

CO₂ Storage in Unconventional Gas Formations with Enhanced Gas Recovery Potential

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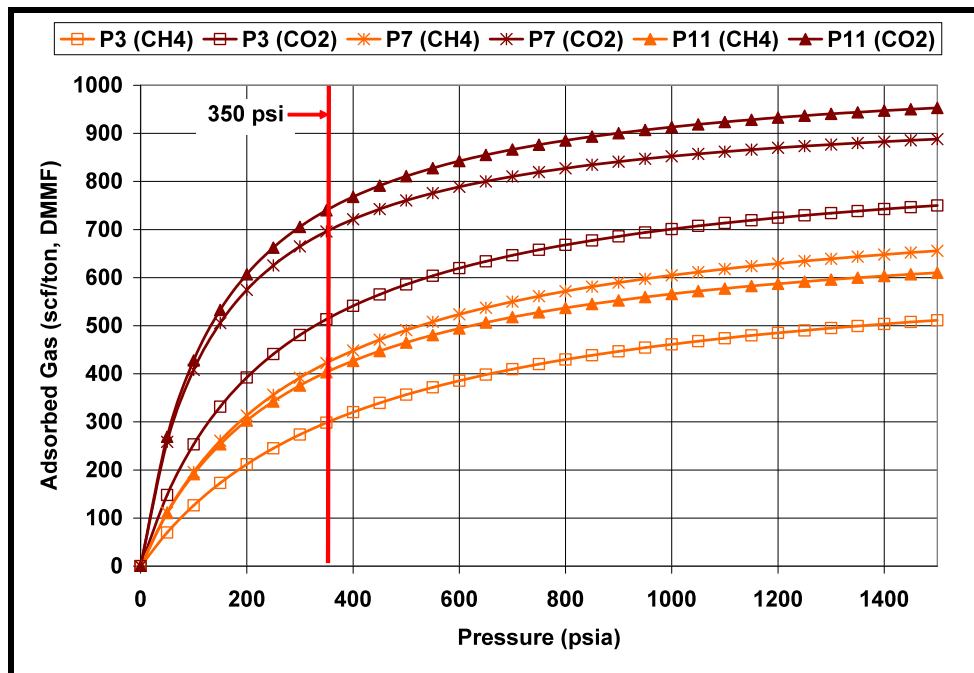
*March 13, 2013 SECARB Stakeholder Briefing,
Atlanta, GA*

Outline

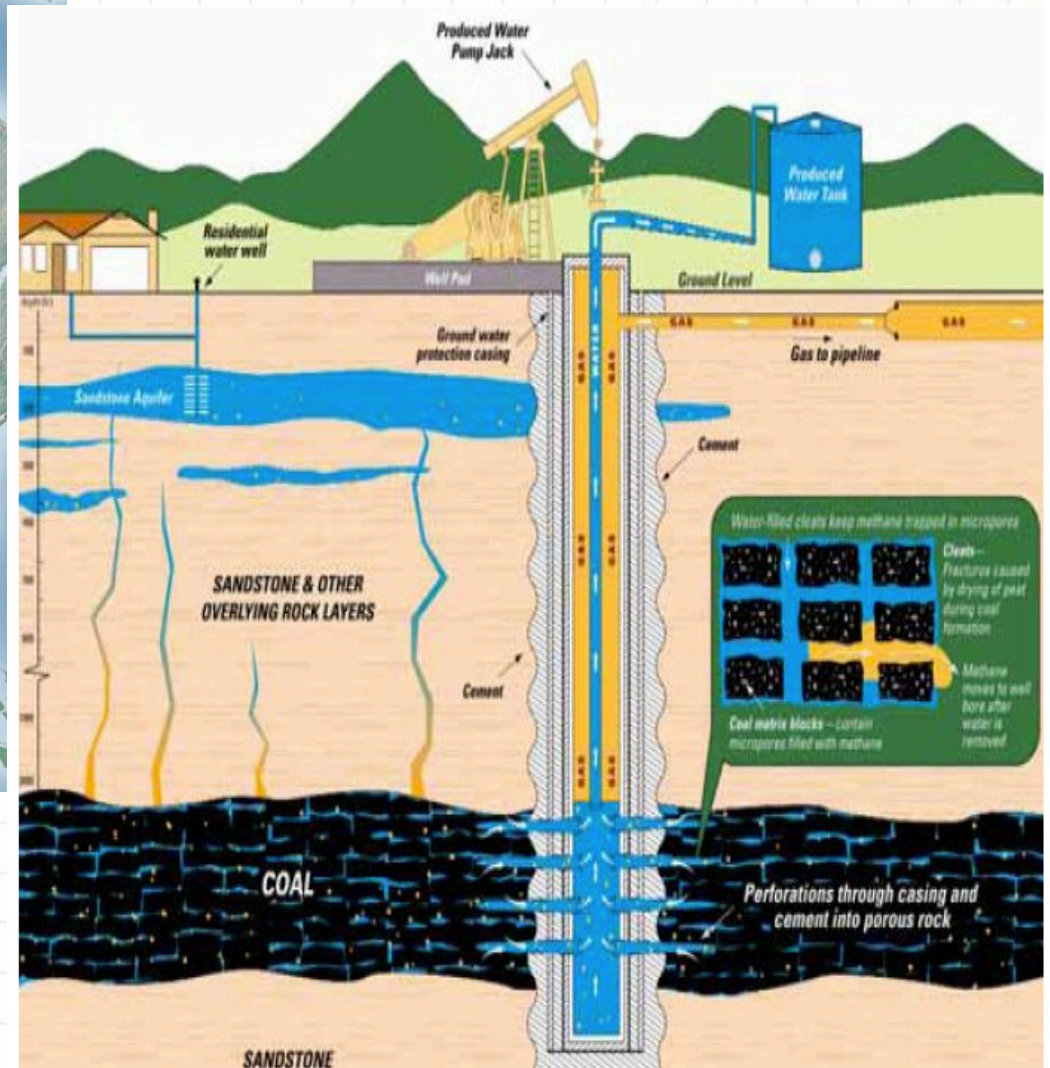
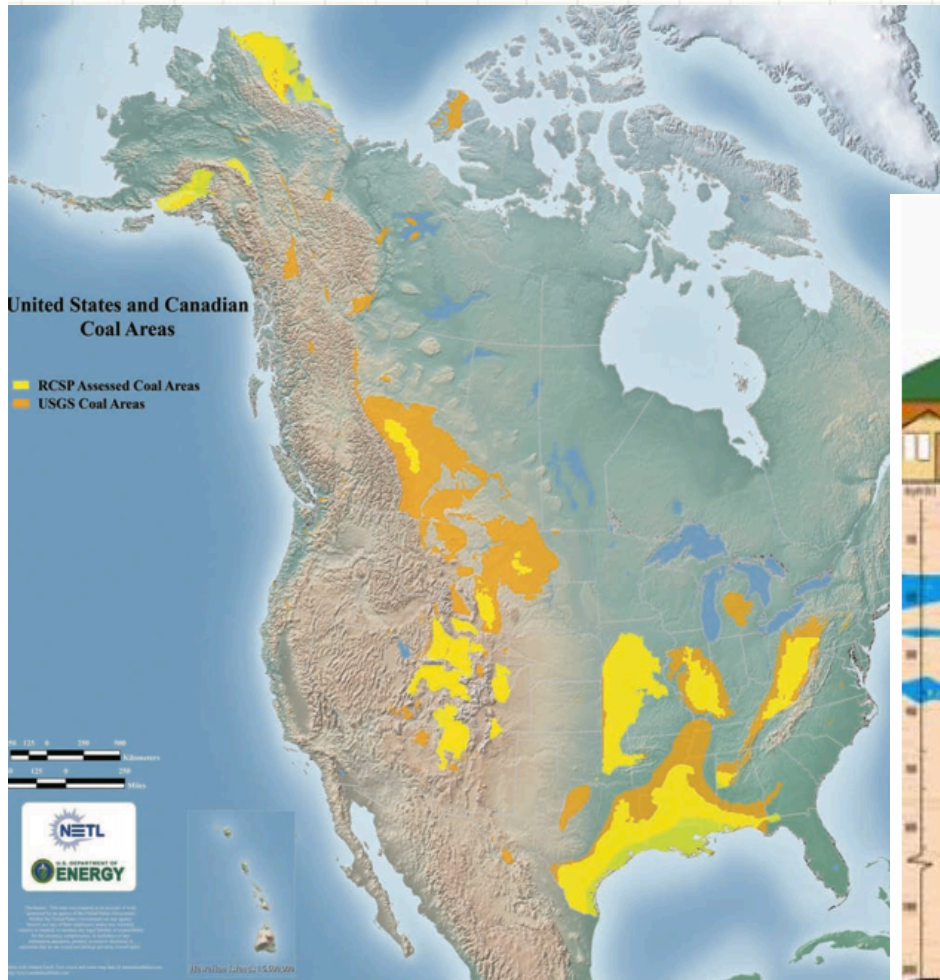
- ECBM / EGR
 - Characterization
 - Injection Tests
- Current Small Scale Tests
 - 20,000 ton test in coal seams
 - 300-1,000 ton test in shale
- Conclusions

CO₂ Sequestration in Coal Seams

- Favorable coal characteristics and depositional environments
- Shallow reservoir with low P & T can result in lower compression costs
- Gas is stored in coal securely by adsorption rather than by free storage or solution




Adsorption Isotherms
from Russell County
test show preferential
adsorption of CO₂ / CH₄
= 1.78



