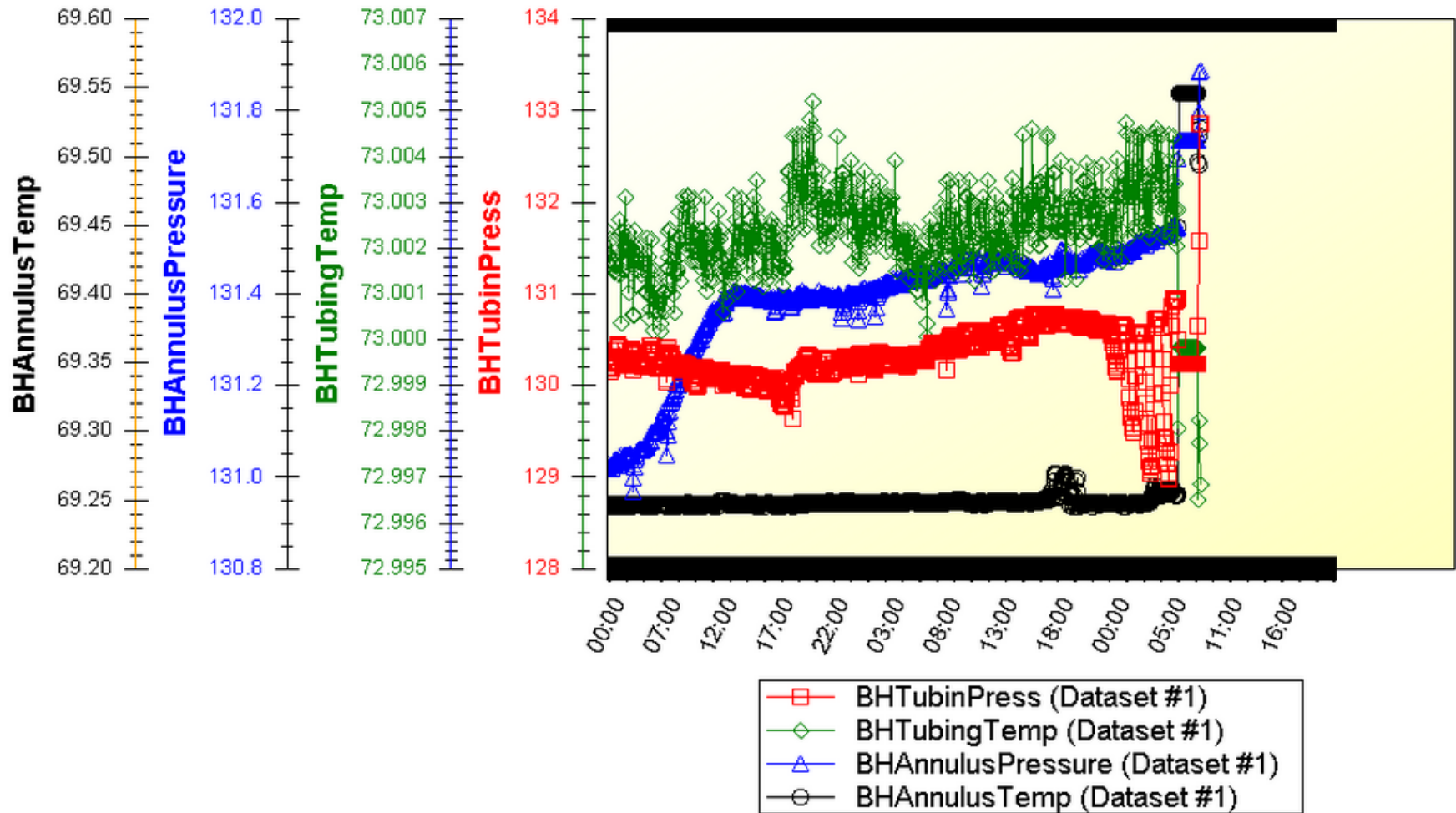
<u>SITE ID</u>	<u>STATION NAME</u>	<u>LAST UPDATE TIME</u>	<u>STATION NUMBER</u>	<u>RTU TYPE</u>	<u>UNIT TYPE</u>	<u>CURRENT DAY VOLUME</u>	<u>PREV DAY VOLUME</u>	<u>DIFF PRESSURE</u>	<u>PRESSURE</u>	<u>GAS TEMP</u>
3078	● DD-7 Front Unit	Dataset #1	8/11/15 11:45 PM		XARTU	60776	4.88	2.58	104.28	68.98
		Dataset #2					4.88	2.58	104.28	68.98
3079	● DD-7A Middle Unit	Dataset #1	8/11/15 11:46 PM		XARTU	60776	4.3	0	175.27	65.13
		Dataset #2					4.3	0	175.27	65.13
3080	● Back Unit DD-8 CO2 Truck	Dataset #1	8/11/15 11:45 PM		XARTU	60776	6.63	12.64	260.27	64.61
		Dataset #2					6.63	12.64	260.27	64.61

