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

Project Number: DE-FE0006827

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Presentation Outline

- **Project Benefits, Objectives and Background**
- **Shale CO_2 Injection Test in Morgan County, Tennessee**
- **Coalbed Methane CO_2 Injection Test in Buchanan County, Virginia**
- **Conclusions**

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

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 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 – 12/31/16)

- 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 – 12/31/16) - CBM

- Monitoring
  - Atmosphere
  - Surface
  - Reservoir

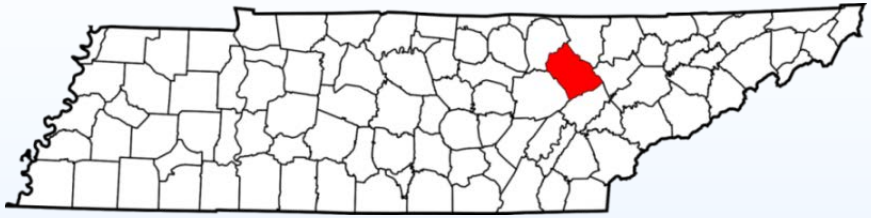
Phase III

(1/1/17 – 12/31/17)

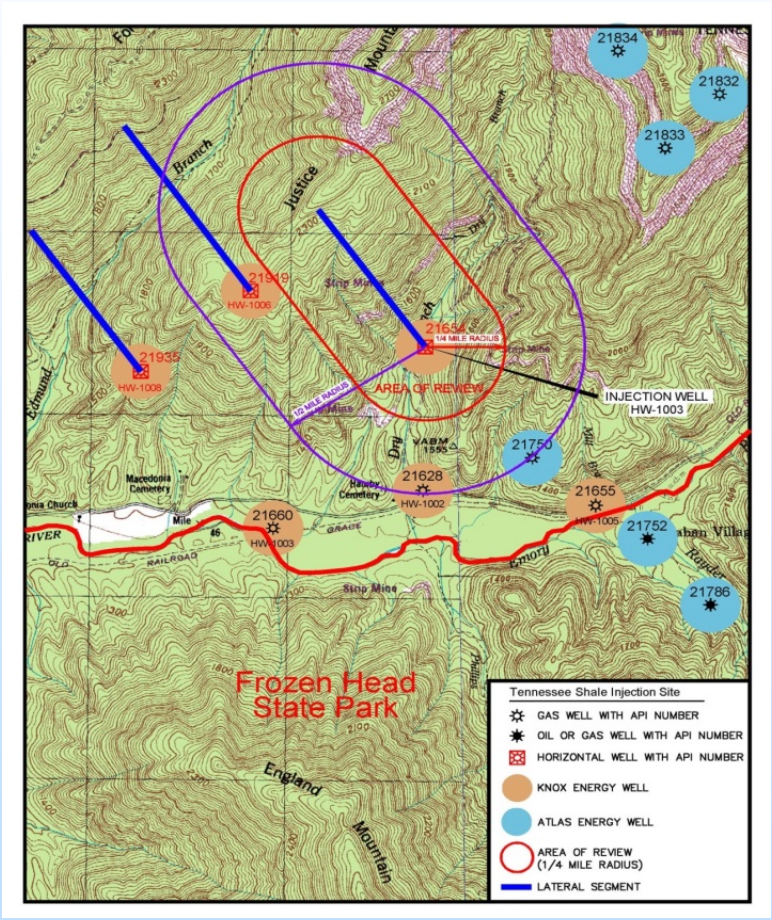
- Site closure
  - Conversion of injection and monitor wells
  - Site restoration
- Post-injection characterization
  - Data analysis and interpretation
  - Post-injection monitoring
  - Reservoir modeling
  - Assessing enhanced recovery for commercialization

Ongoing: CO_2 Injections, Reservoir Modeling, Monitoring, Education/Outreach

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

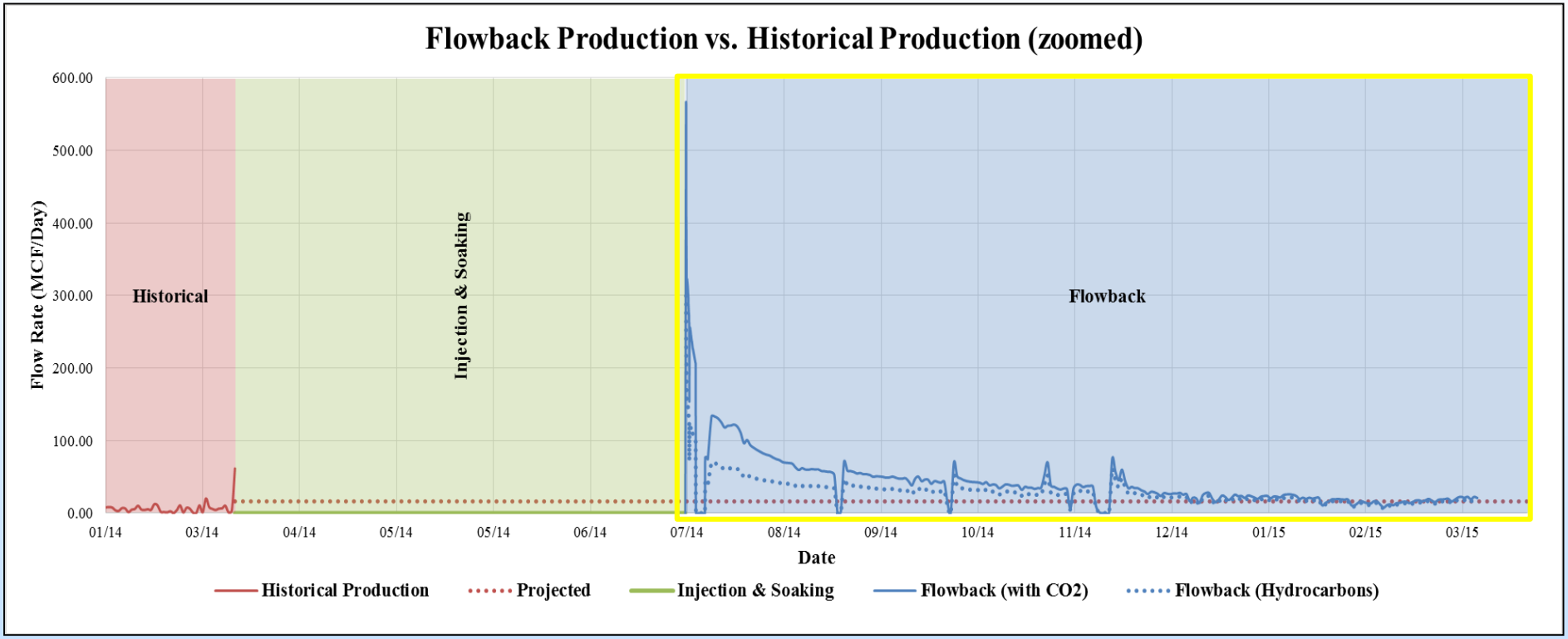


- Horizontal well in Chattanooga Shale formation, drilled in 2009
- Legacy producing gas well permitted under TDEC
- 510 tons for “huff and puff” injection test
- Injection period: March 18-31, 2014 (14 days)
- Shut-in period: March 31- July 29, 2014 (~4 months)
- Flowback period: July 29, 2014- present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



Shale CO_2 Injection Test in Morgan County, Tennessee

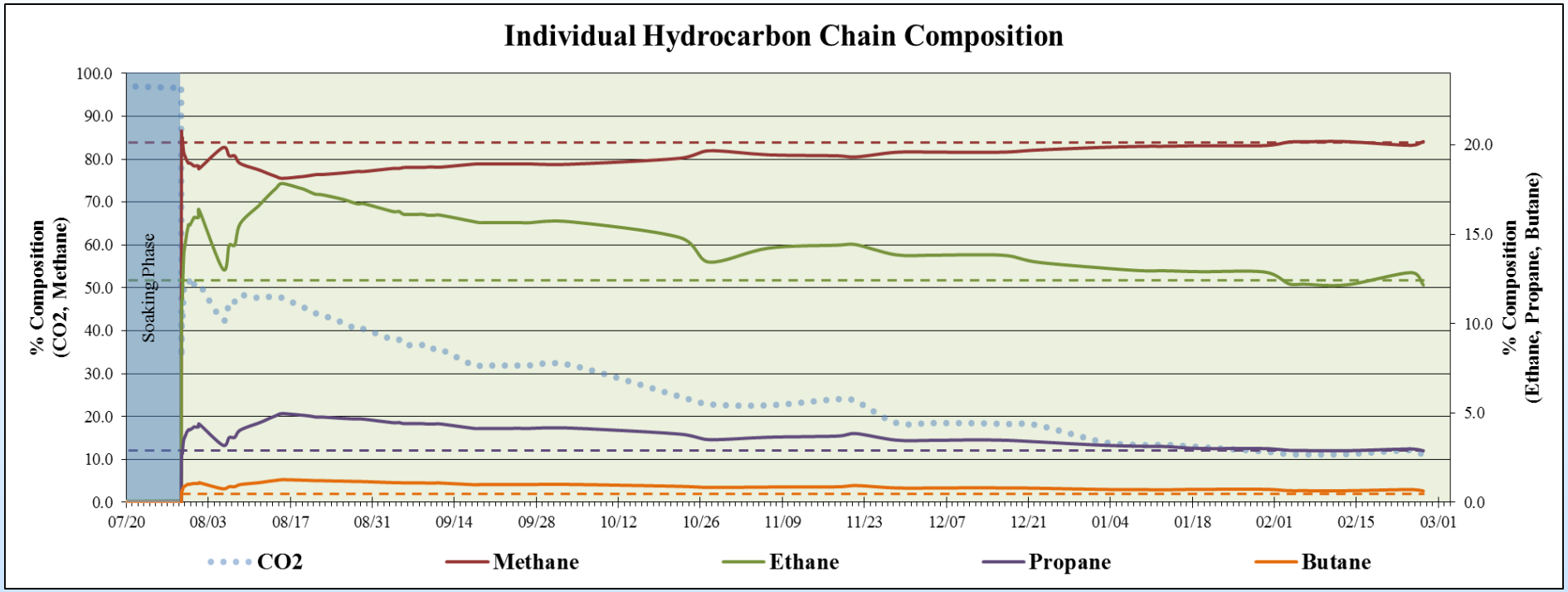
Flowback Results



- **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

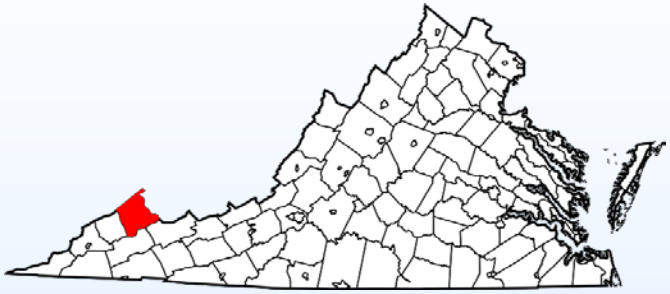
Results to Date



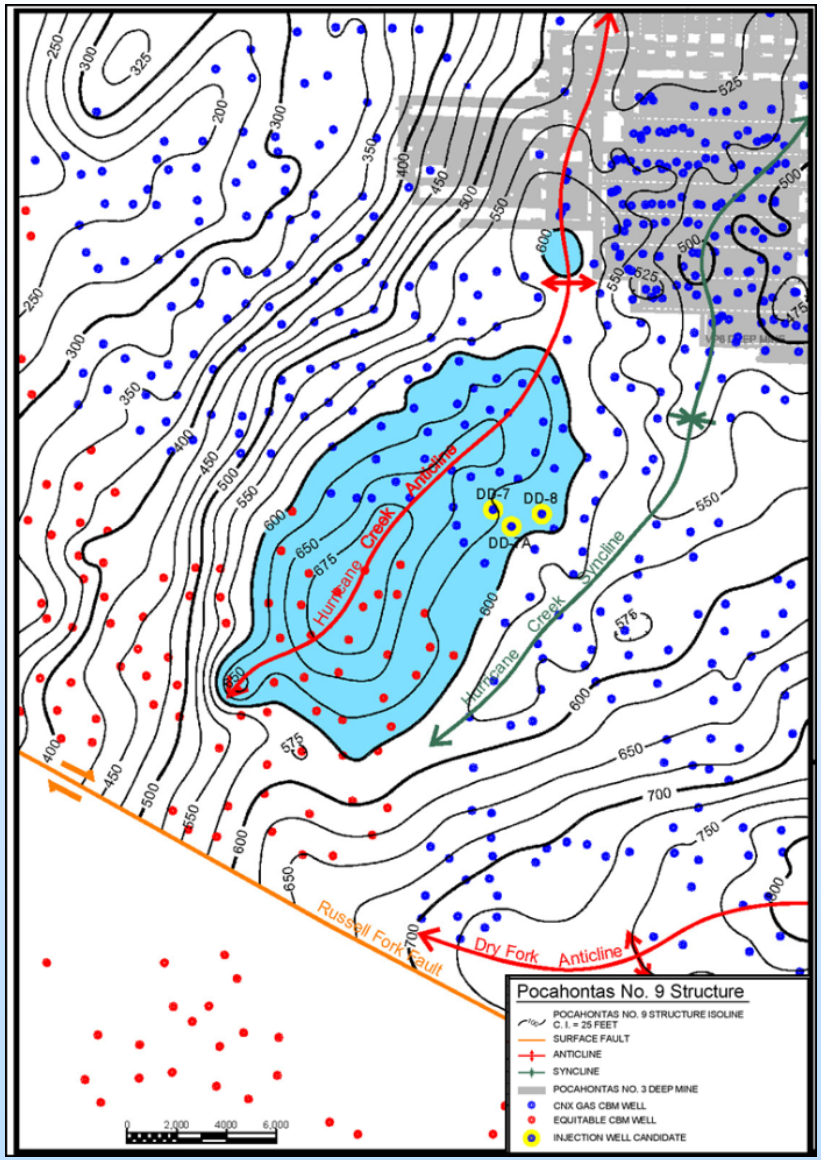
Production of heavy hydrocarbons elevated from baseline values:

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

CBM CO_2 Injection Test in Buchanan County, Virginia



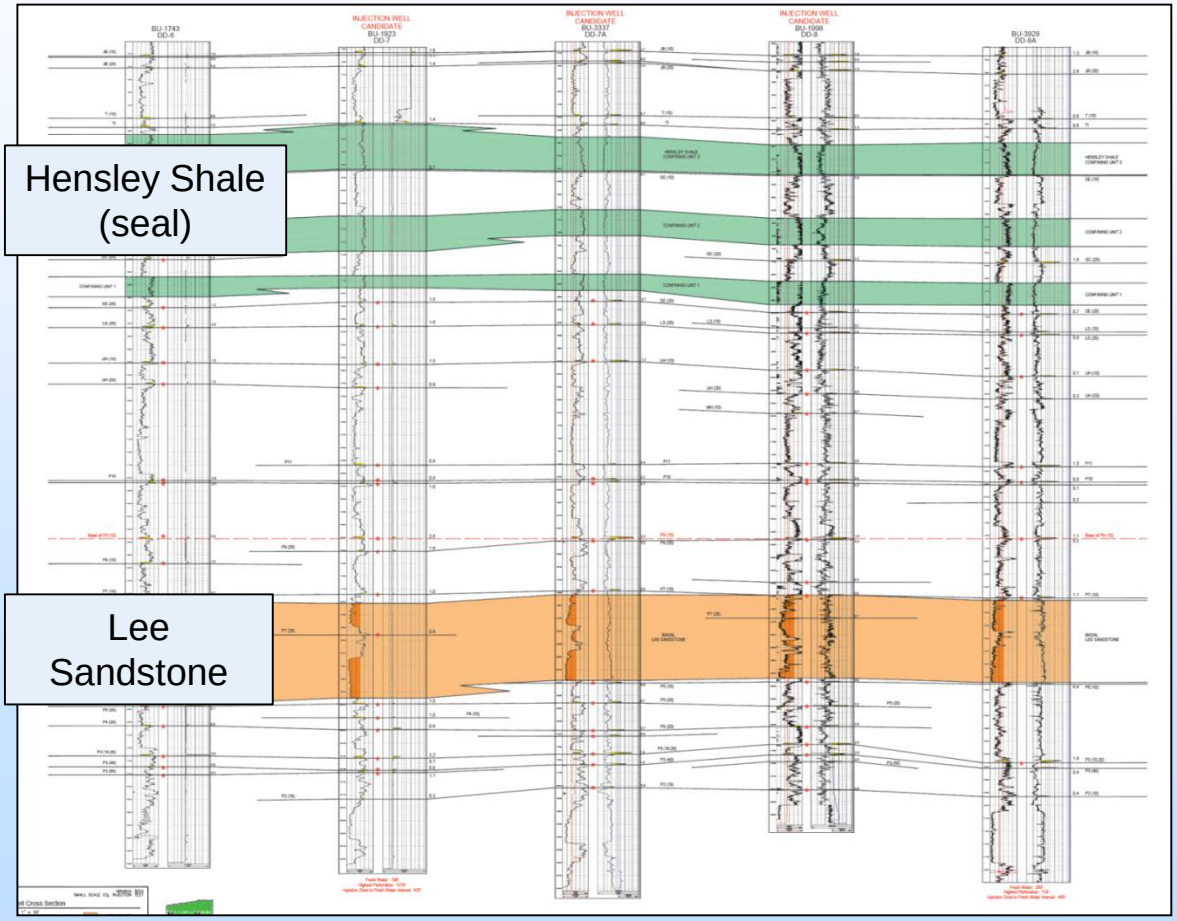
- Oakwood coalbed methane field
- Stacked coal reservoir, 15-20 seams
- Tight shale and sandstone confining units
- 20,000-tonne CO_2 injection over one year in three legacy production wells
- CO_2 storage + Enhanced gas recovery (EGR)
- US EPA Class II UIC Permit
- Current status: Injection on-going.



CBM CO_2 Injection Test in Buchanan County, Virginia

Reservoir Modeling

Stratigraphic cross section through injection wells

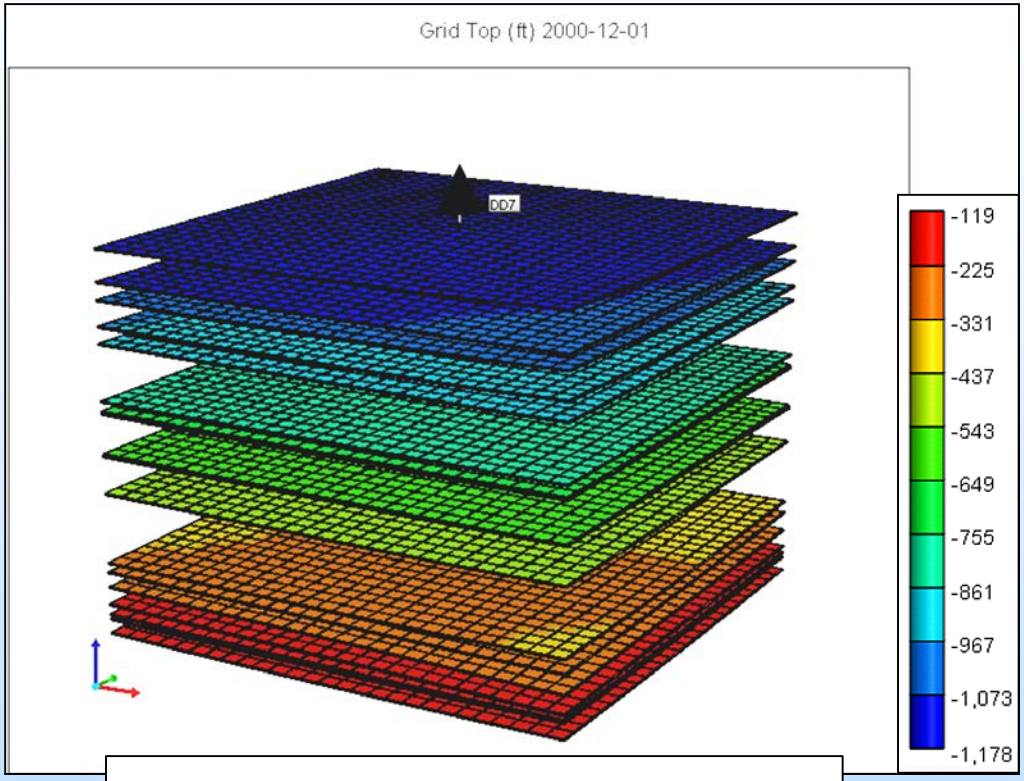


Modeling Considerations:

- 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

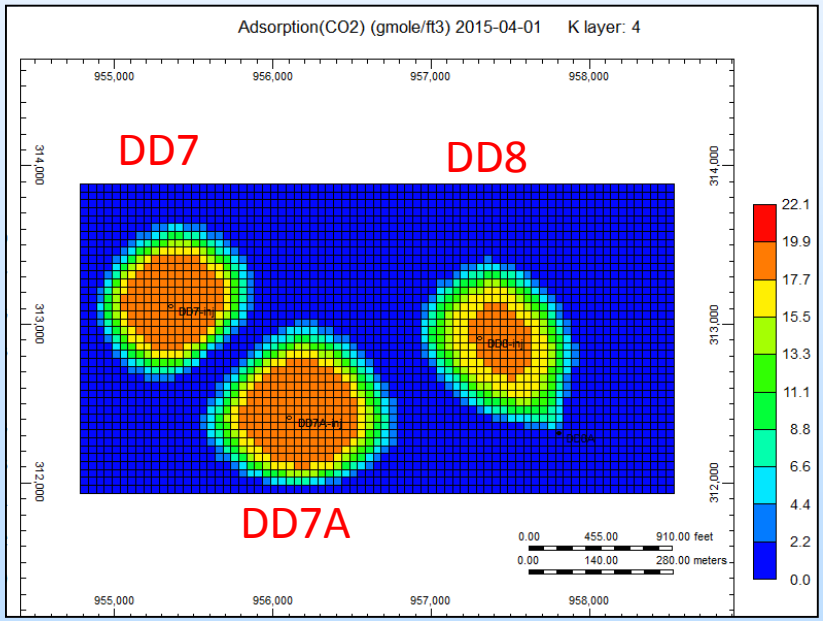
CBM CO_2 Injection Test in Buchanan County, Virginia

Reservoir Modeling



18-layer reservoir model

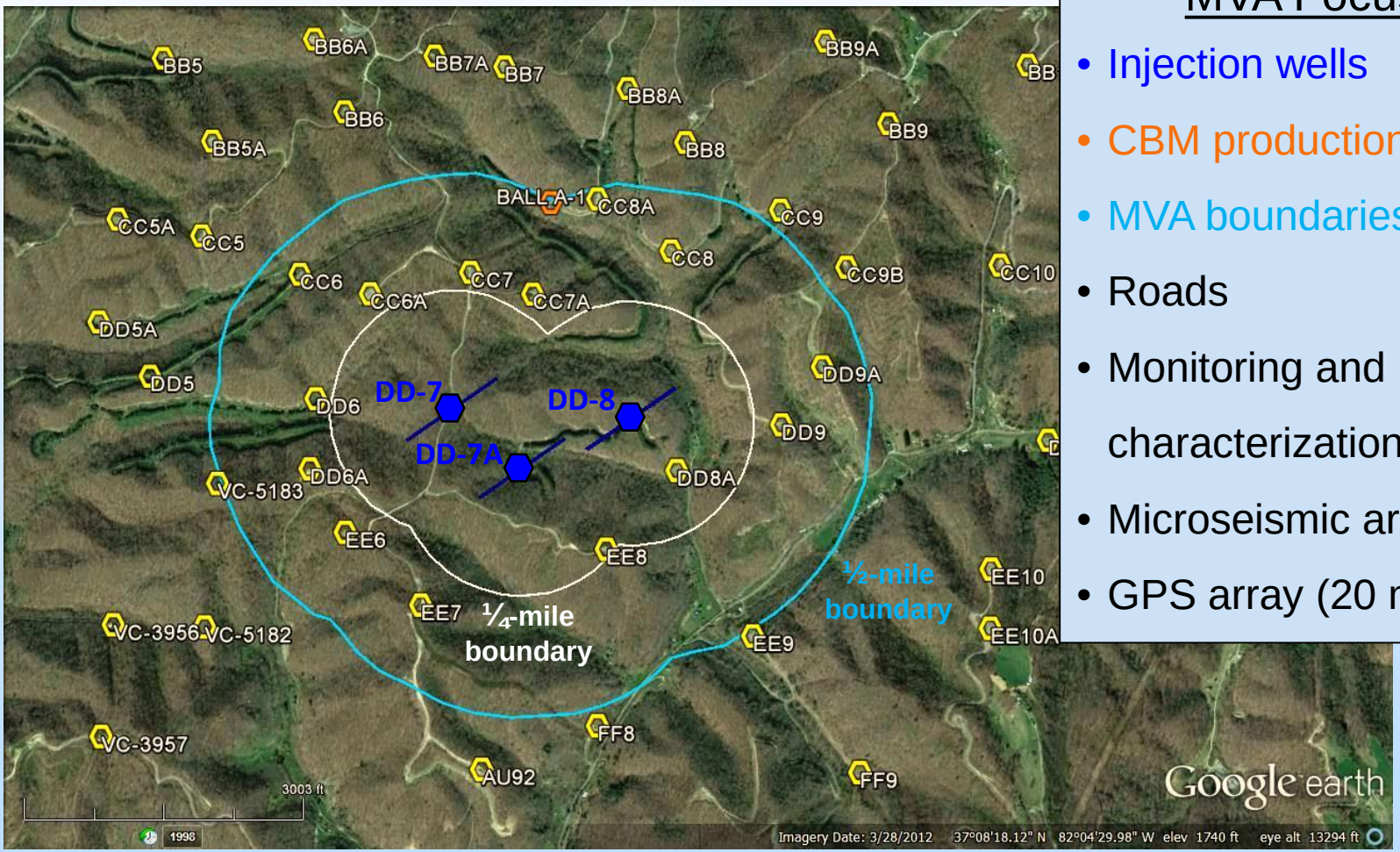
CO_2 Injection simulations used to define Area of Review (AOR) for monitoring program