CO₂ Storage and ECBM Potential

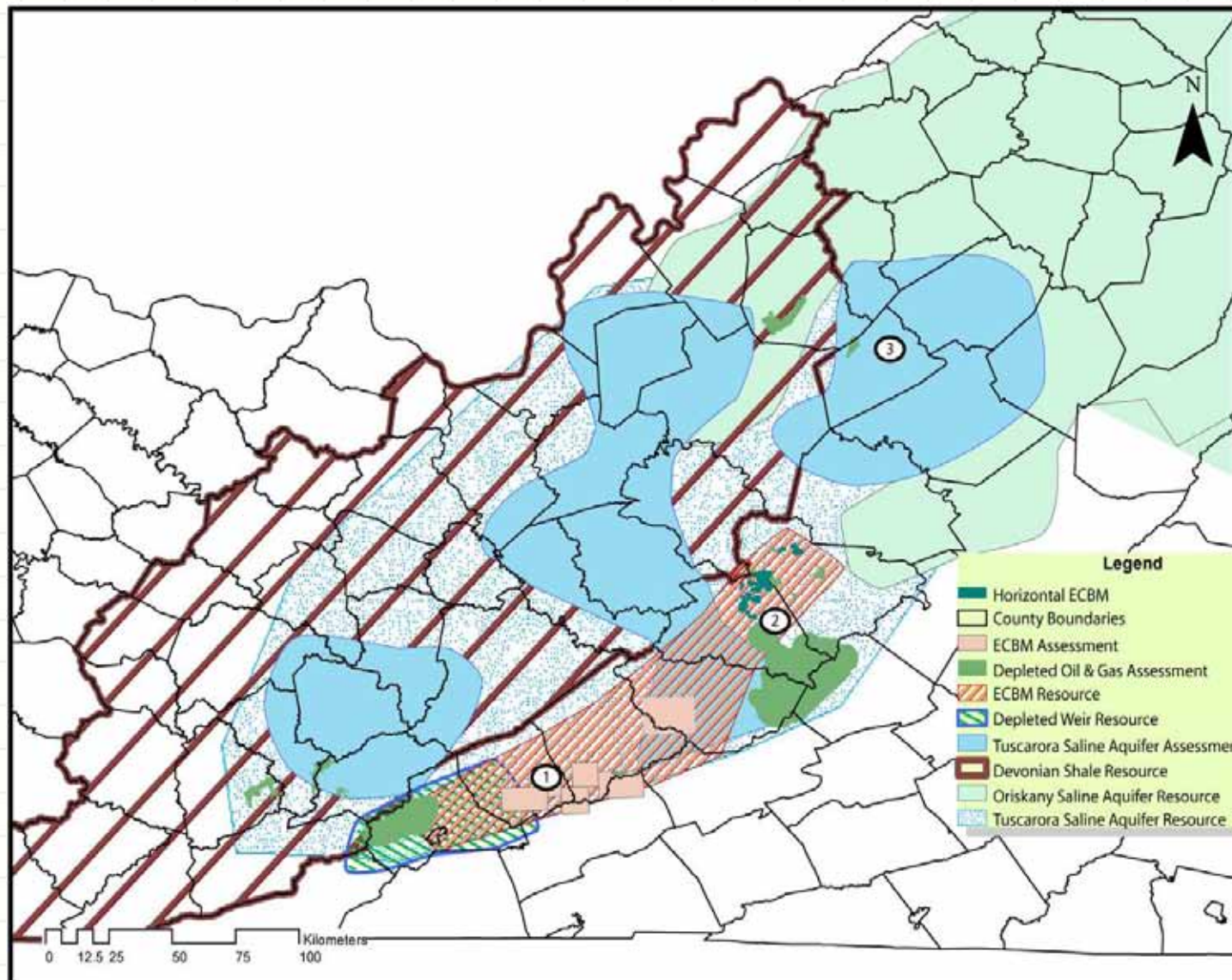
- Unmineable Coal Seams: 200 Billion Tons of Capacity in the U.S. – 25 years of current GHG emissions (DOE)
- Potential of CO₂-stimulated Enhanced Coal Bed Methane (ECBM) recovery provides an economic incentive
 - ECBM potential ~ 150 Tcf (Reeves, 2002)



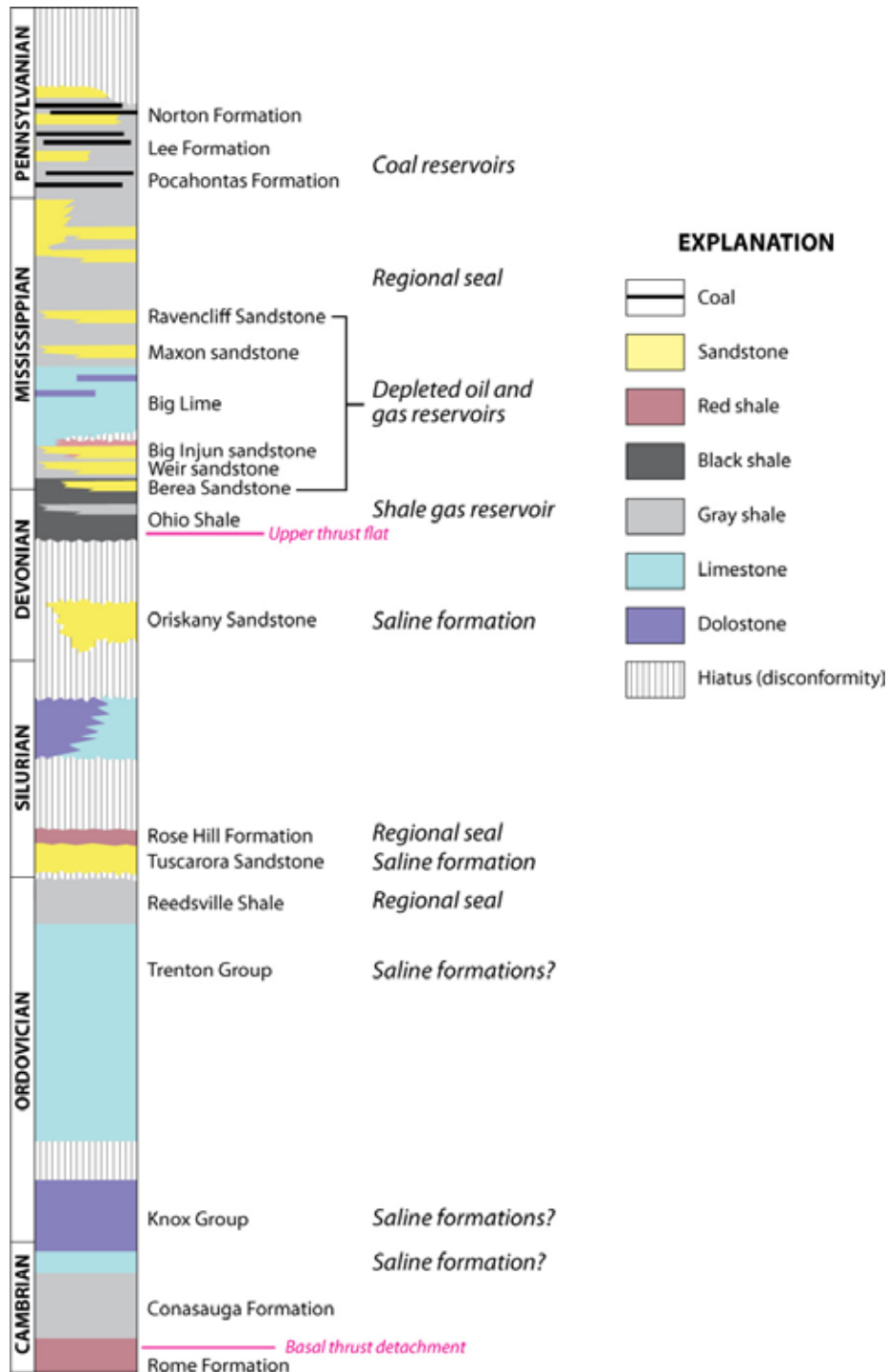
Virginia Tech Characterization Studies (Funded by NETL/DOE, Managed by SECARB/ SSEB)

- Geological and Terrestrial Characterization and Initial Feasibility Study for CO₂ storage in southwest Virginia (Phase I, 2004–2005)
- Geologic Characterization, Reservoir Modeling and Evaluation of Potential Large-Volume Injection Sites in Central Appalachia (Phase II, 2008-2010)

Characterization Studies - Central Appalachia



Stacked Storage



Virginia Tech Injection Tests

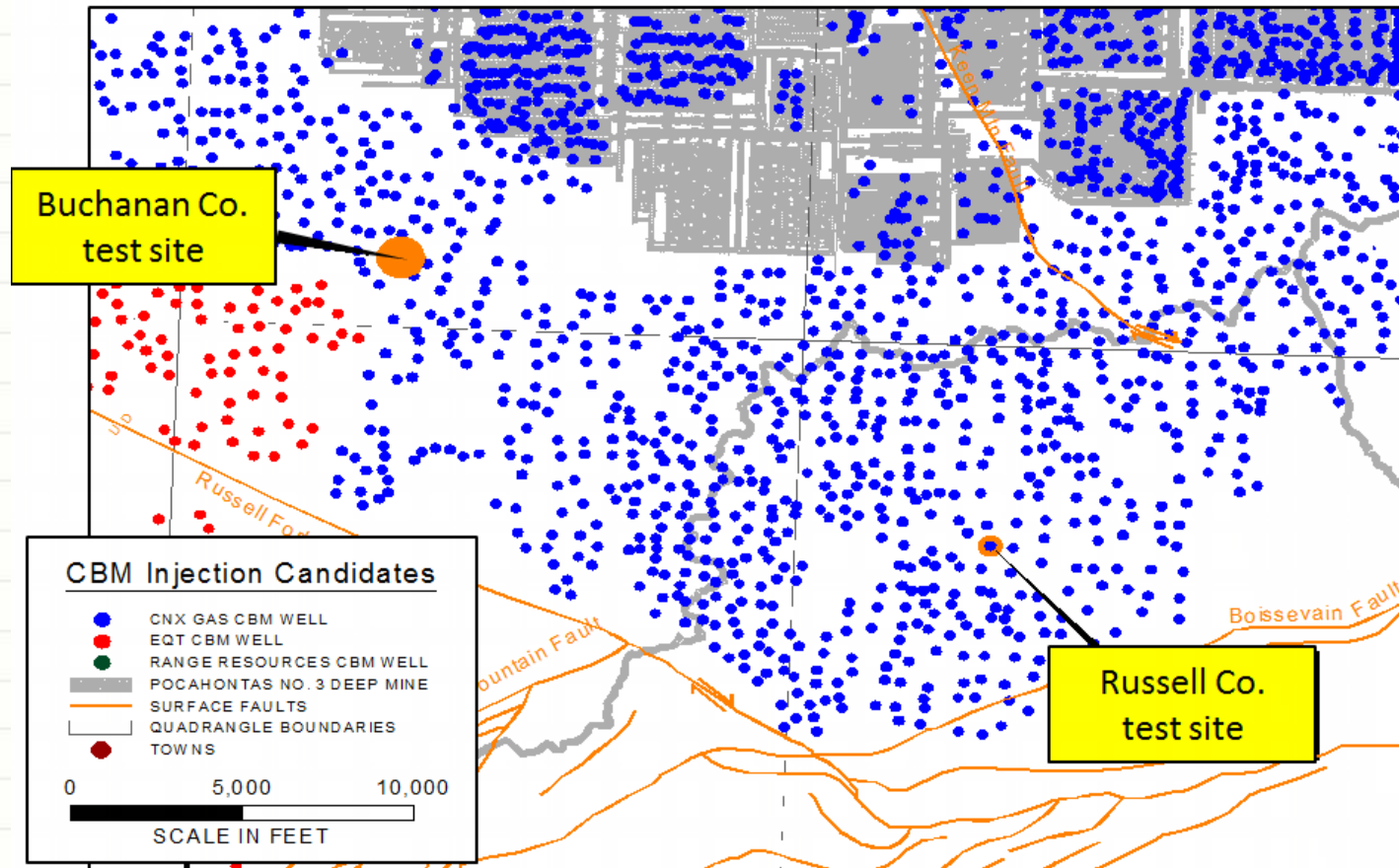
(Funded by NETL/DOE, Managed or in Partnership with SECARB/SSEB)