- Real-time graphing
- Alarms and Valve control:
 - flowrate, injection pressure, casing pressure
 - 30 second communication via radio

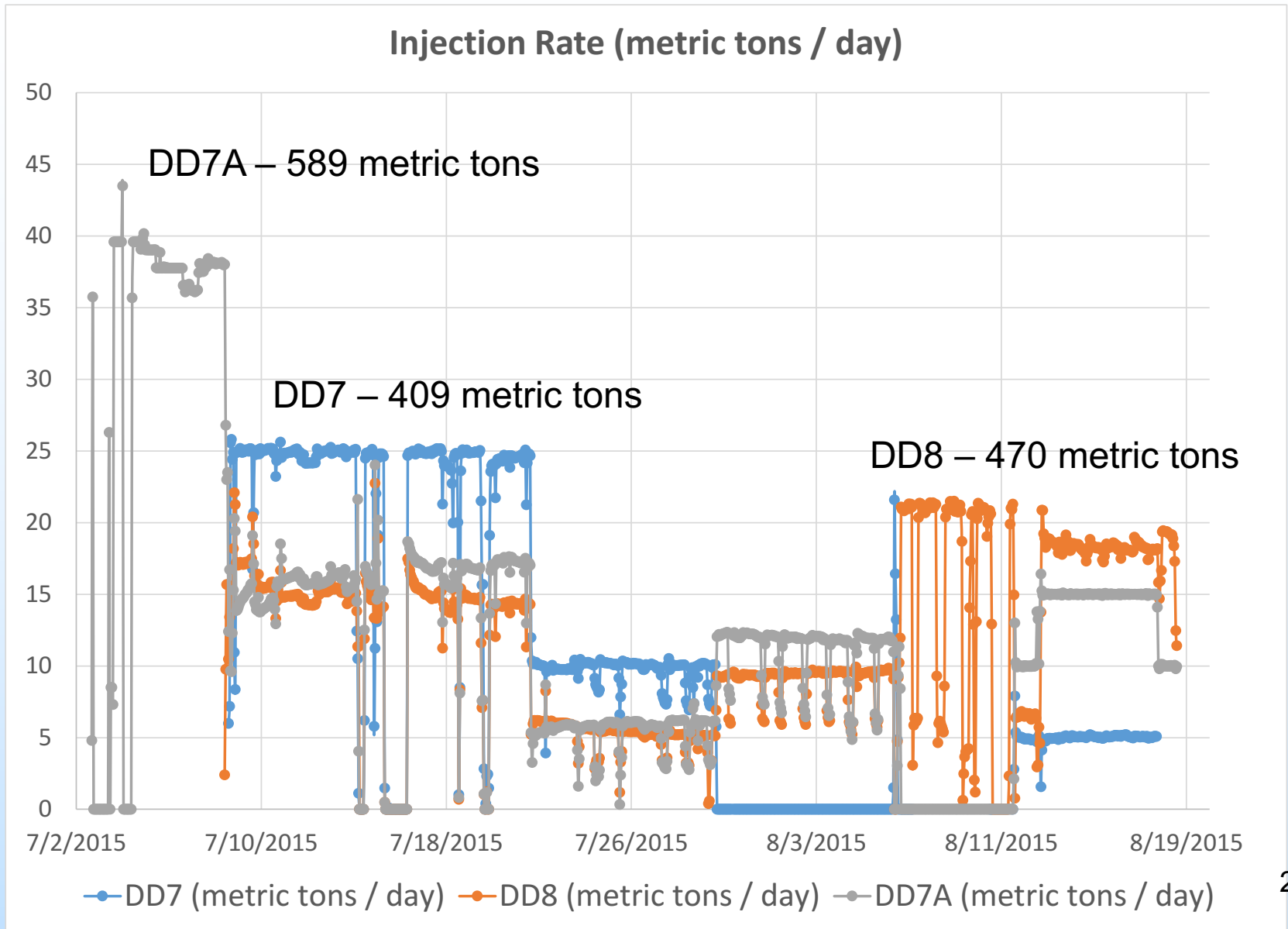