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

Monitoring, Verification, and Accounting (MVA)

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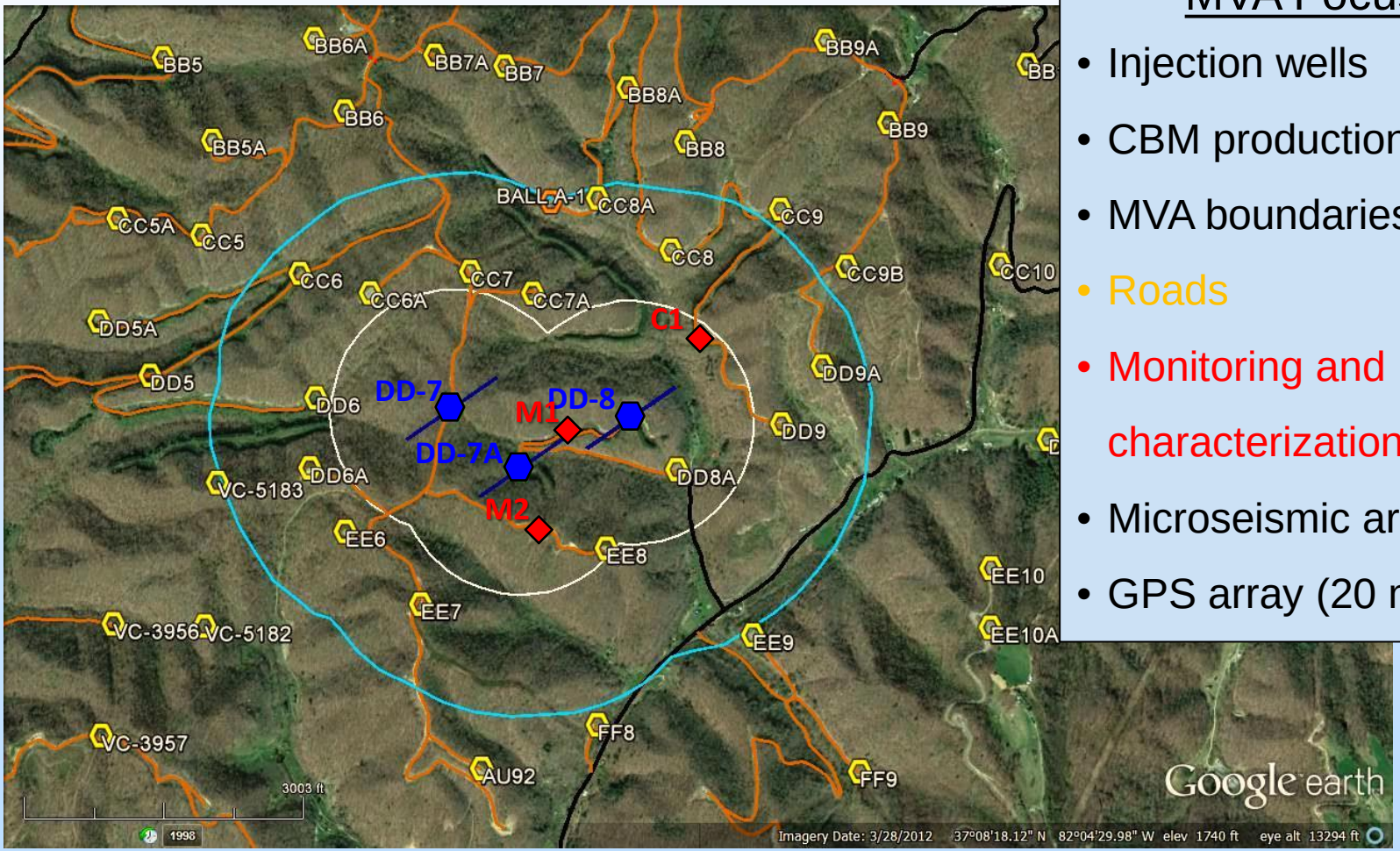

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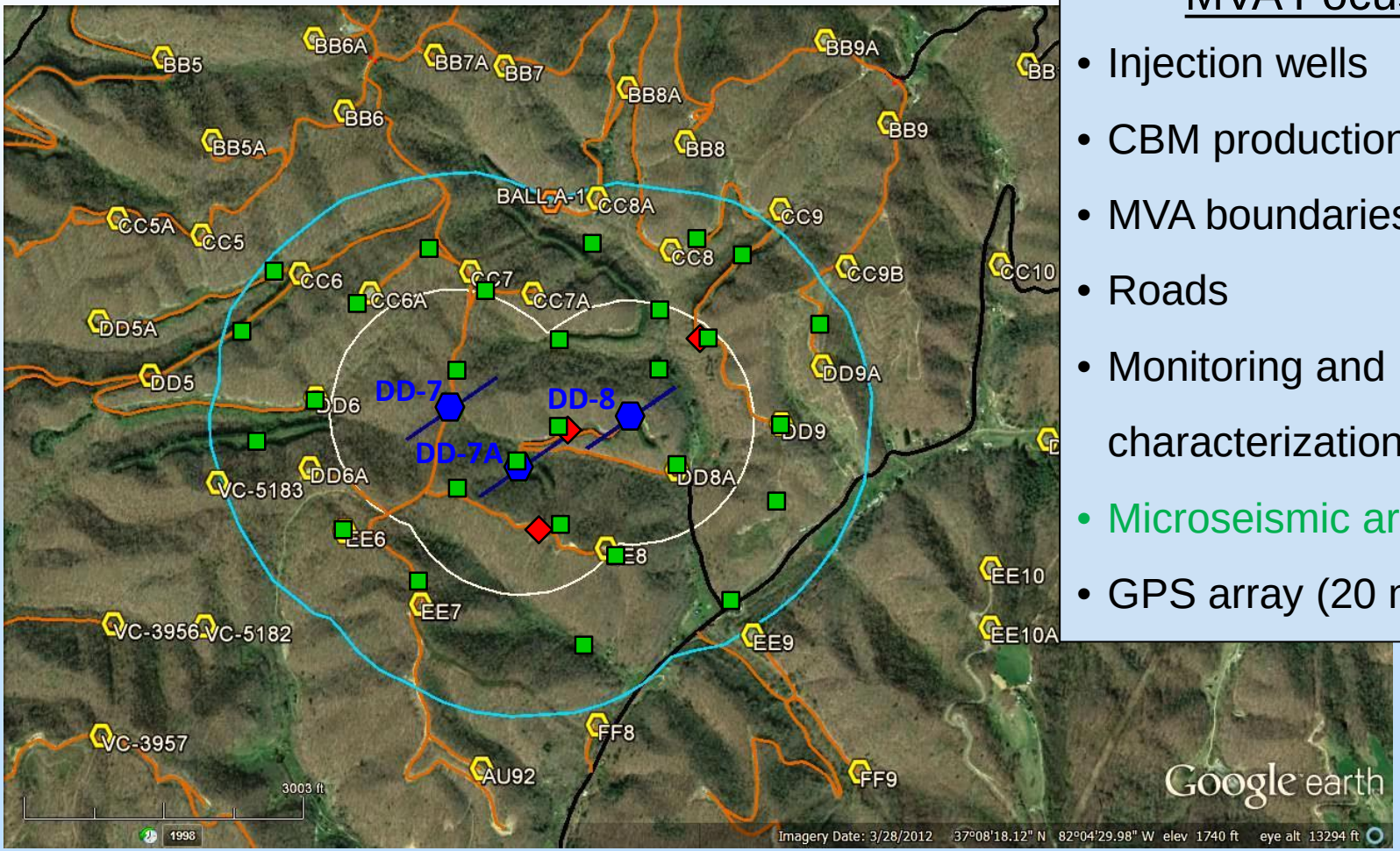

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Monitoring, Verification, and Accounting (MVA)

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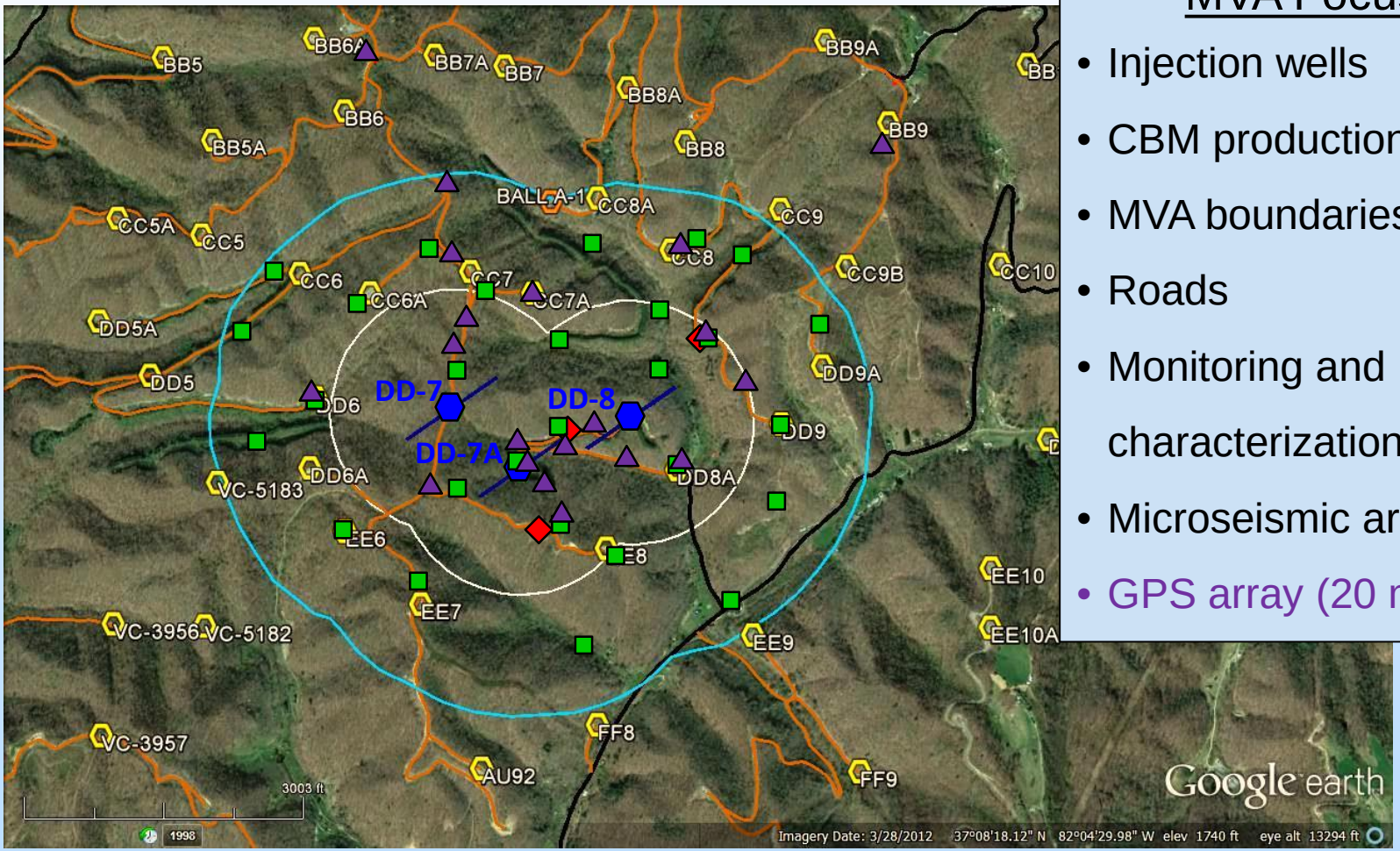

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CBM CO_2 Injection Test in Buchanan County, Virginia

Monitoring, Verification, and Accounting (MVA)

MVA Approach

Borehole-scale technologies:

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

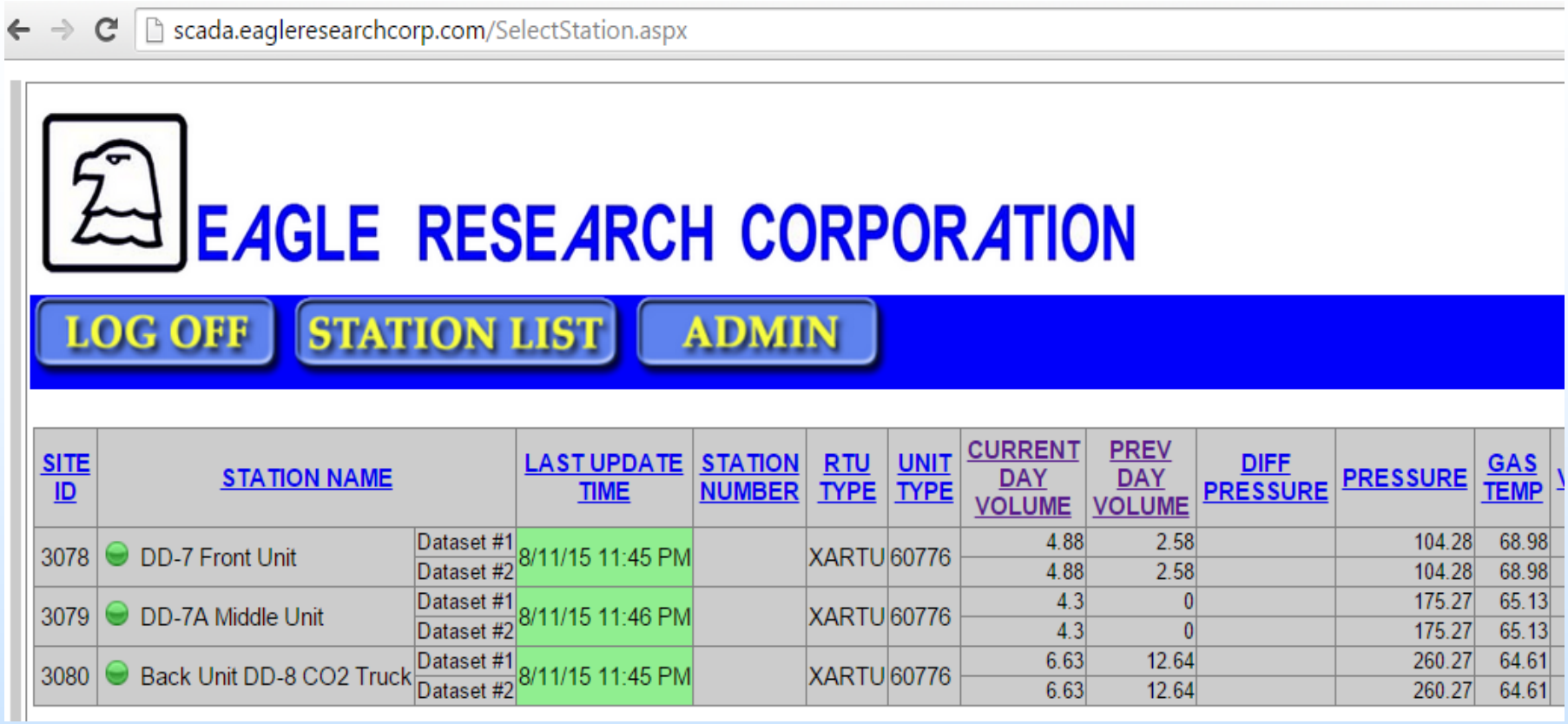
Technologies deployed over large areal extents:

- 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

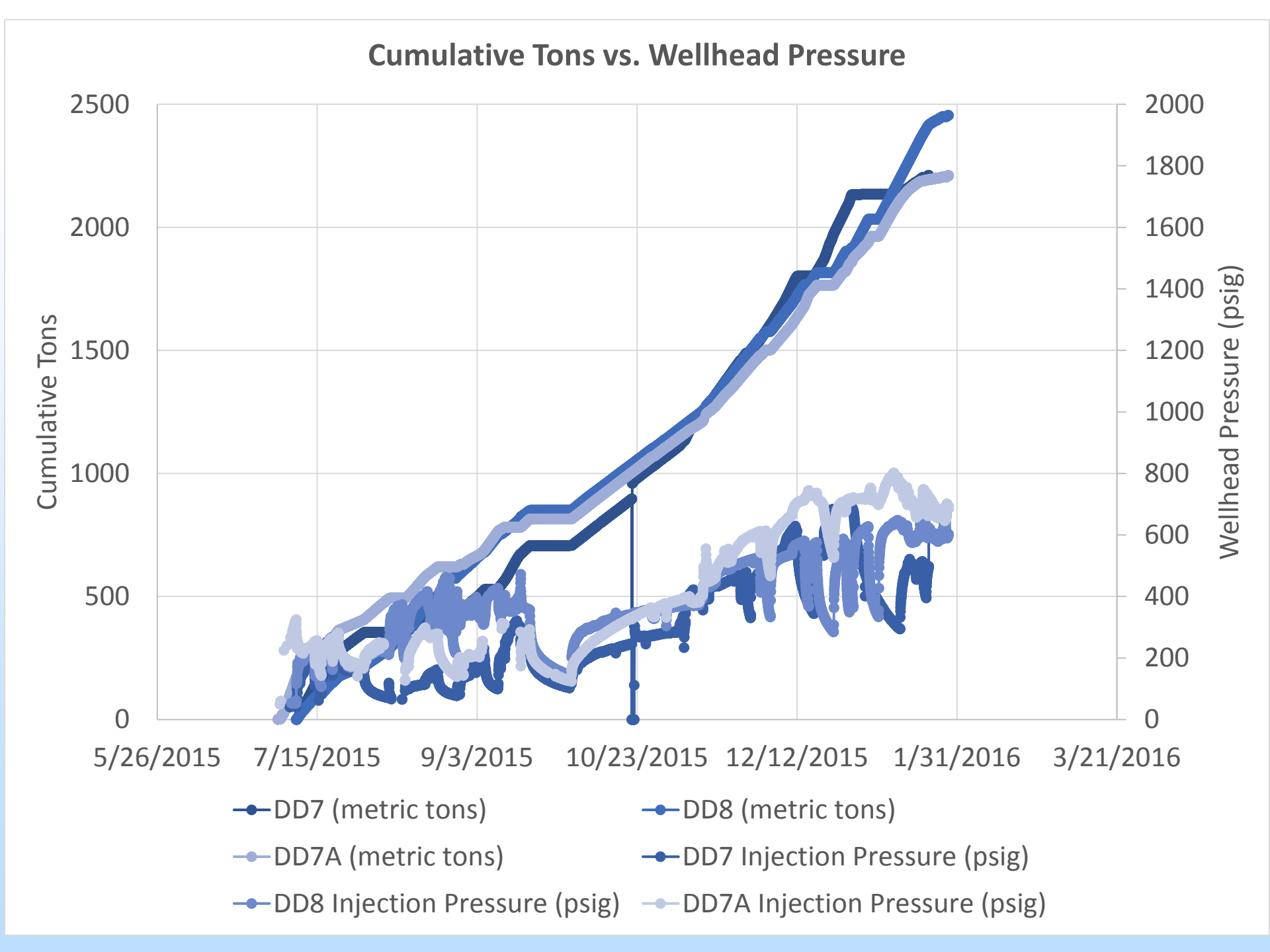
Injection Skid for 3 wells w/ Coriolis Flowmeters, Valves and Radio/Cell Communication

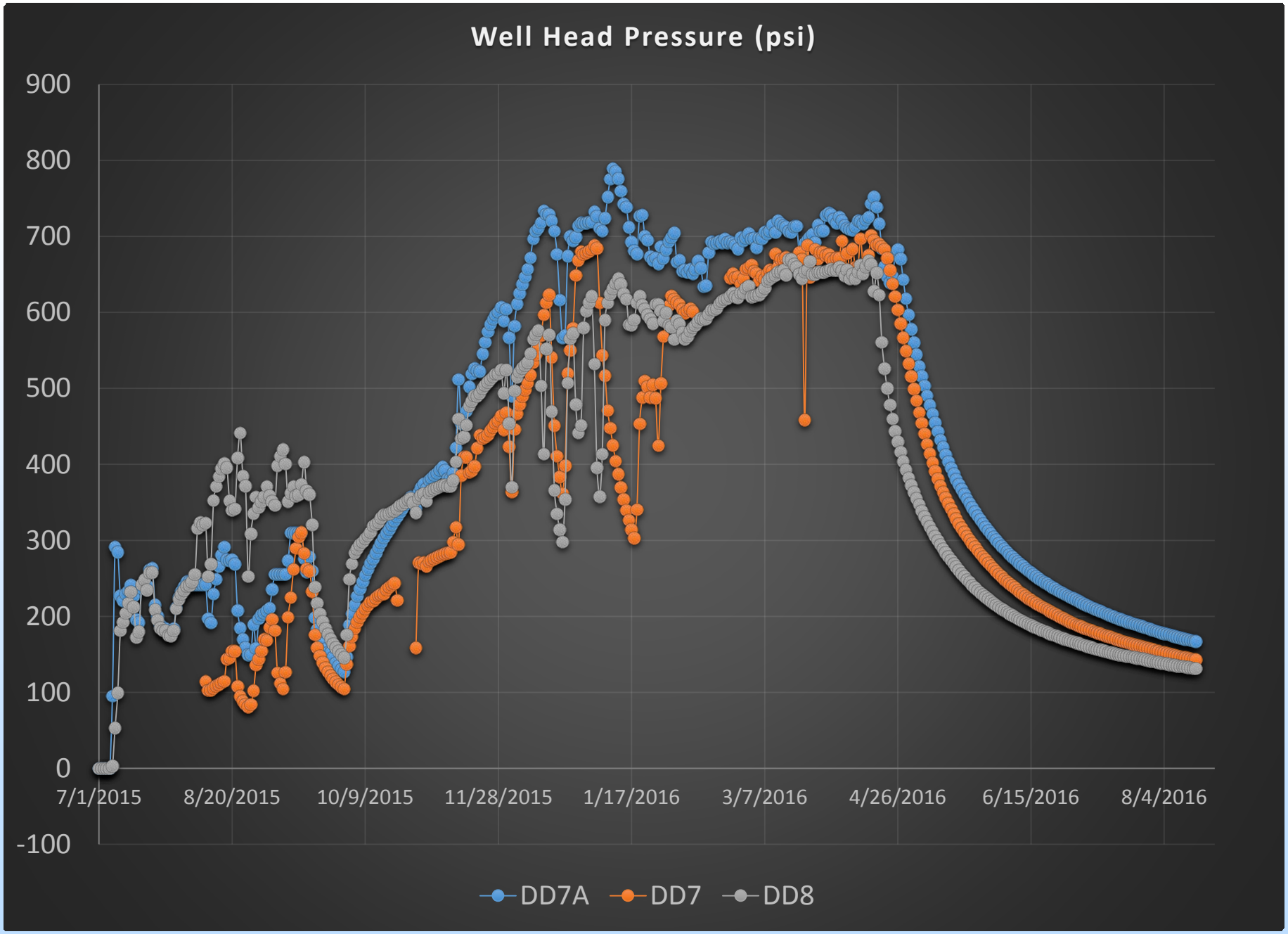
SCADA (supervisory control and data acquisition) system