- Performed Pilot CO₂ Injection Field Tests in Virginia (1,000 tons) and, under the direction of the GSA, in Alabama (300 tons) (Phase II, 2005–2010)
- In Progress, a Small-Scale Injection Test in Central Appalachia (20,000 tons) into **Unconventional** Storage Reservoirs with Emphasis on Enhanced Coalbed Methane Recovery (2011–2015)

Previous study:
Field validation test in Russell County, VA
January 2009

Injected 907 tonnes of CO₂ over one-month period using converted CBM well in order to assess storage capacity

Reservoir composed of 19 individual coal seams, net thickness of 26 feet



Pilot CO2 Injection Field Tests in Virginia

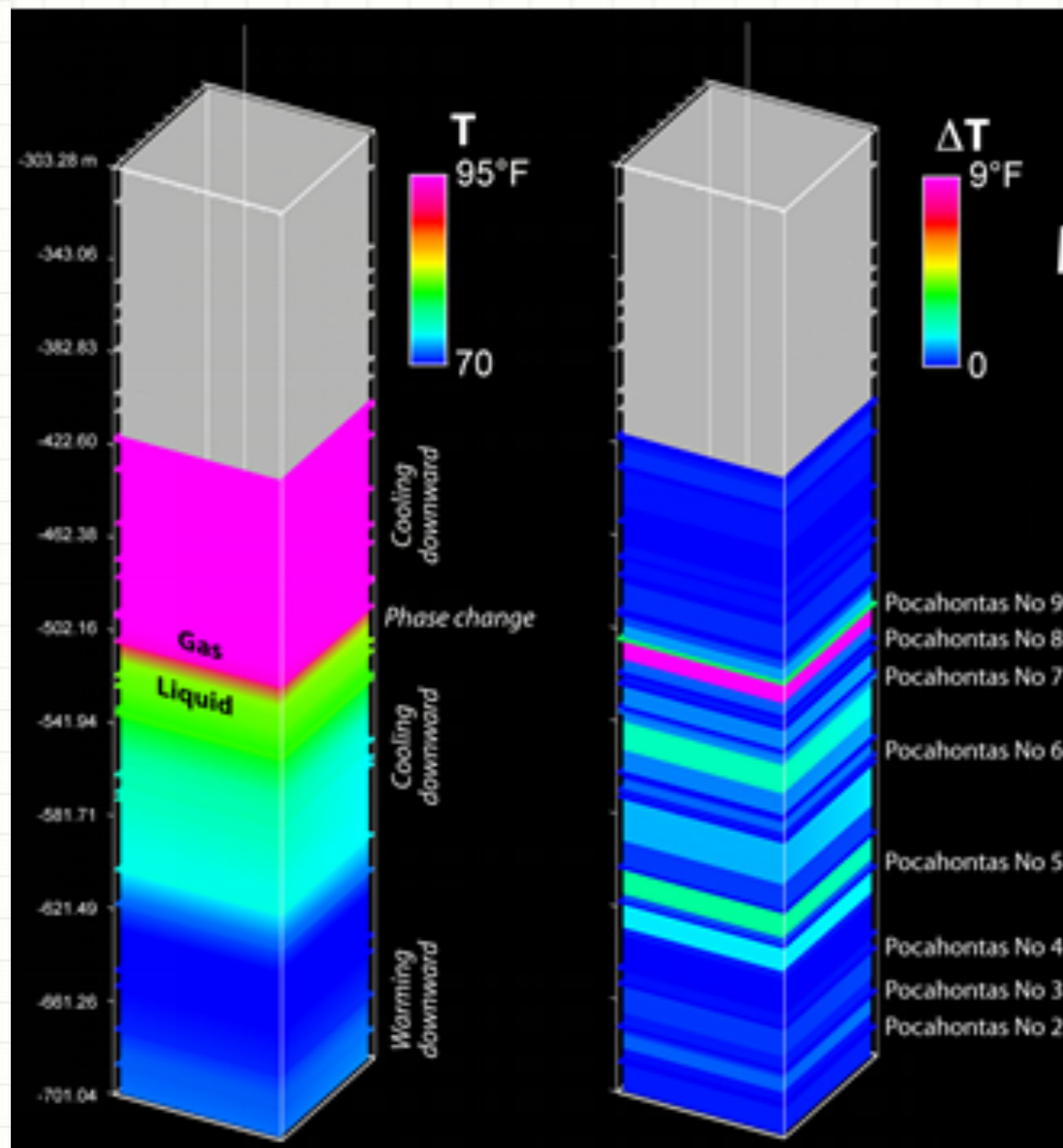
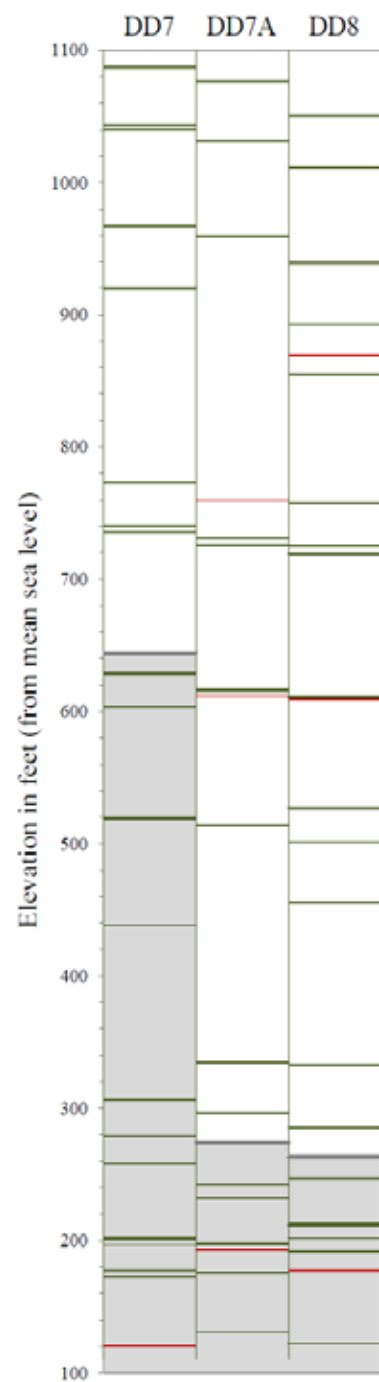