Real-time Injection and Monitoring Data

Hourly Graph for Station: DD-7A Middle Unit

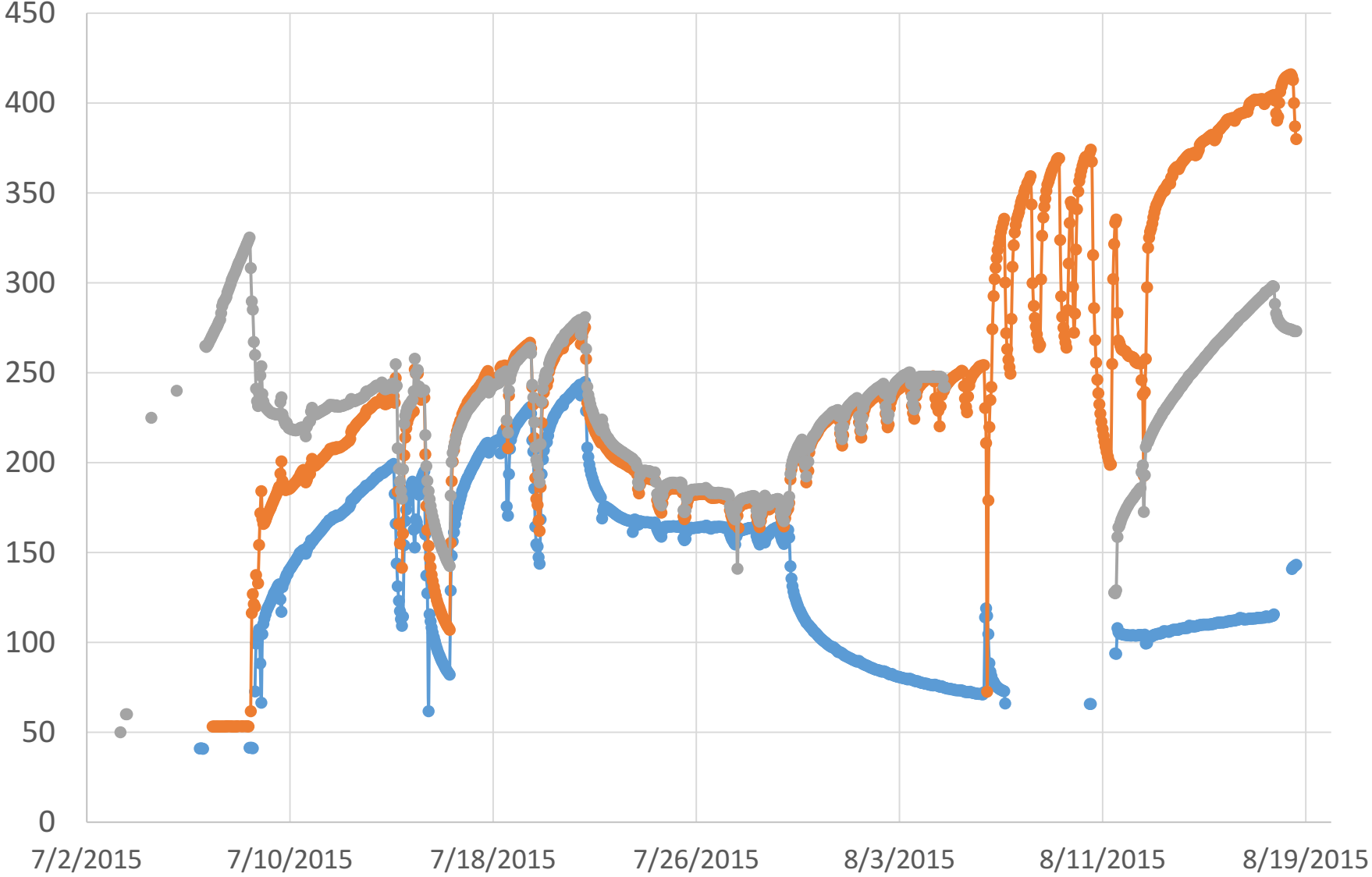
Site ID: 3079



1,470 metric tons injected to date (1,617 tons)