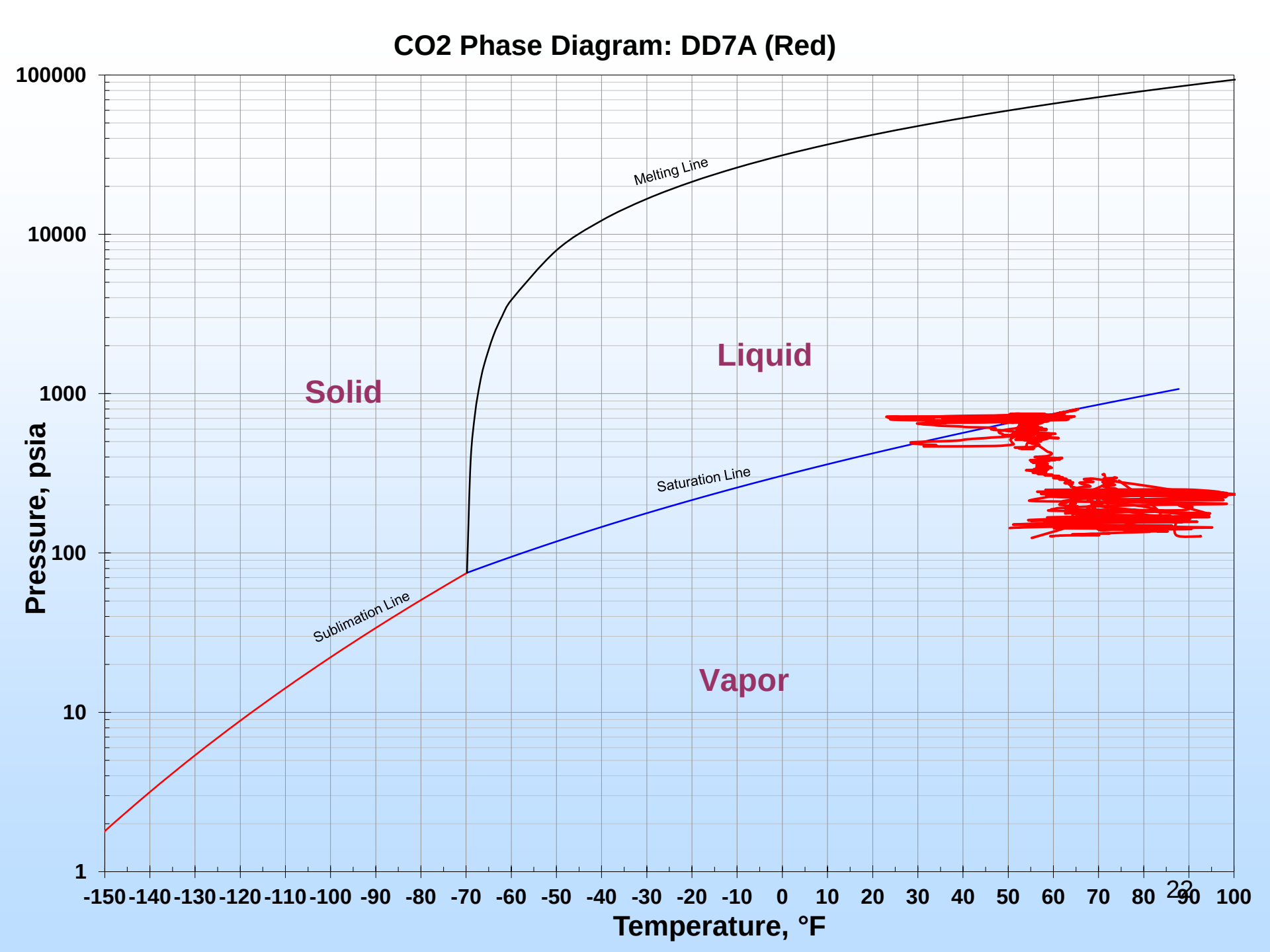


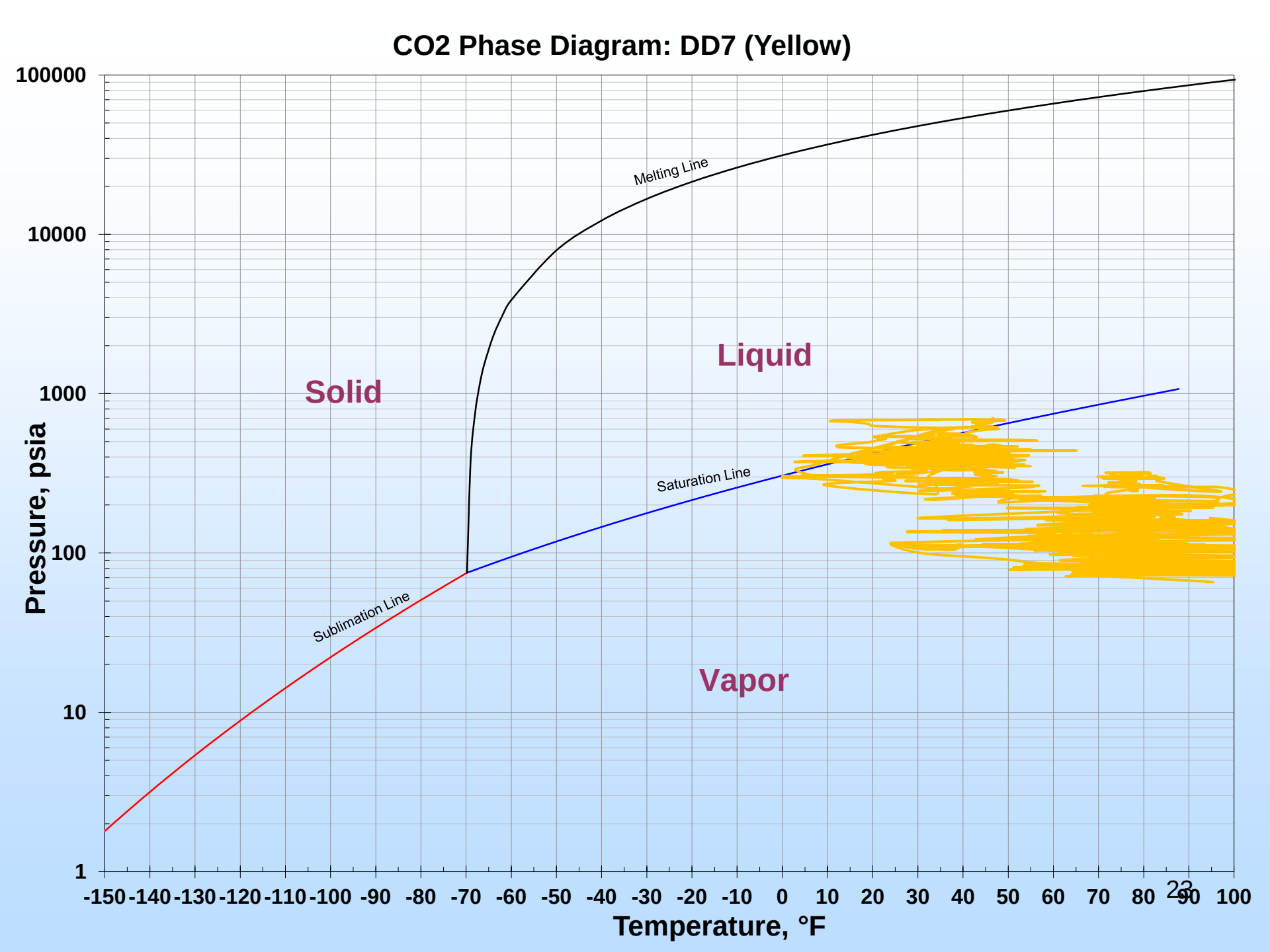
SITE ID	STATION NAME		LAST UPDATE TIME	STATION NUMBER	RTU TYPE	UNIT TYPE	CURRENT DAY VOLUME	PREV DAY VOLUME	DIFF PRESSURE	PRESSURE	GAS TEMP
3078	DD-7 Front Unit	Dataset #1	8/11/15 11:45 PM		XARTU	60776	4.88	2.58		104.28	68.98
		Dataset #2					4.88	2.58		104.28	68.98
3079	DD-7A Middle Unit	Dataset #1	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

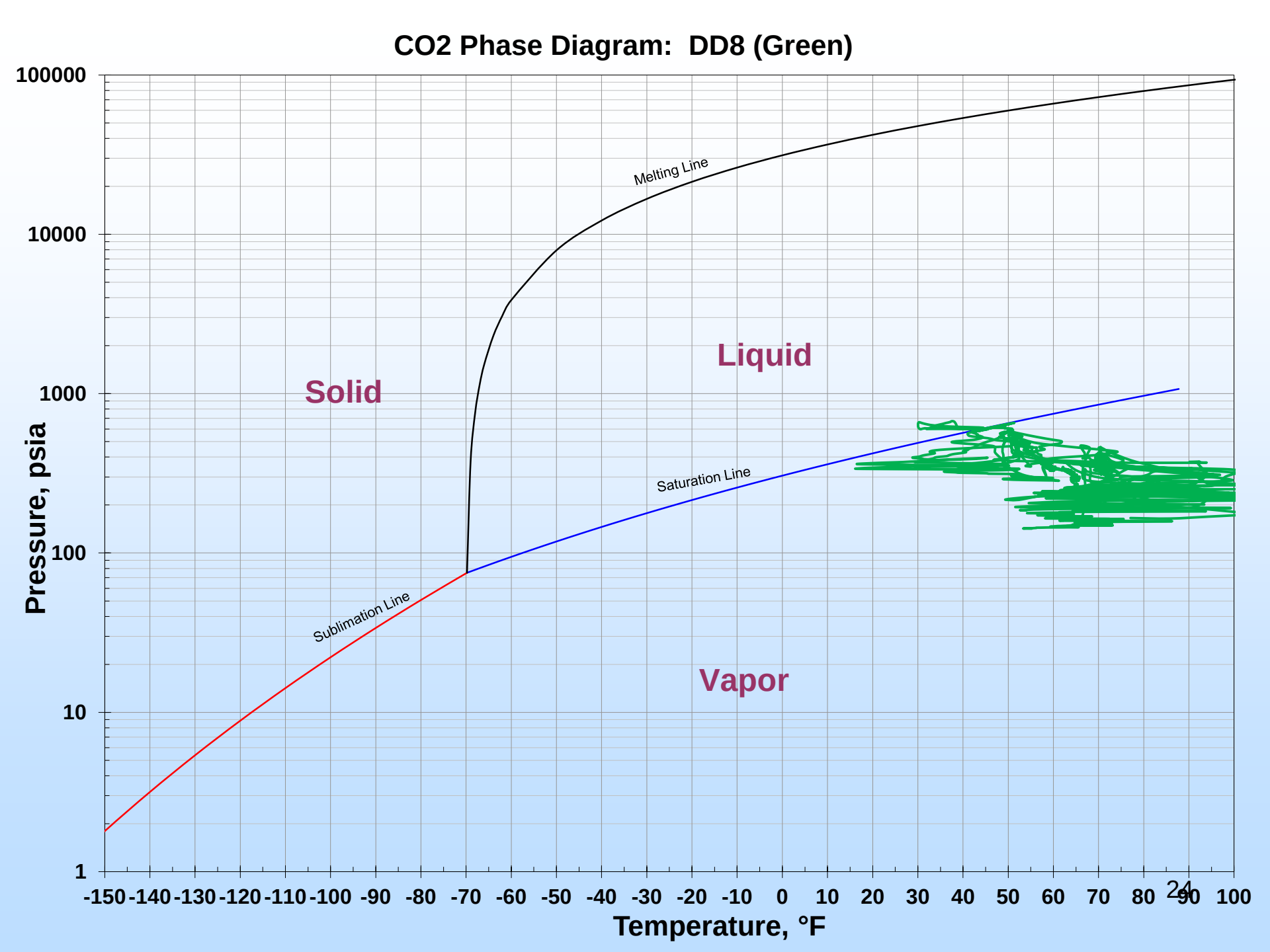
- Real-time graphing
- Alarms and Valve control:
  - flowrate, injection pressure, casing pressure
  - 30 second communication via radio

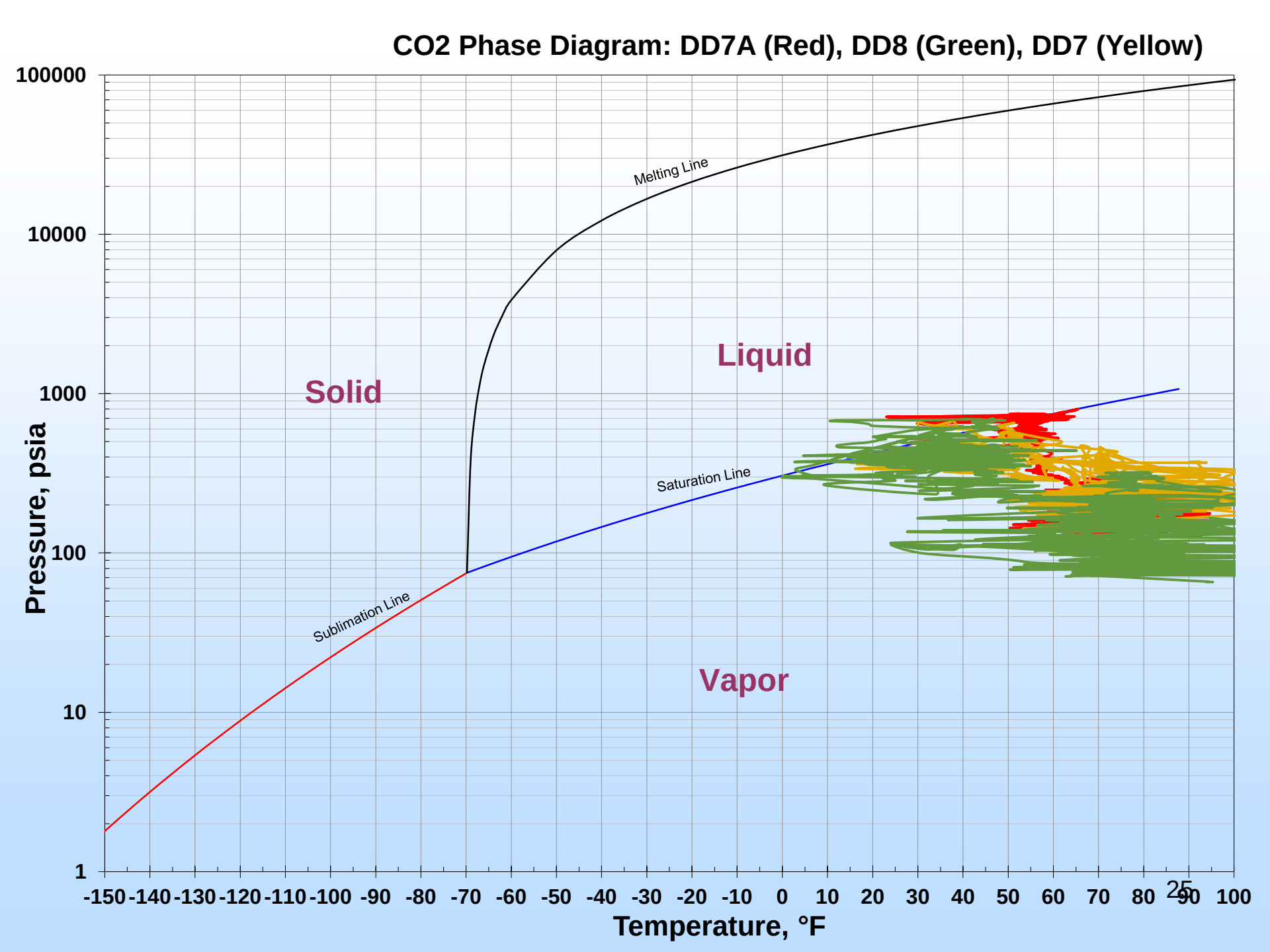

Cumulative Tons vs. Wellhead Pressure
Cumulative Tons
Wellhead Pressure (psig)
2500
2000
1500
1000
500
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5/26/2015
7/15/2015
9/3/2015
10/23/2015
12/12/2015
1/31/2016
3/21/2016
DD7 (metric tons)
DD8 (metric tons)
DD7A (metric tons)
DD7 Injection Pressure (psig)
DD8 Injection Pressure (psig)
DD7A Injection Pressure (psig)