**Drilling Monitoring Well
(BD114-M2) Cementing
Surface Casing**

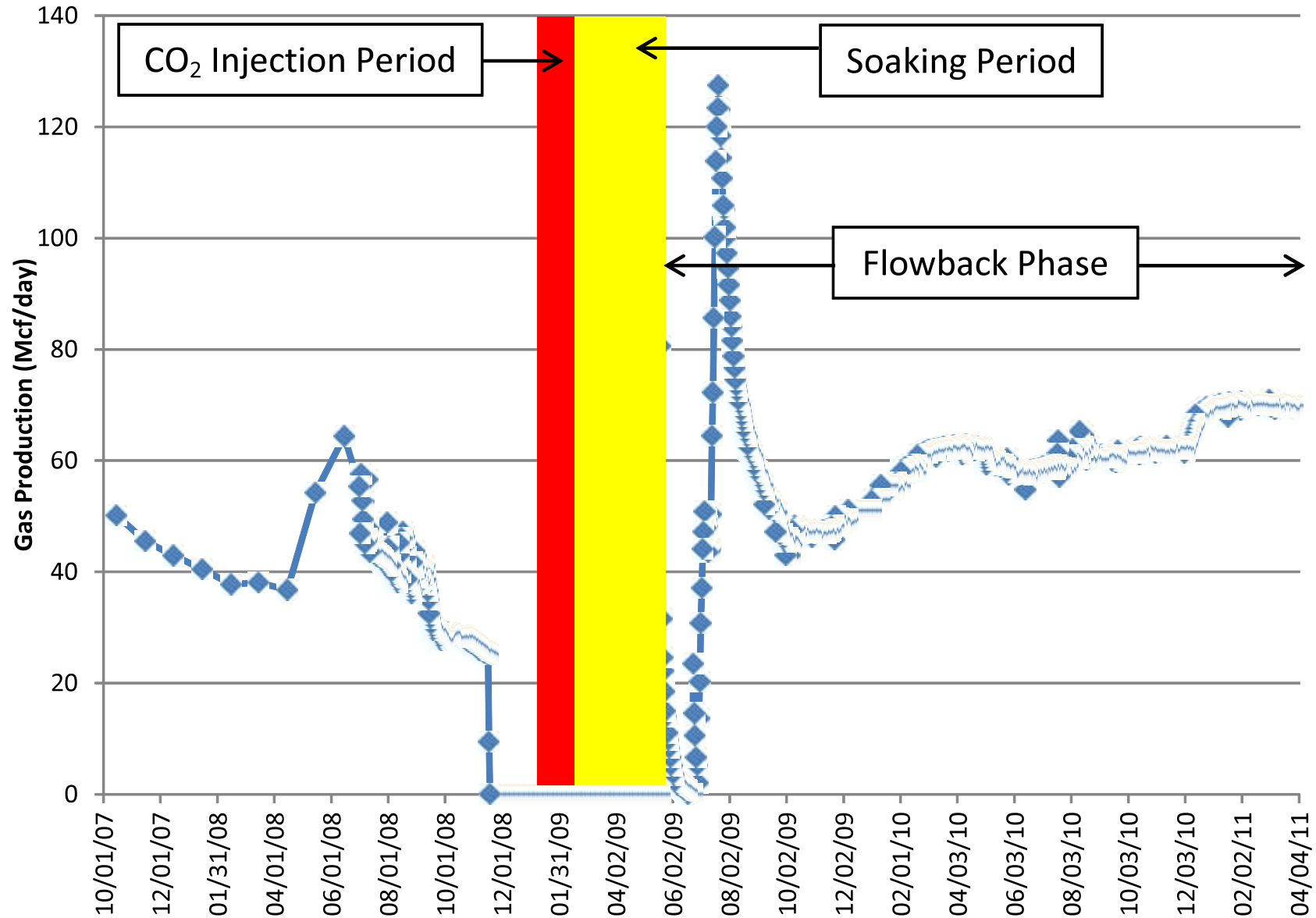


CO2 Injection

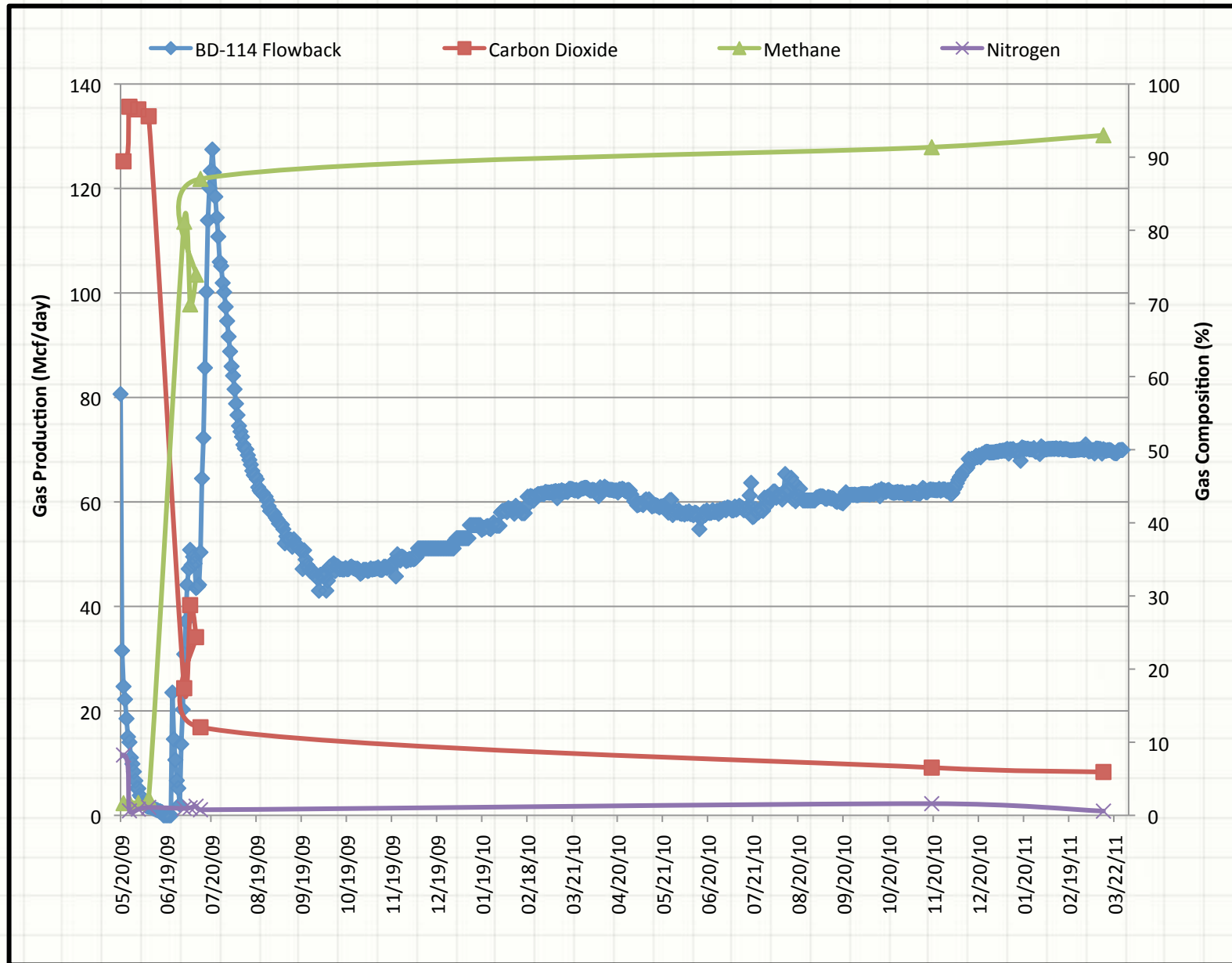




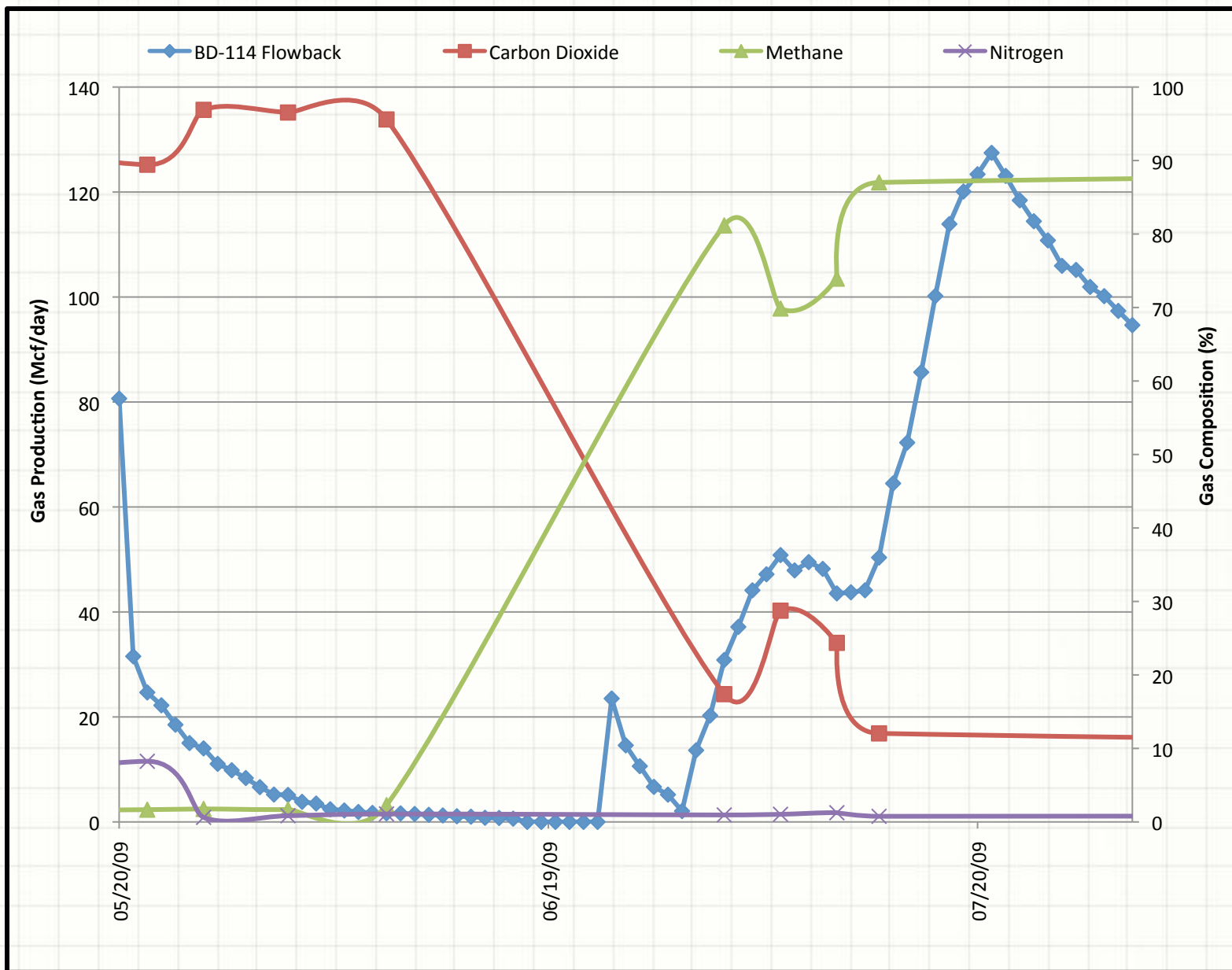
Russell County Injection and Flowback



Russell County Flowback



Russell County Flowback



Conclusions from Russell County Injection Test

- 1,007 tons of CO₂ injected into 19 coal seams in 2009
- Injection rate higher than anticipated at an average of over 40 tons per day, but decrease at the end to an injection rate of <20 tons per day
- ECBM measured in 2 wells (Unsustainable due to small CO₂ volume)
- Tracer detection at off-set wells, but no measured CO₂ breakthrough
- Flowback
 - Production returned to better than pre-injection rates
 - Flowback showed N₂, CH₄ then CO₂ desorption

Current Small-Scale Injection Test in Central Appalachia

★ Objectives:

- Inject 20,000 metric tons of CO₂ into **CBM wells** over a one-year period in Central Appalachia
- Perform a small 300-1,000 ton Huff and Puff test in a **shale gas well**

★ Duration:

- 4 years, October 1, 2011–September 30, 2015



Research Partners (Current Project)