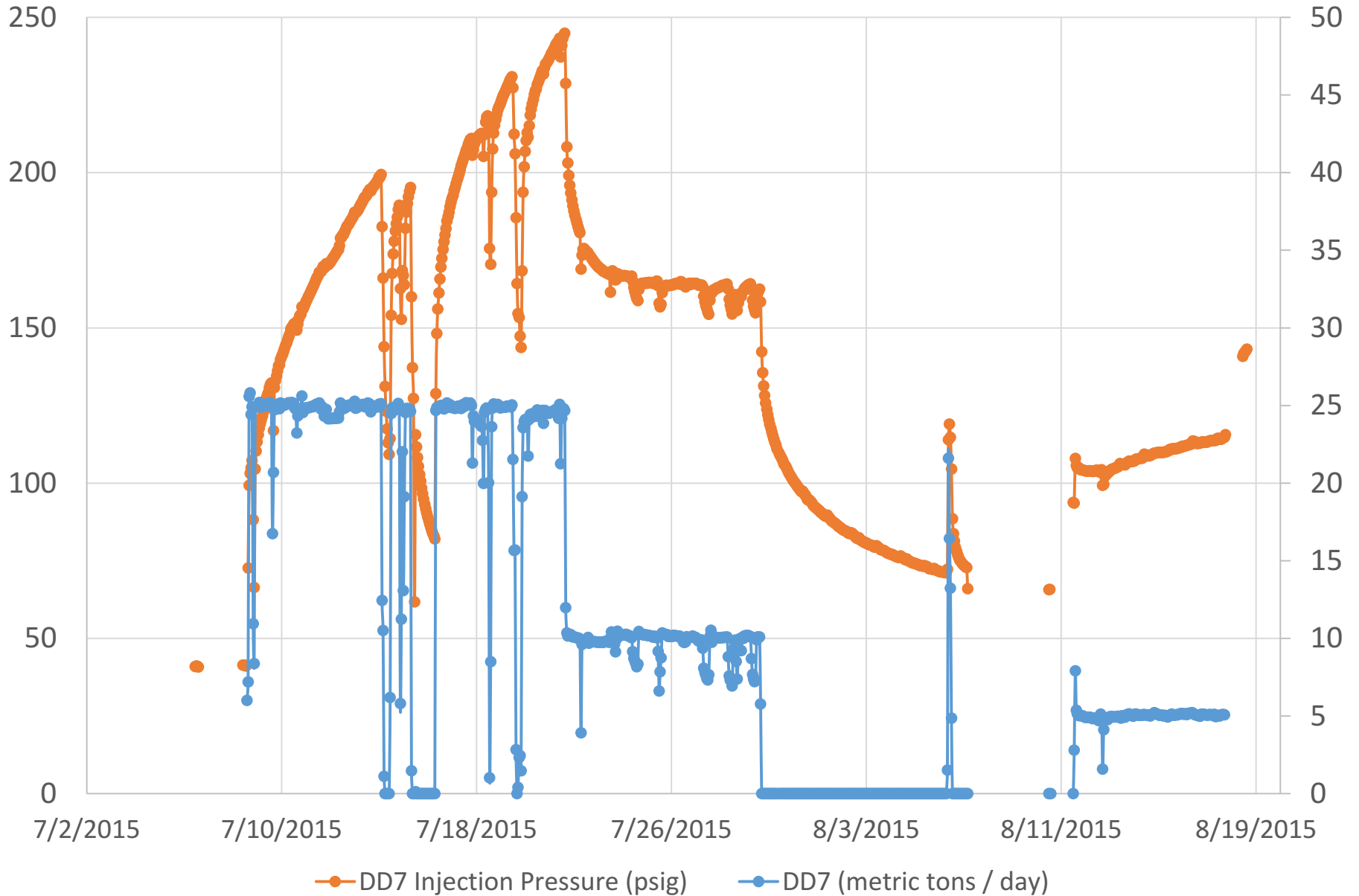


WellHead Pressure (psi)

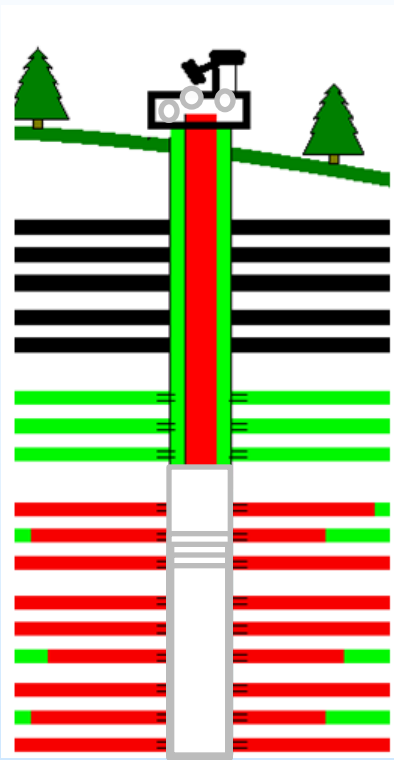


—●— DD7 Injection Pressure (psig) —●— DD8 Injection Pressure (psig) —●— DD7A Injection Pressure (psig)

DD7 Injection Rate and WellHead Pressure



Injection Well Liquid Level



4/9/2015
 4/29/2015
 6/02/2015
 7/3/2015
 7/12/2015
 7/15/2015
 7/22/2015
 7/28/2015
 8/04/2015

Date	Time	Depth To liquid level (ft)
4/9/2015	10:50:34	1778.78
4/9/2015	10:56:53	1778.05
4/9/2015	11:37:27	1778.02
4/9/2015	12:46:42	1846.43
4/9/2015	13:32:13	1868.61
4/29/2015	15:18:56	1229.35
6/2/2015	8:29:04	1485.11
7/12/2015	12:25:24	1492.28
7/12/2015	12:26:20	1493.22
7/15/2015	14:49:21	1482.11
7/22/2015	7:47:58	1477.9
7/28/2015	10:54:21	1481.36
8/4/2015	16:56:49	1511.35



Accomplishments to Date

- Completed Geologic Characterization for CBM Test Site and Shale Test Site
- Site Selection of 3 CBM Wells in VA for Injection
- Site Selection of 1 Horizontal Shale Well in TN for Injection
- Access Agreements for CBM Test completed
- Access Agreements for Shale Test completed
- Conducted Risk Workshop and developed Risk Register
- Performed detailed reservoir modeling analysis and assessment for CBM and Shale Tests
- Developed Drilling, Monitoring and Injection Plans
- Initiated Public Outreach Plan
- Shale Test Injection Complete – Flowback Underway
- Coring/Drilling at CBM Test Site complete
- CBM Test Injection Underway

Synergistic Activities

- Reservoir Modeling
- Core Analysis
- Field Projects
- Tracer Studies
- Gas and Water Sampling

Summary

- Shale Test Injection successful
 - Flowback showed EGR and specifically NGLs
- CBM Test Injection underway
 - Multiple wells allow for varied injection rates and pressures as well as fall-off testing
 - No breakthrough at monitoring or offset wells

Appendix

Benefit to the Program

- Develop technologies that will support industries' ability to predict CO₂ storage capacity in geologic formations to within ± 30 percent.
- Conduct field tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.
- The research project is testing the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery
- The technology, when successfully demonstrated, will provide guidance for commercialization applications of ECBM and EGR

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