Well Head Pressure (psi)
900
800
700
600
500
400
300
200
100
0
-100
7/1/2015
8/20/2015
10/9/2015
11/28/2015
1/17/2016
3/7/2016
4/26/2016
6/15/2016
8/4/2016
DD7A
DD7
DD8


CO2 Phase Diagram: DD7A (Red)
100000
10000
1000
100
10
1
Pressure, psia
Melting Line
Liquid
Solid
Saturation Line
Sublimation Line
Vapor
-150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Temperature, °F

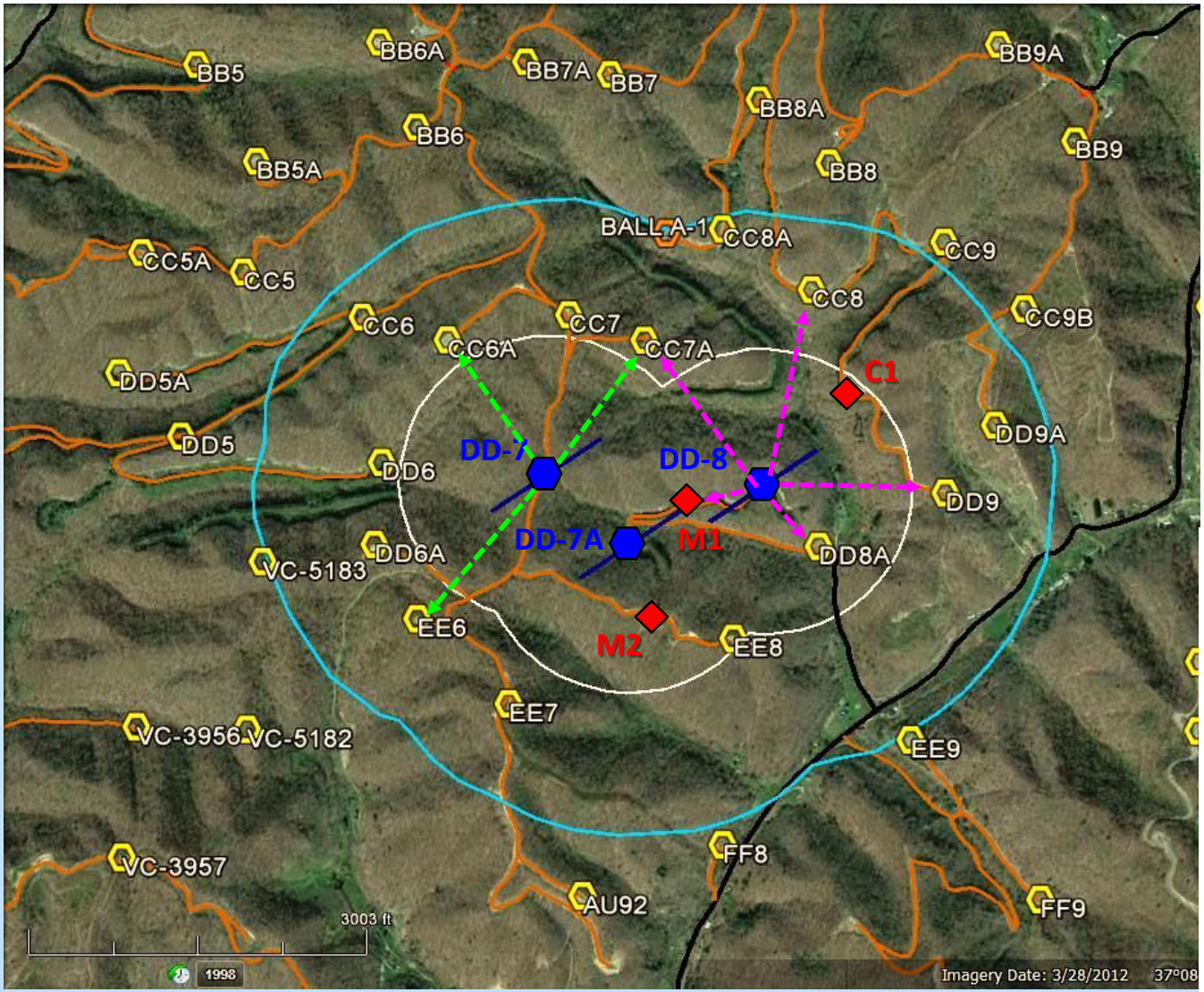

CO2 Phase Diagram: DD7 (Yellow)
100000
10000
1000
100
10
1
Pressure, psia
Melting Line
Solid
Liquid
Saturation Line
Sublimation Line
Vapor
-150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Temperature, °F


CO2 Phase Diagram: DD8 (Green)
100000
10000
1000
100
10
1
Pressure, psia
Melting Line
Solid
Liquid
Saturation Line
Sublimation Line
Vapor
-150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Temperature, °F


CO2 Phase Diagram: DD7A (Red), DD8 (Green), DD7 (Yellow)
Pressure, psia
Temperature, °F
100000
10000
1000
100
10
1
-150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Melting Line
Saturation Line
Sublimation Line
Solid
Liquid
Vapor

CBM CO_2 Injection Test in Buchanan County, Virginia

Tracer Results to Date



Tracer Plan:

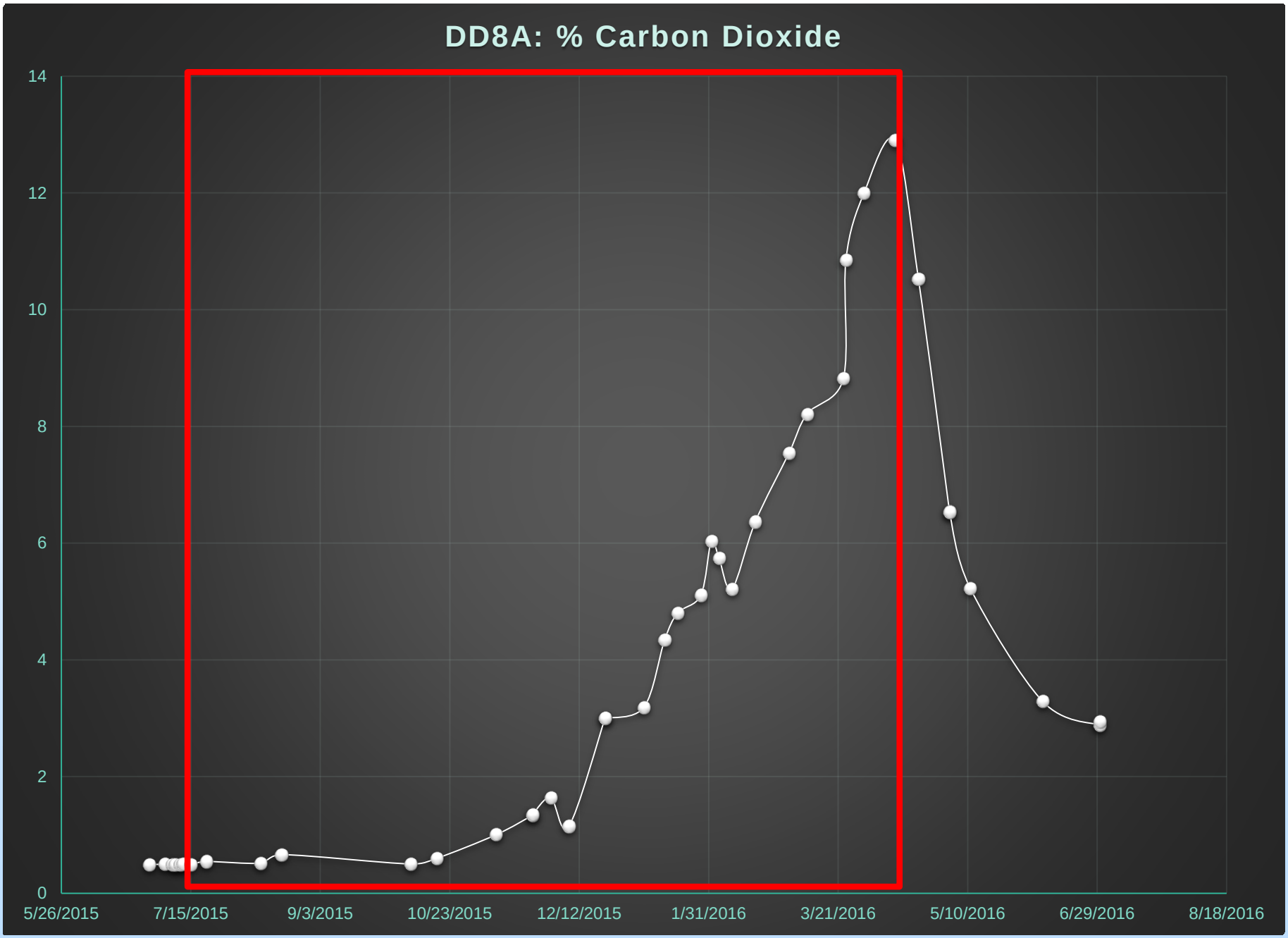
- 3 PFTs in water prior to injection (7/2,7/8)
- SF6 in gas stream (7/17) before water is pushed out of well
- 3 Refrigerants at 15%
- 3 PFTs at 40%