- Virginia Center for Coal and Energy Research (Virginia Tech)
- CARDNO MM&A (Marshall Miller & Associates)
- Jerry Hill & Southern States Energy Board
- Virginia Department of Mines, Minerals and Energy
- Geological Survey of Alabama
- Sandia Technologies
- Det Norske Veritas (DNV)
- Consol Energy (Research Group)

Industrial Partners

- Consol Energy
- Harrison-Wyatt, L.L.C.
- Alpha Natural Resources
- Dominion Energy



Project Goals

- Test the storage potential of unmineable coal seams and shale reservoirs
- Learn about adsorption and swelling behaviors of coal and shale (methane vs. CO₂)
- Improve knowledge of unconventional and stacked storage systems (coal and shale)
- Test the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery
- Provide guidance for commercialization applications of ECBM and EGR

Project Timeline →

Phase I

18 months

(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

18 months

(4/1/13 – 9/30/14)

- Site preparation
 - Conversion of production wells
 - Drill monitor wells
 - Install additional monitor stations
- CO₂ injection (10/01/2013-09/30/2014)
- Monitoring
 - Atmosphere
 - Surface
 - Reservoir

Phase III

12 months

(10/1/14 – 9/30/15)

- Site closure
 - Conversion of injection and monitor wells
 - Site restoration
- Post-injection characterization
 - Data analysis and interpretation
 - Post-injection monitoring
 - Reservoir modeling

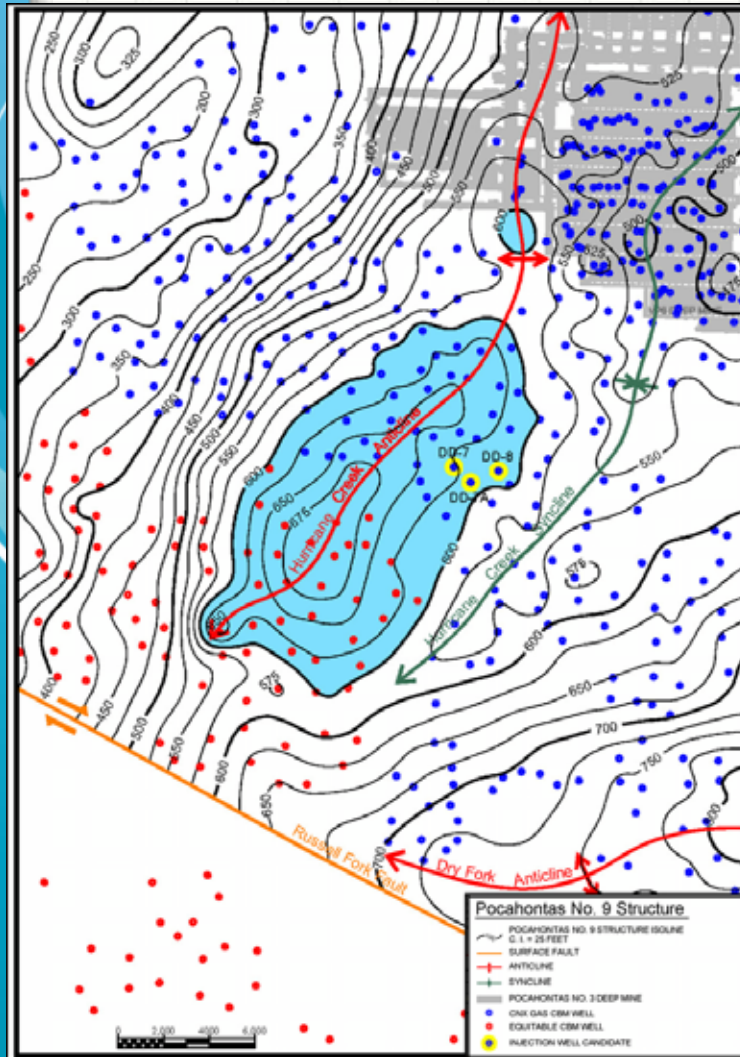
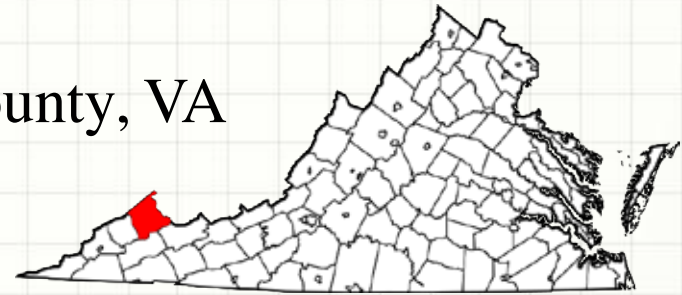
Ongoing: Management and Planning, Risk Analysis and Assessment, Characterization, Modeling, Monitoring, Education/Outreach



Shale Injection Test: Site Selection

- West Virginia Targets: Lower Huron Shale
- Virginia Targets: Lower Huron Shale
- Tennessee Targets: Chattanooga Shale
- Selection Criteria
 - Ownership / Access
 - Vertical vs. Horizontal
 - Co-Mingled Production
 - Production
 - Depth
 - Structure
 - Liquids Production
 - Completion and Stimulation

Current Study:
Field demonstration in Buchanan County, VA
Scheduled October 2013



Objective: inject up to 20,000 tonnes of CO₂ over one-year period using three converted CBM wells in order to assess injection and storage potential as well as potential for ECBM

Reservoir: 15-20 individual coal seams, net thickness of 15-20 feet

Site Characteristics:

- Structurally quiet, on flank of anticline
- Depleted reservoir
- Low-traffic
- Single, agreeable landowner

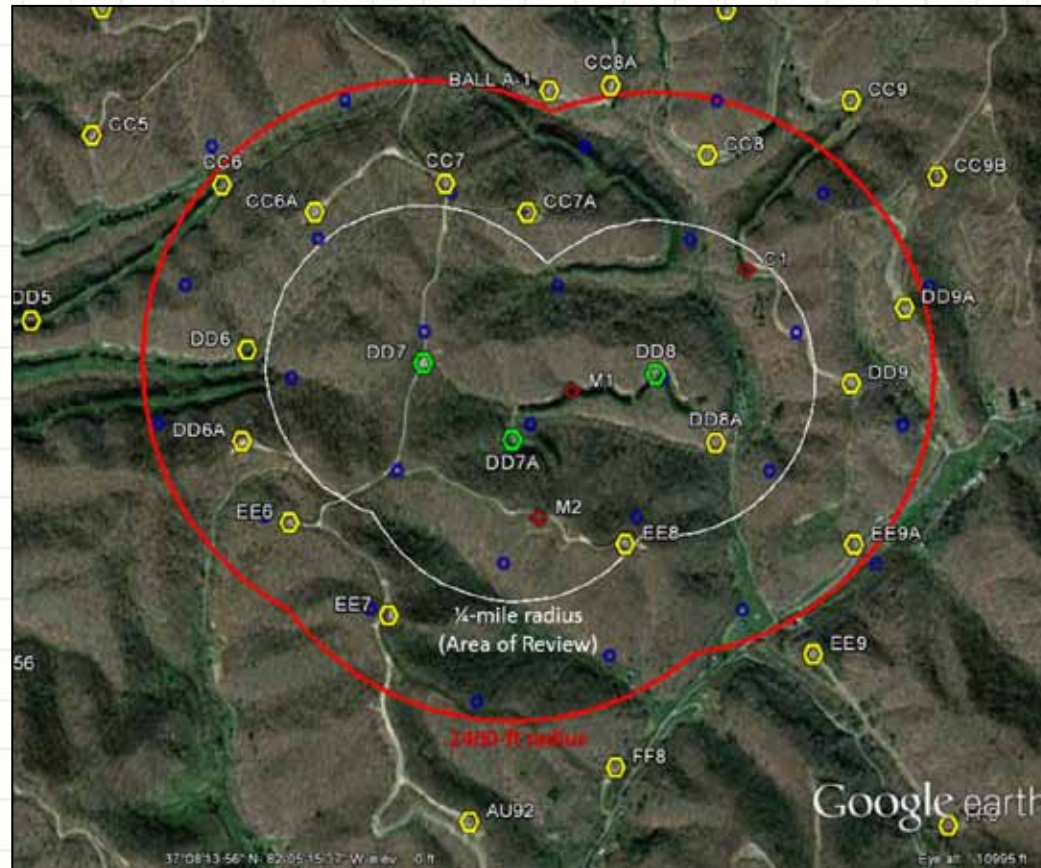
Permitting:

- Class II UIC Permit submitted to EPA Region III

MVA program for Buchanan County test

Repeated from Russell County test:

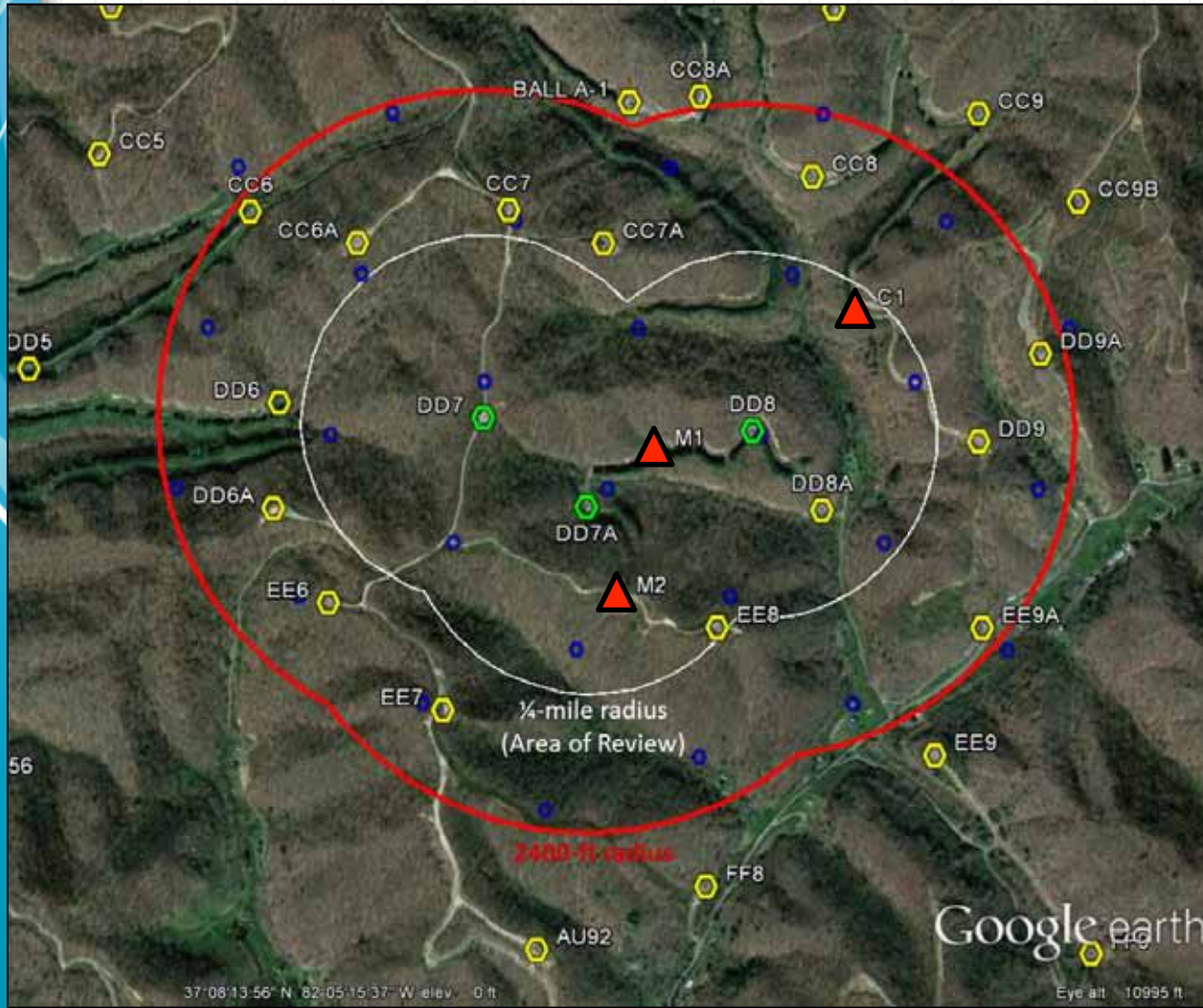
- Atmospheric monitoring with IRGAs to measure CO₂ concentration
- Surface methods including soil CO₂ flux, surface water sampling and shallow tracer detection
- Offset well testing for gas composition (CO₂ concentration, tracers, ECBM)



New components:

- Tracer injection
- 3 monitoring wells
- Surface deformation measurement
- Tomographic fracture imaging

Three monitoring wells



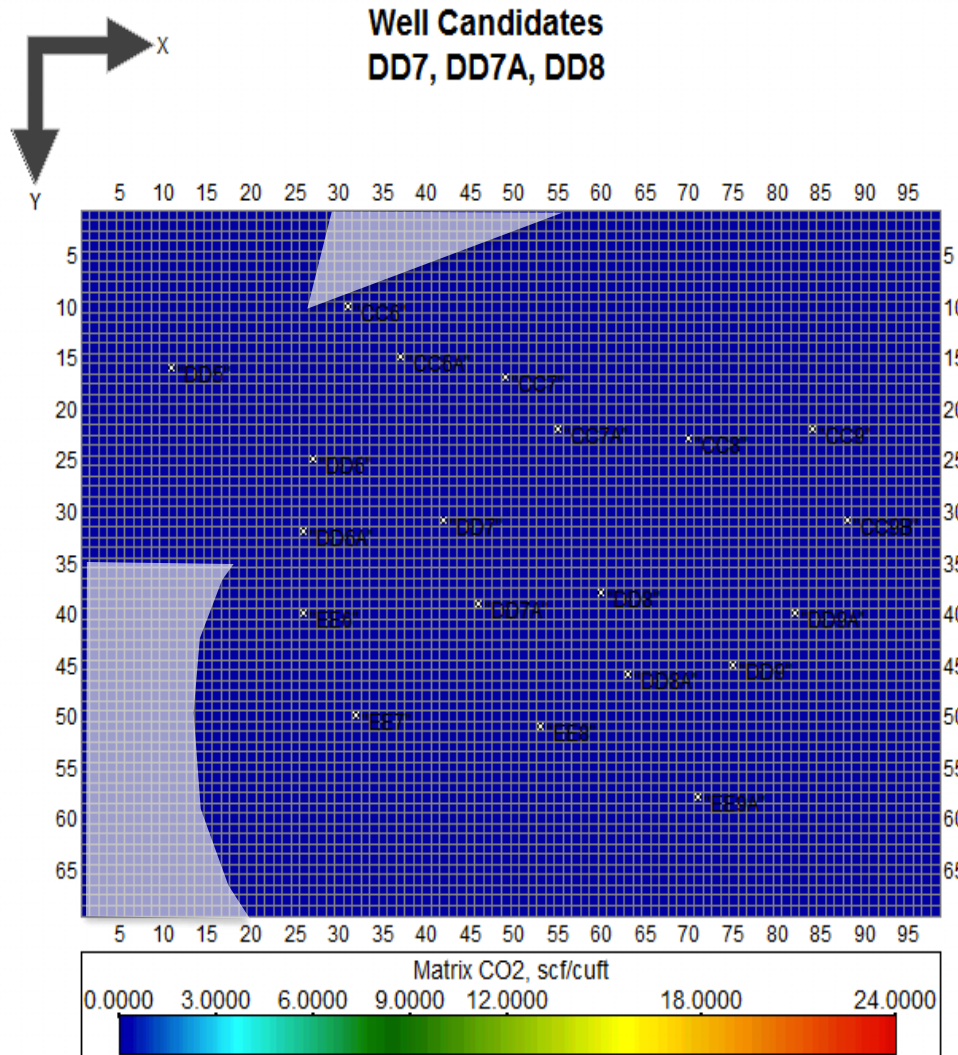
- Location factors:
 - Access
 - Predicted plume growth
 - Specific tests
 - Future use
- Formation logging:
 - Reservoir saturation
 - Sonic
 - Others TBD
- Gas content:
 - CO₂
 - Methane
 - Tracers
- Core collection

Conclusions

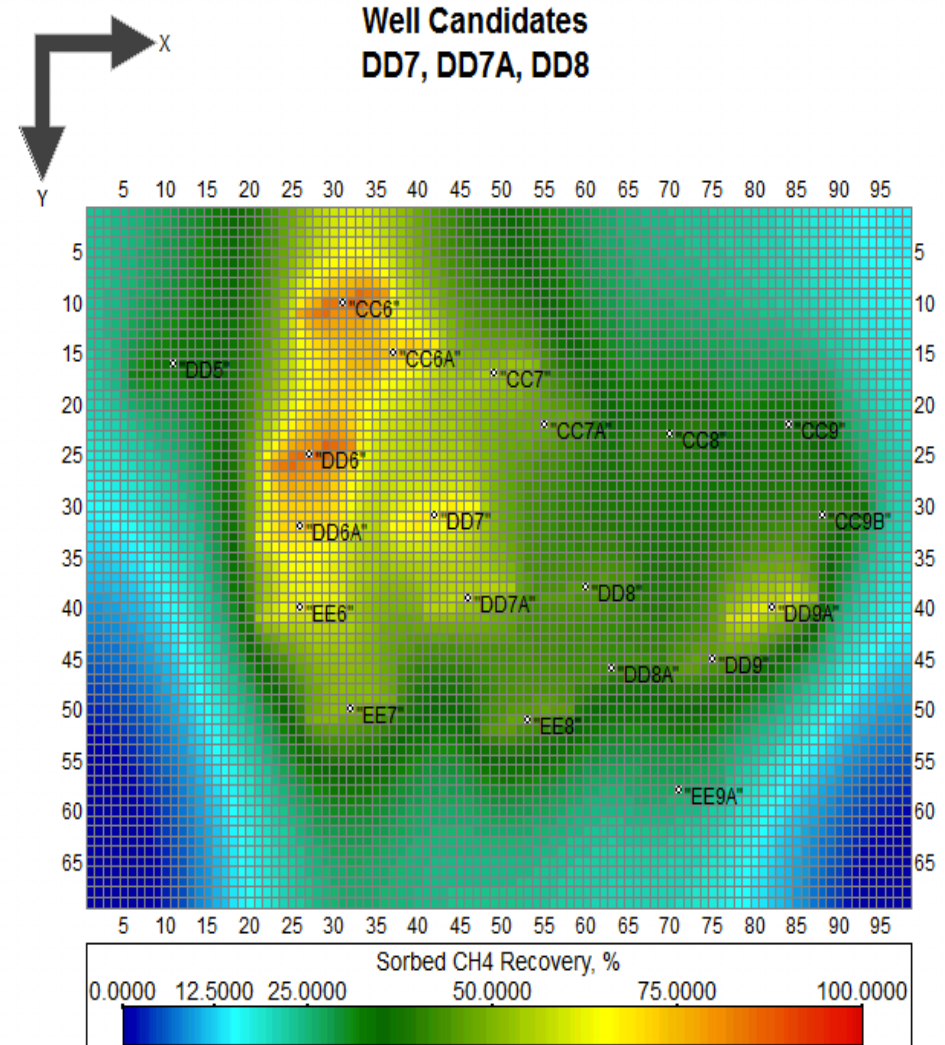
- The Buchanan County test site is a unique setting for a CCUS test, which limits the use of some MVA technologies and favors the use of others.
- MVA challenges:
 - Site characteristics, including mountainous terrain, dense tree cover, and limited road/foot access which limit locations for boreholes and instruments
 - Geometry of the coal reservoir, which prohibits some imaging technologies and complicates interpretation of results for others
- The MVA program will combine technologies deployed at the borehole scale (gas composition, tracers, formation logging) with ones deployed over large areal extents (TFI, surface deformation). Most technologies feature dense temporal sampling, important for understanding plume growth.
- The combination of technologies is significant. Borehole methods will provide important information about the relationships between plumes of pressure, CO₂, methane, and tracer. Large areal extent methods will allow extrapolation of the relationships over the area of the plume and potentially tie borehole measurements to matrix swelling via surface uplift and seismic response.
- The results of the MVA program used at the Buchanan County test site will help guide future MVA efforts in thin, stacked coals and improve best practices for monitoring CCUS in coal reservoirs.