SF6 in DD8

M1 A – 6 days
DD8A – 18 days
CC8 – 26 days
CC7A – 40 days
DD9 – 55 days

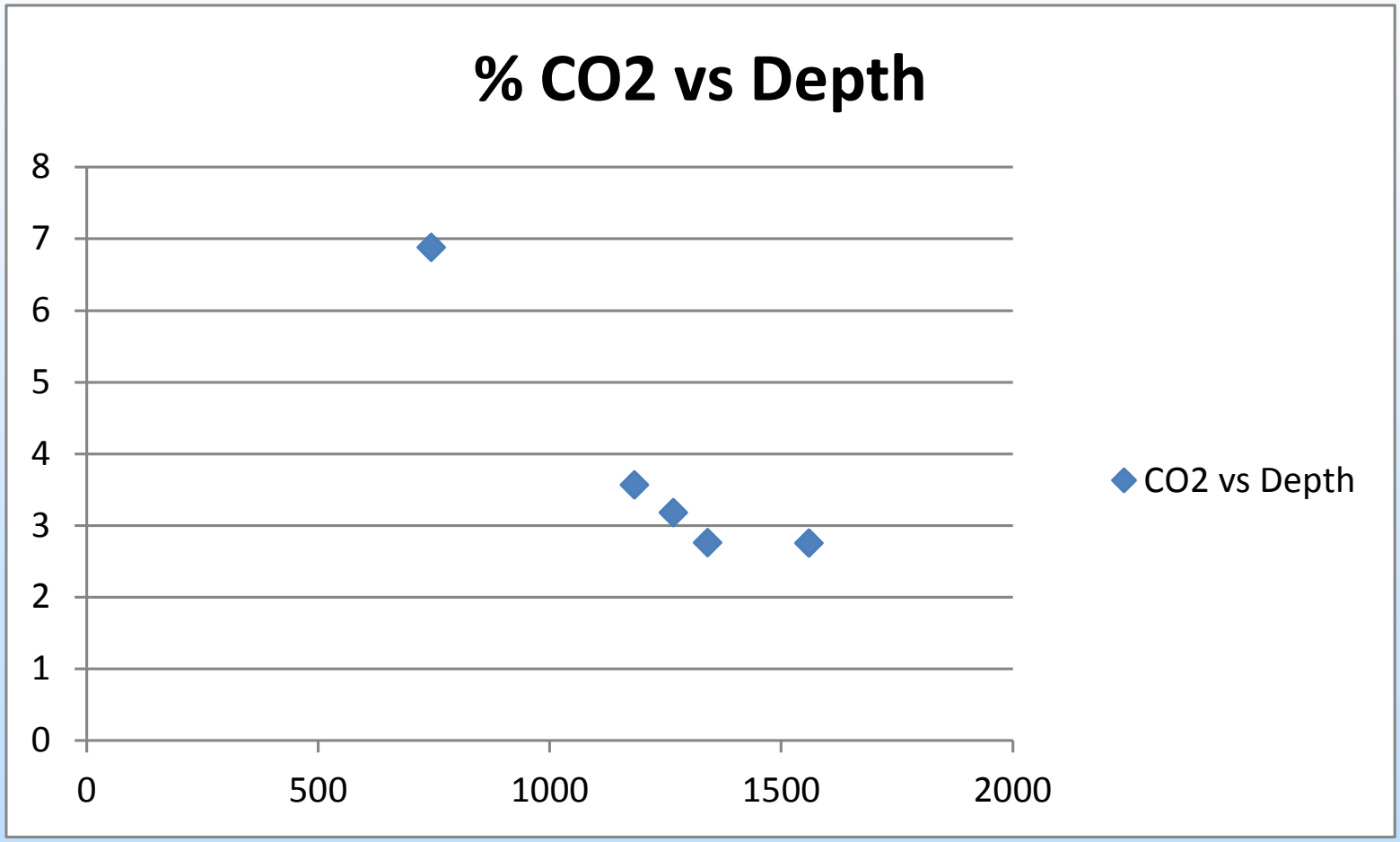
PFT in H_2O in DD7

CC7A – 35 days
EE6, CC6A – 104 days


DD8A: % Carbon Dioxide
14
12
10
8
6
4
2
0
5/26/2015
7/15/2015
9/3/2015
10/23/2015
12/12/2015
1/31/2016
3/21/2016
5/10/2016
6/29/2016
8/18/2016

DD8A – Well Killing Test

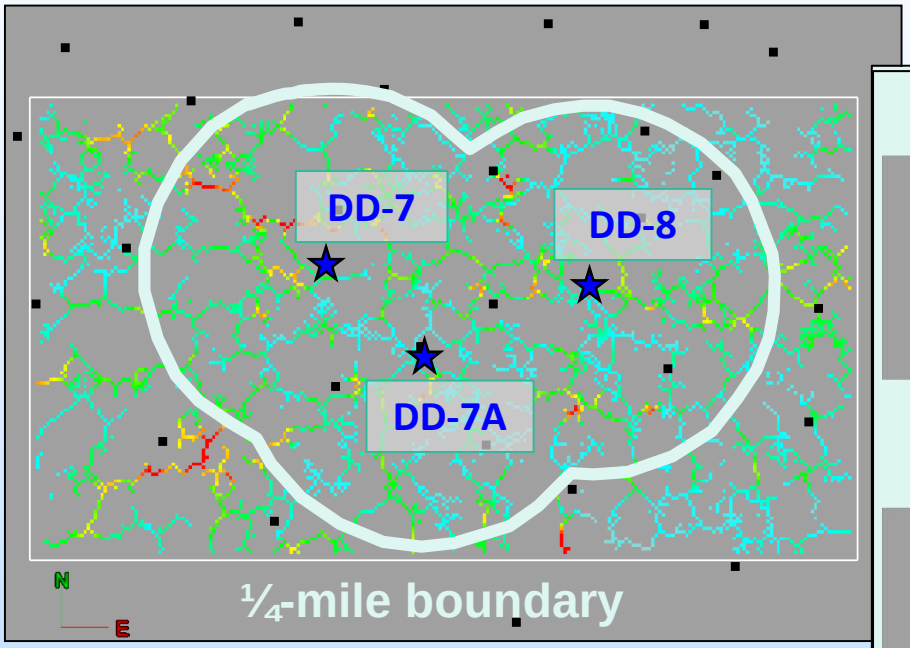
CO2 is most present in the shallow coals



Passive Microseismic Monitoring: Ambient Analysis

Global Geophysical Services, Inc.

***No microseimic events recorded**

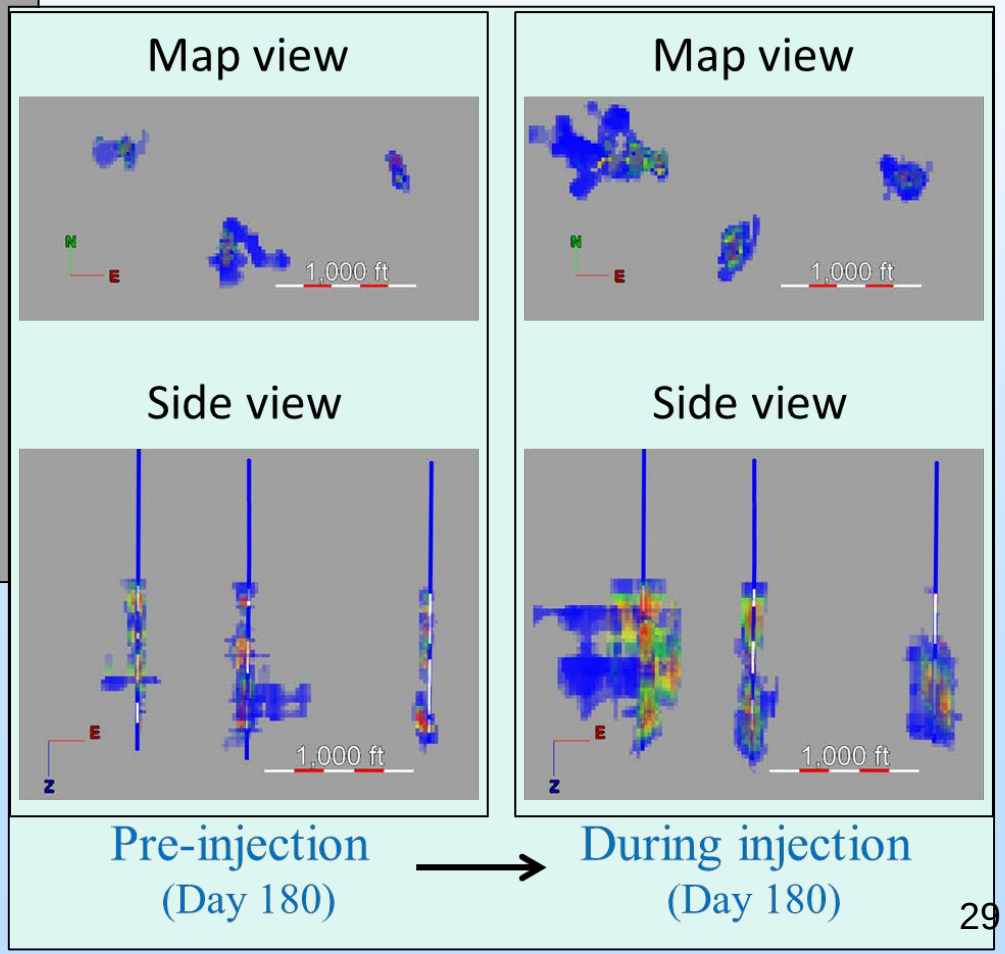


Active fracture network

Inferred from Tomographic Fracture Imaging™

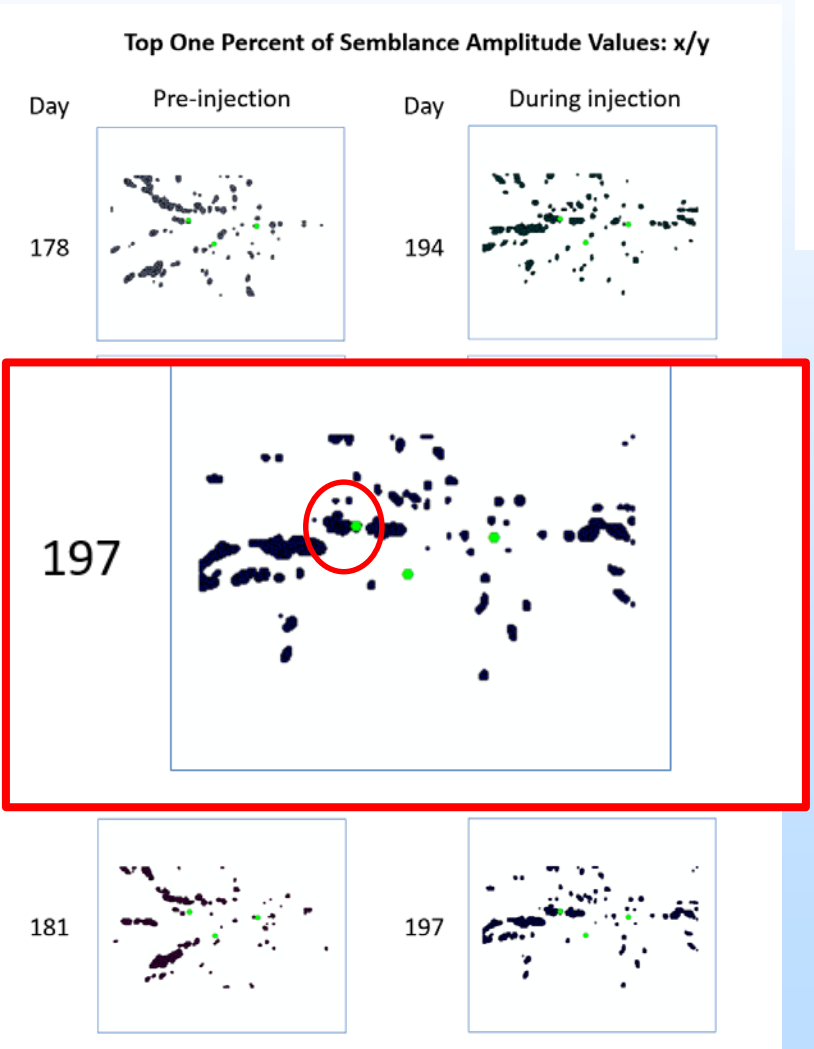
CO_2 plume evolution

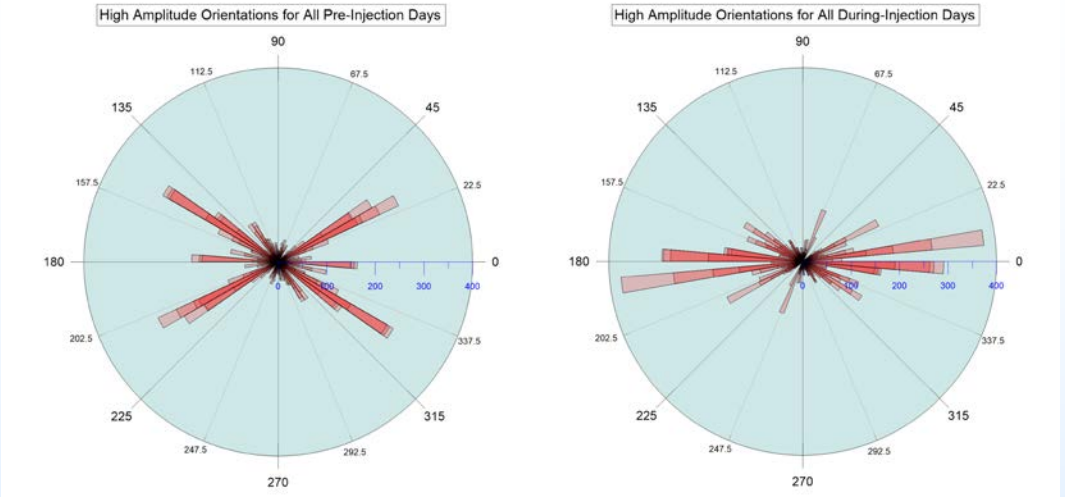
Inferred from Wellbore Activated Volumes