Initiation of Injection, October 2013

Well Candidates: DD7, DD7A , DD8



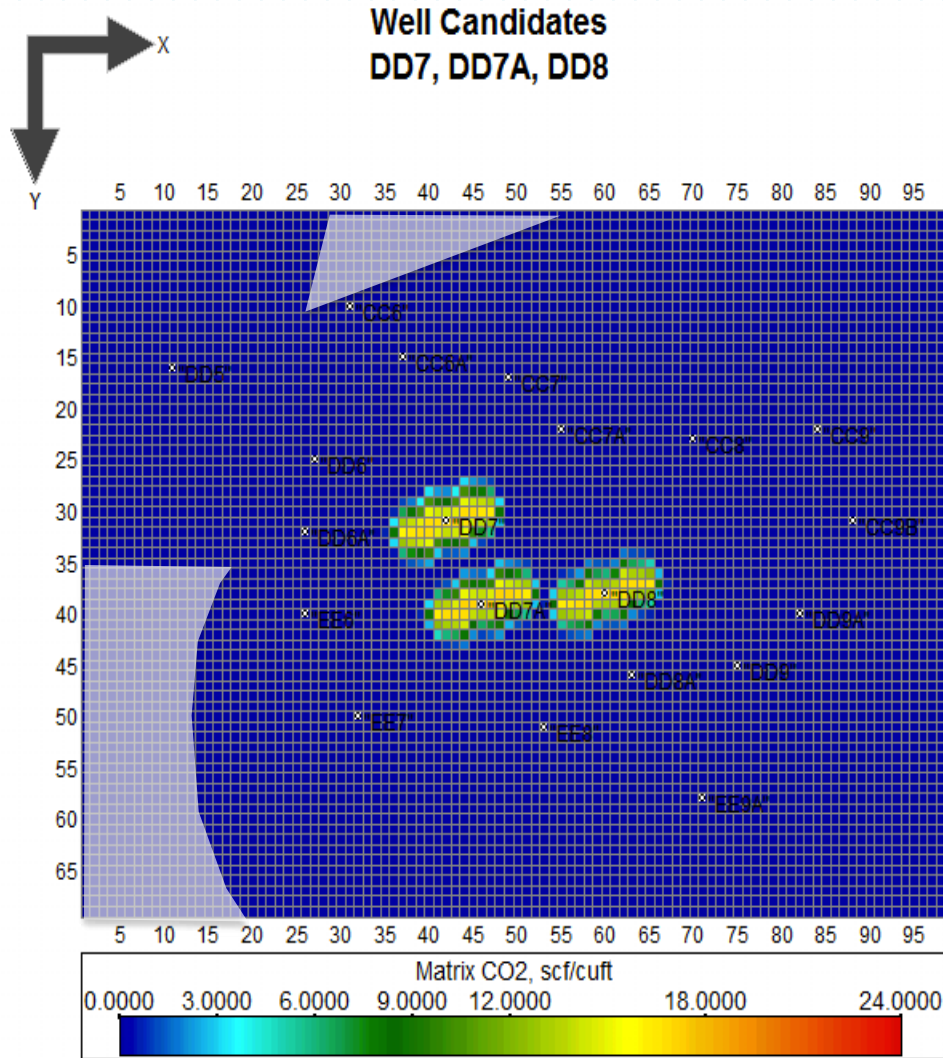
Matrix CO₂, scf/ cuft



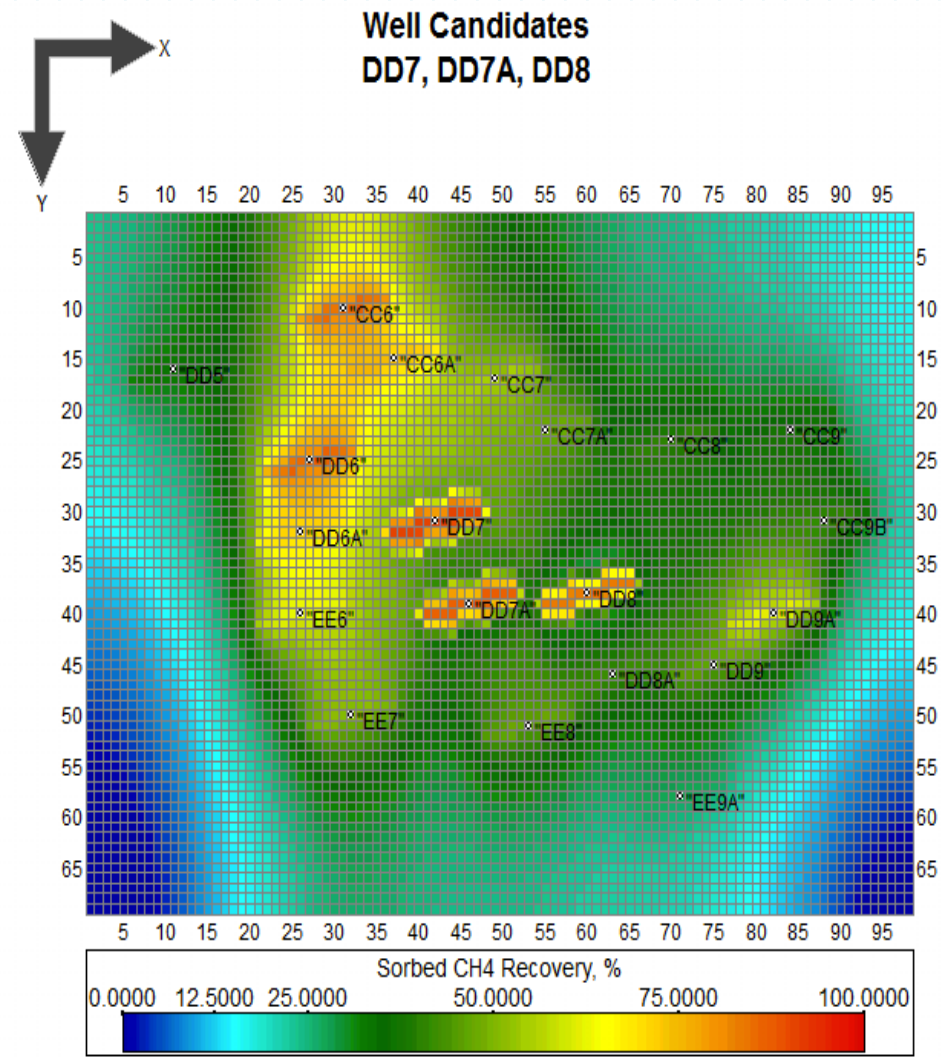
Sorbed CH₄ Recovery, %

After 20,000 Tons Injected

Well Candidates: DD7, DD7A , DD8



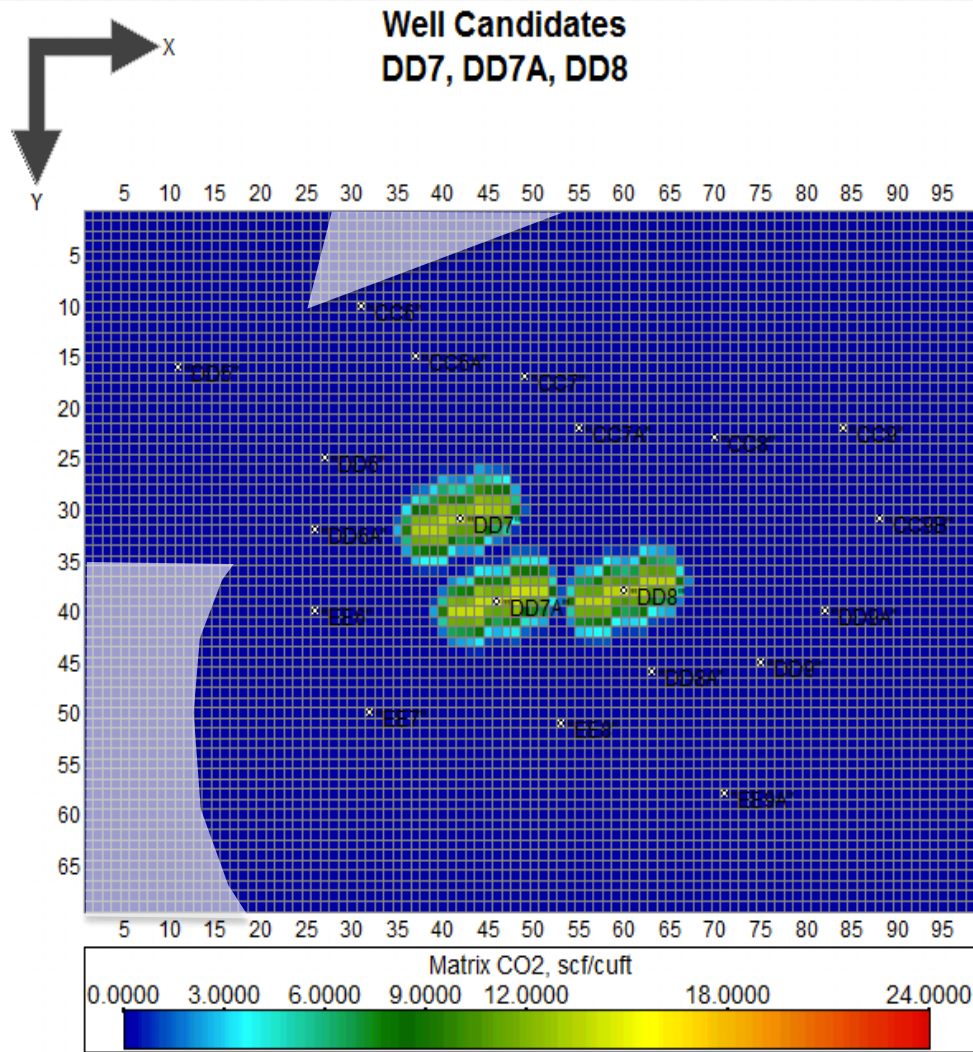
Matrix CO₂, scf/ cuft



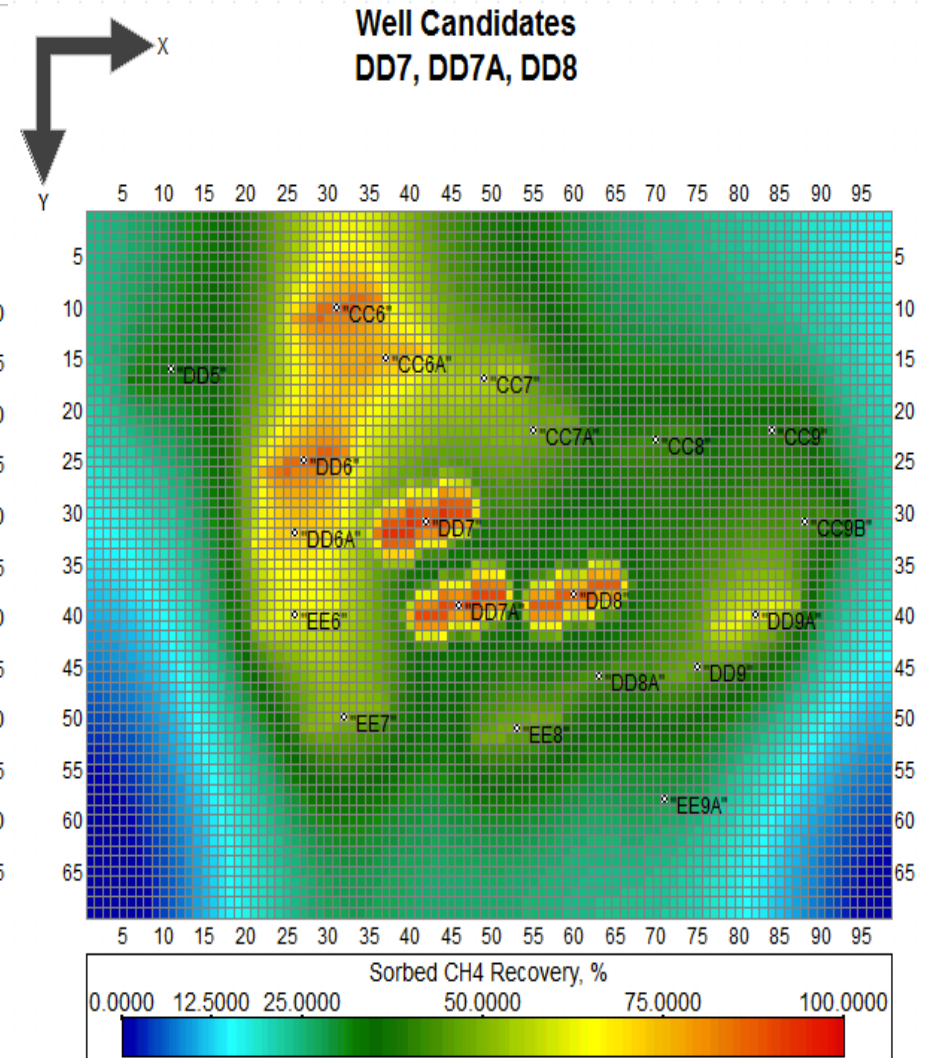
Sorbed CH₄ Recovery, %

End of Injection, October 2014

Well Candidates: DD7, DD7A, DD8



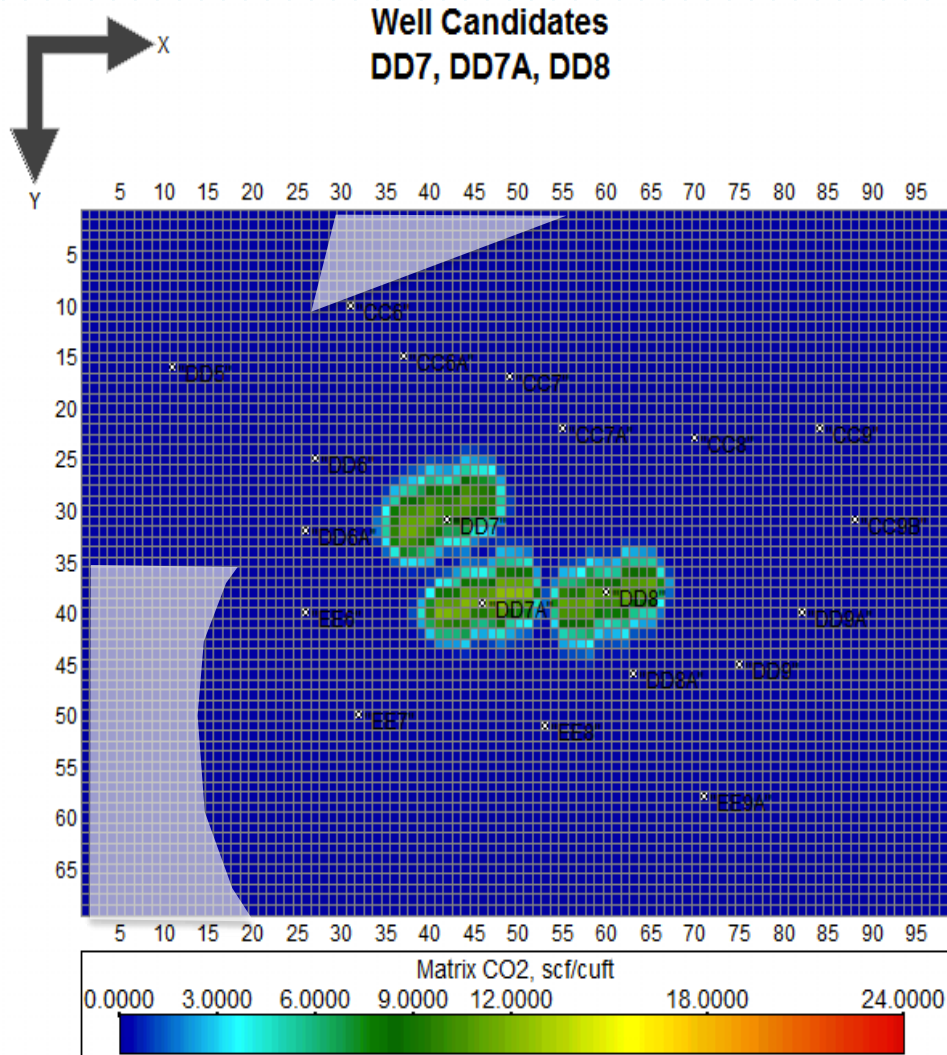
Matrix CO₂, scf/cuft



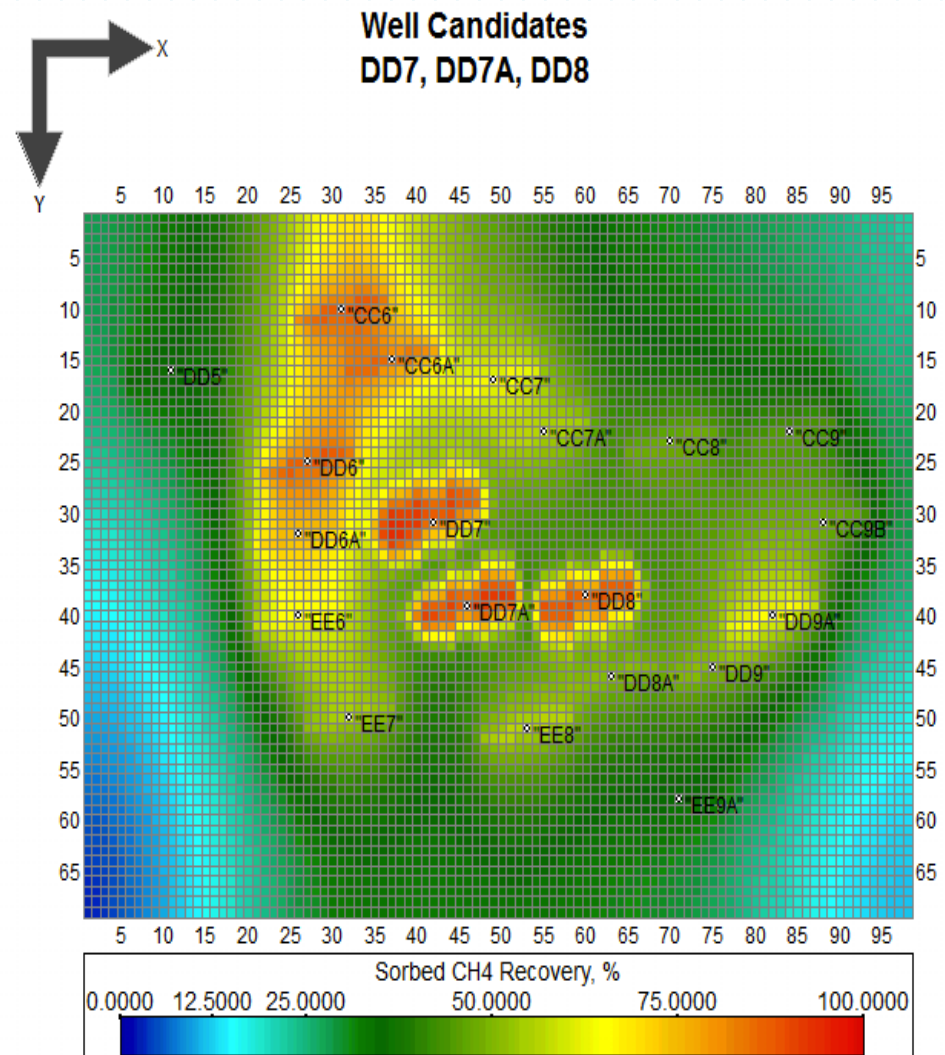
Sorbed CH₄ Recovery, %

4 Years After the End of the Injection, October 2017

Well Candidates: DD7, DD7A , DD8



Matrix CO₂, scf/ cuft



Sorbed CH₄ Recovery, %

Acknowledgements

Project partners:

Consol Energy
CNX Gas
Alpha Natural Resources
Dominion Energy
Harrison-Wyatt, L.L.C.
Cardno-MM&A

Southern States Energy Board
Virginia Department of Mines,
Minerals, and Energy
Geological Survey of Alabama
Sandia Technologies
Det Norske Veritas (DNV)

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.