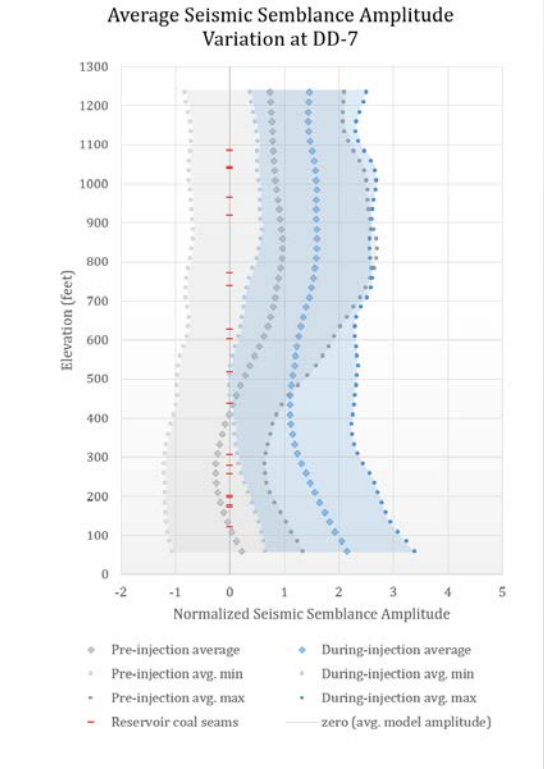


Passive Microseismic Monitoring

Consistent reorganization of acoustic energy during injection







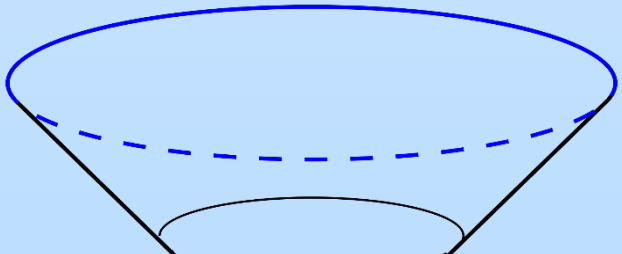
Simulated time-lapse "acoustic log" of DD7

Injection Overview

- 11,700 tons injected to date
  - DD7: 3,837 tons
  - DD7A: 3,640 tons
  - DD8: 4,223 tons
- Tracer breakthrough confirmed at 7 off-set wells and 1 monitoring well
- Tracer breakthrough precedes CO2 in DD8A by months
  - Tracer breakthrough in less than 3 weeks
  - CO2 breakthrough at DD8A (4.5 months)
- Transitionined from Gas to Liquid injection based on pressure/temperature
- Monitoring Wells showing a slow increase in bottom-hole pressure, but more importantly have shown water levels increasing than decreasing (likely the CO2 is pushing a water front past the monitoring wells)

Injection Overview

- All tests have shown CO2 injection has been primarily in the shallower coals (likely due to higher permeability and more depletion of methane from production)
  - Well Flooding Test on CC7A prior to injection showed the deeper coals producing 60+% of the gas (higher pressure and less depleted)
  - Well Flooding Test: upper seams contributing majority of CO2 to breakthrough at DD8A
  - Spinner Survey shows upper seams taking majority of the CO2: 60% in upper ¼ of the stacked coals, 30% in 2nd quarter, 10% in 3rd quarter, 0% (spinner not turning, so not quantifiable) in deepest quarter
  - Microseismic survey showed more activity in the shallower formations
- **Plume: an inverted frustum (cone)**
  - Reservoir Models being updated based on spinner and production surveys



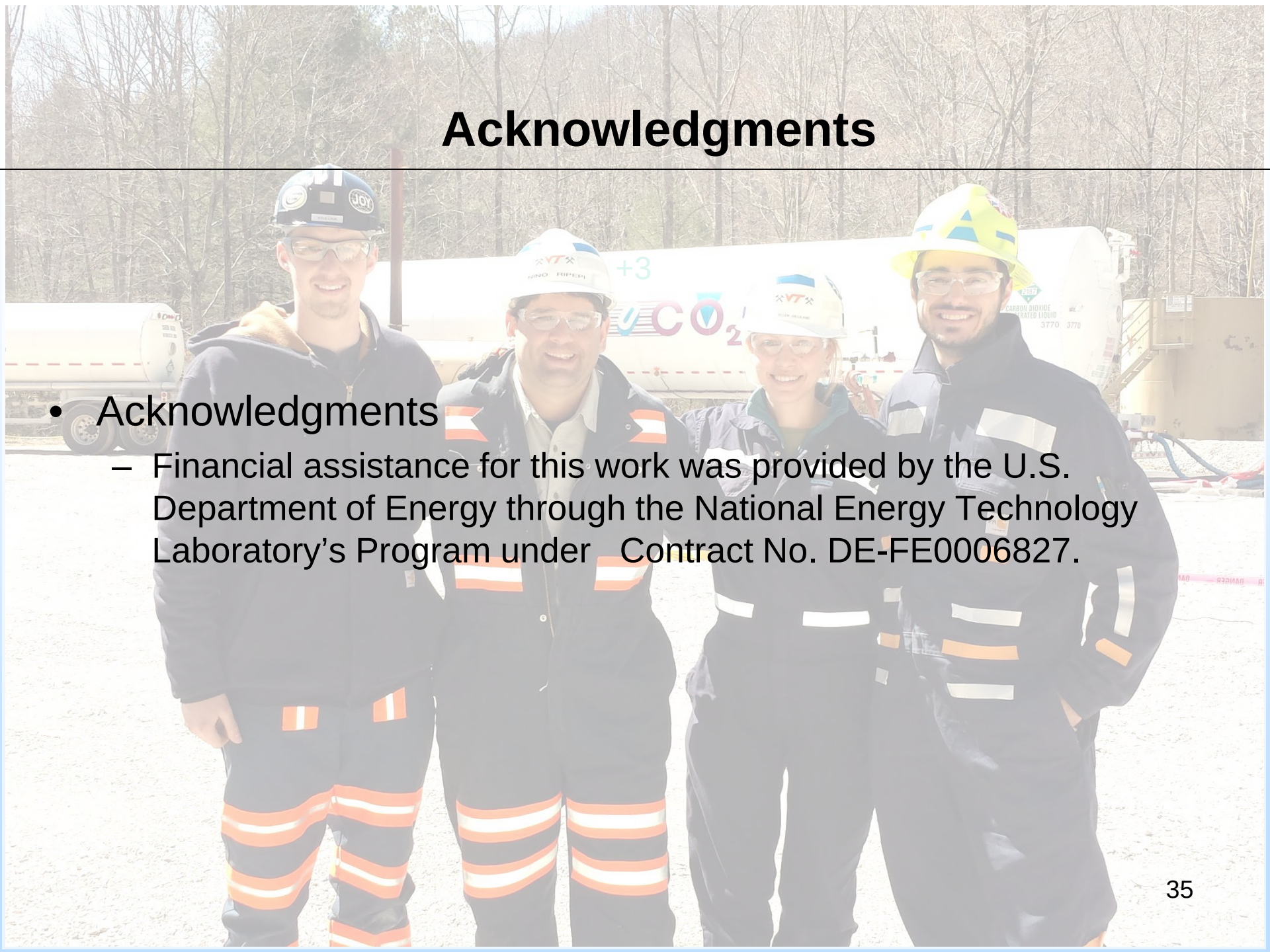
Summary

- Shale Test Injection successful
  - Flowback showed EGR and specifically NGLs
- CBM Test Injection
  - Continuous injection for 10 months
  - Multiple wells allow for varied injection rates and pressures as well as fall-off testing
  - Breakthrough of CO2 at 1 offset well
  - Expect to continue injection for 3+ months

Synergistic Activities

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

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.

Appendix

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 On-Going

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]

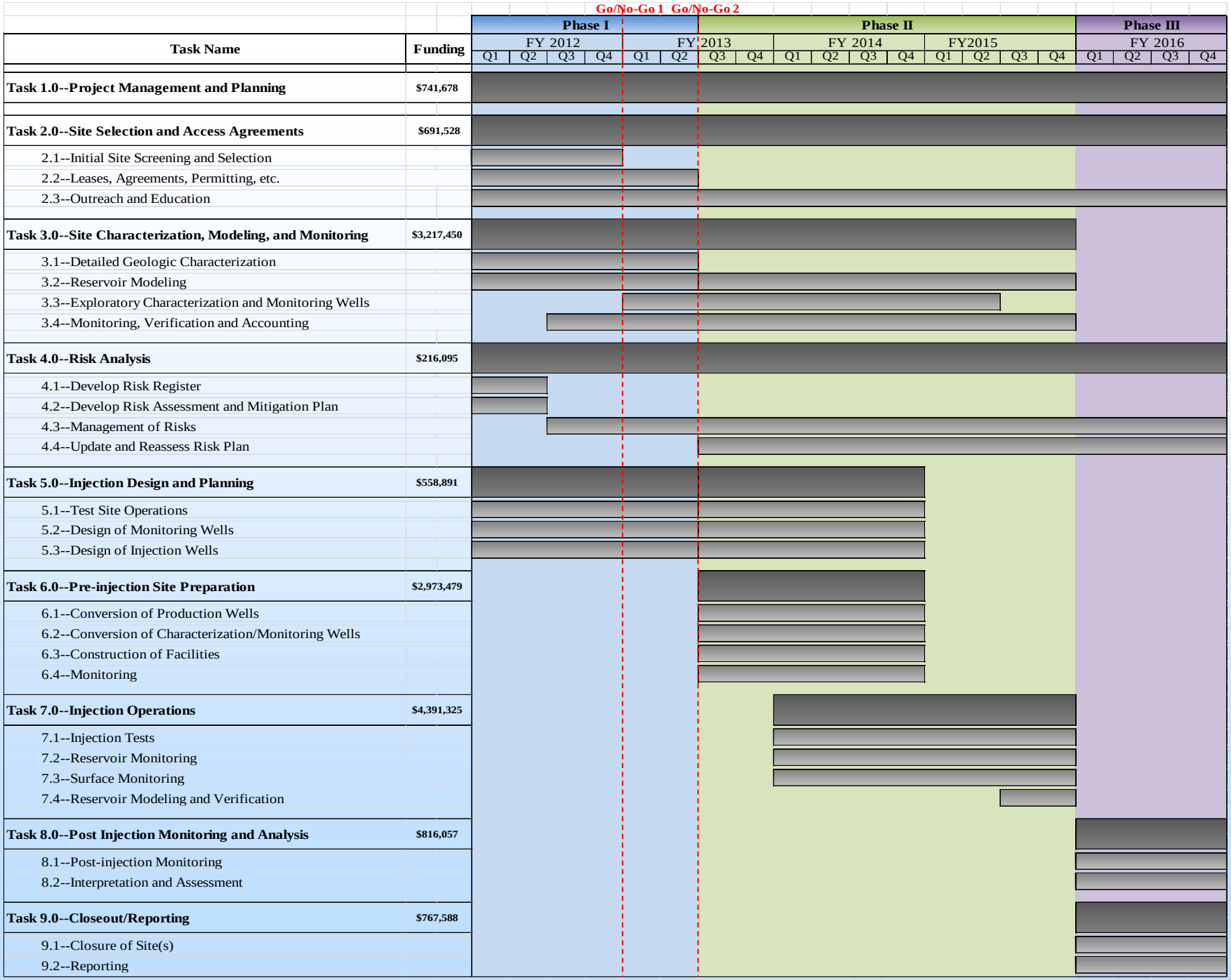
[1] **Project management**
[2] **Operations**
[3] **Research**
[4] **Risk management**
[5] **Outreach**

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 Tennessee
- University of Virginia
- Southern Illinois University
- Oklahoma State University


Go/No-Go 1
Go/No-Go 2
Phase I
Phase II
Phase III
Task Name
Funding
FY 2012
FY 2013
FY 2014
FY2015
FY 2016
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Task 1.0--Project Management and Planning
$741,678
Task 2.0--Site Selection and Access Agreements
$691,528
2.1--Initial Site Screening and Selection
2.2--Leases, Agreements, Permitting, etc.
2.3--Outreach and Education
Task 3.0--Site Characterization, Modeling, and Monitoring
$3,217,450
3.1--Detailed Geologic Characterization
3.2--Reservoir Modeling
3.3--Exploratory Characterization and Monitoring Wells
3.4--Monitoring, Verification and Accounting
Task 4.0--Risk Analysis
$216,095
4.1--Develop Risk Register
4.2--Develop Risk Assessment and Mitigation Plan
4.3--Management of Risks
4.4--Update and Reassess Risk Plan
Task 5.0--Injection Design and Planning
$558,891
5.1--Test Site Operations
5.2--Design of Monitoring Wells
5.3--Design of Injection Wells
Task 6.0--Pre-injection Site Preparation
$2,973,479
6.1--Conversion of Production Wells
6.2--Conversion of Characterization/Monitoring Wells
6.3--Construction of Facilities
6.4--Monitoring
Task 7.0--Injection Operations
$4,391,325
7.1--Injection Tests
7.2--Reservoir Monitoring
7.3--Surface Monitoring
7.4--Reservoir Modeling and Verification
Task 8.0--Post Injection Monitoring and Analysis
$816,057
8.1--Post-injection Monitoring
8.2--Interpretation and Assessment
Task 9.0--Closeout/Reporting
$767,588
9.1--Closure of Site(s)
9.2--Reporting

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