Injecting Carbon Dioxide into Unconventional Storage Reservoirs in the Central Appalachian Basin with an emphasis on Enhanced Coalbed Methane Recovery

Project Number: DE-FE0006827

Nino Ripepi

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 CO_2 Storage

August 21-23, 2012

Presentation Outline

- Benefit to the Program
- Goals and Objectives
- Organization
- Technical Overview
  - Characterization
  - Modeling
  - MVA Plans
- Schedule

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 20,000 metric tons of CO2 into **CBM wells** over a one-year period in Central Appalachia
  - Perform a small (approximately 300 tons) Huff and Puff test in a **shale gas well**
- **Duration:** 4 years, October 1, 2011–September 30, 2015
- **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)
  - Test the potential for enhanced coalbed methane (ECBM) and enhanced gas (EGR) production and recovery
  - Improve knowledge of unconventional and stacked storage systems (coal and shale)

Research Partners

- Virginia Center for Coal and Energy Research (Virginia Tech)
- Cardno Marshall Miller & Associates
- Gerald 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 (CNX Gas)
- Harrison-Wyatt, L.L.C.
- Alpha Natural Resources
- Dominion Energy

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
- **CO_2 injection**

(10/01/2013-09/30/2014)

- Monitoring
  - Atmosphere
  - Surface
  - Reservoir

Phase III

12 months

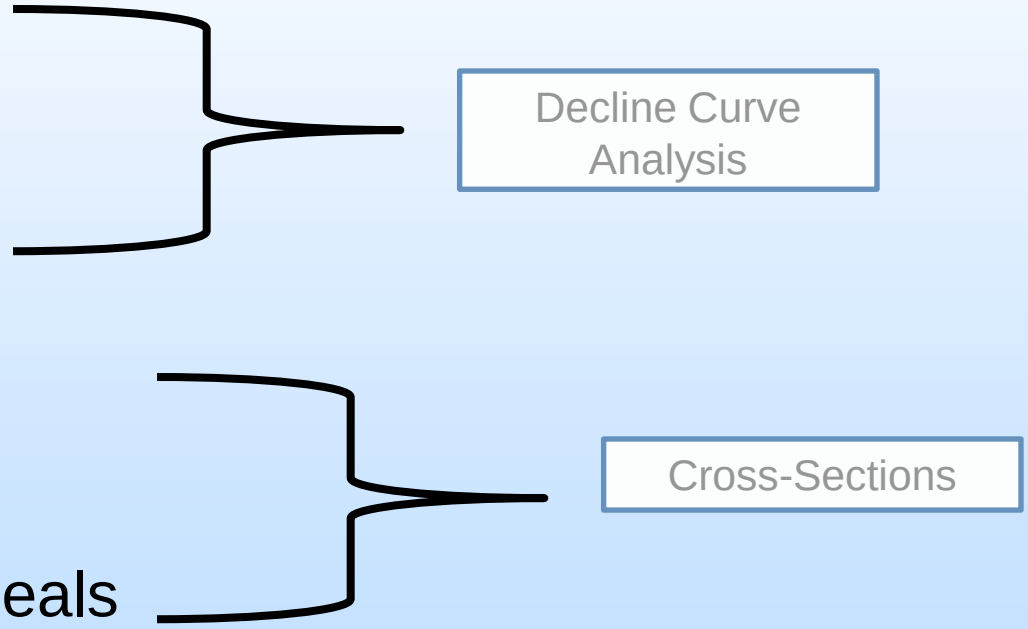
(10/1/14 – 9/30/15)

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

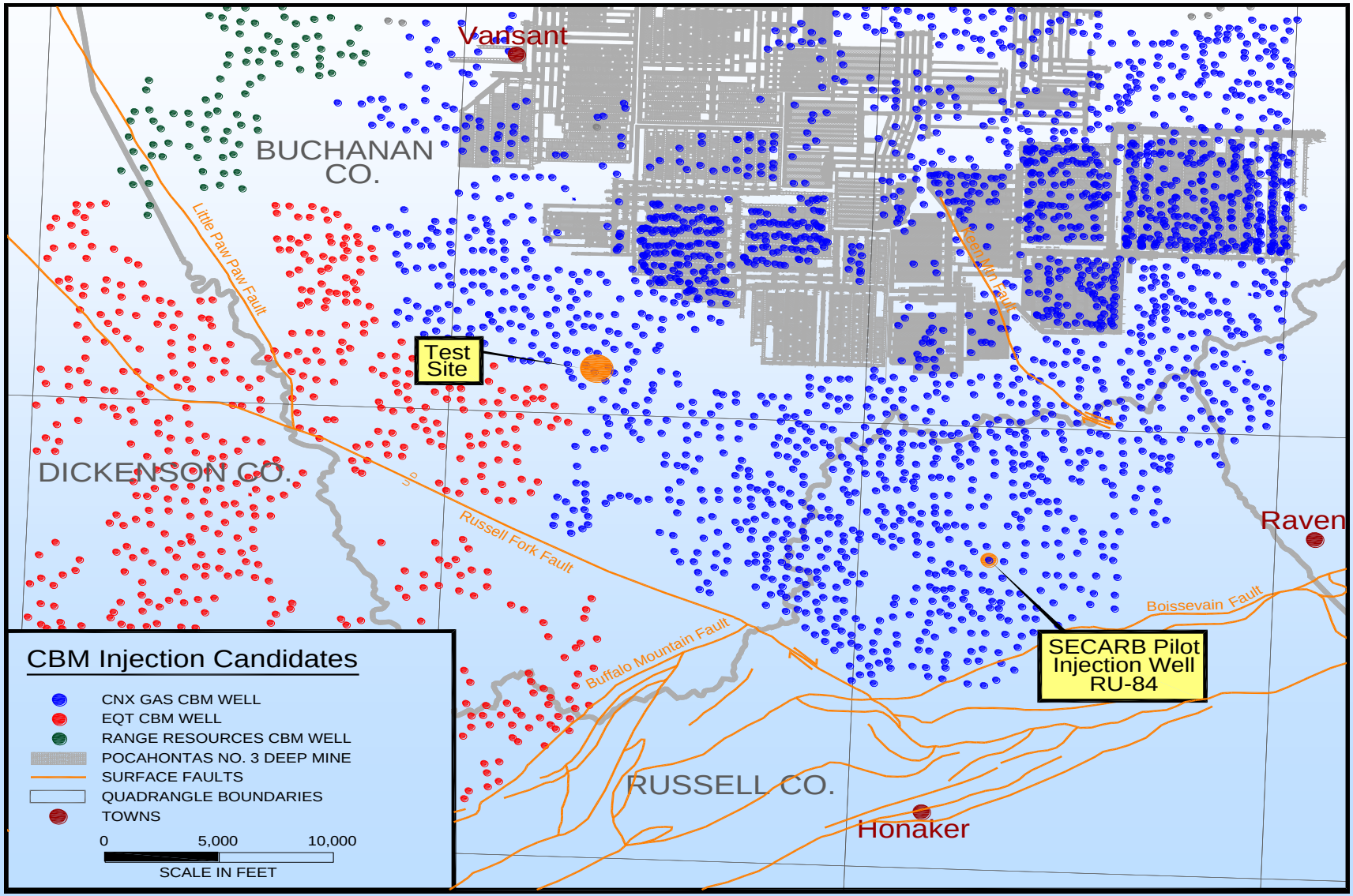
Ongoing: Management and Planning, Risk Analysis and Assessment, Characterization, Modeling, Monitoring, Education/Outreach

CBM Test – Selection Criteria

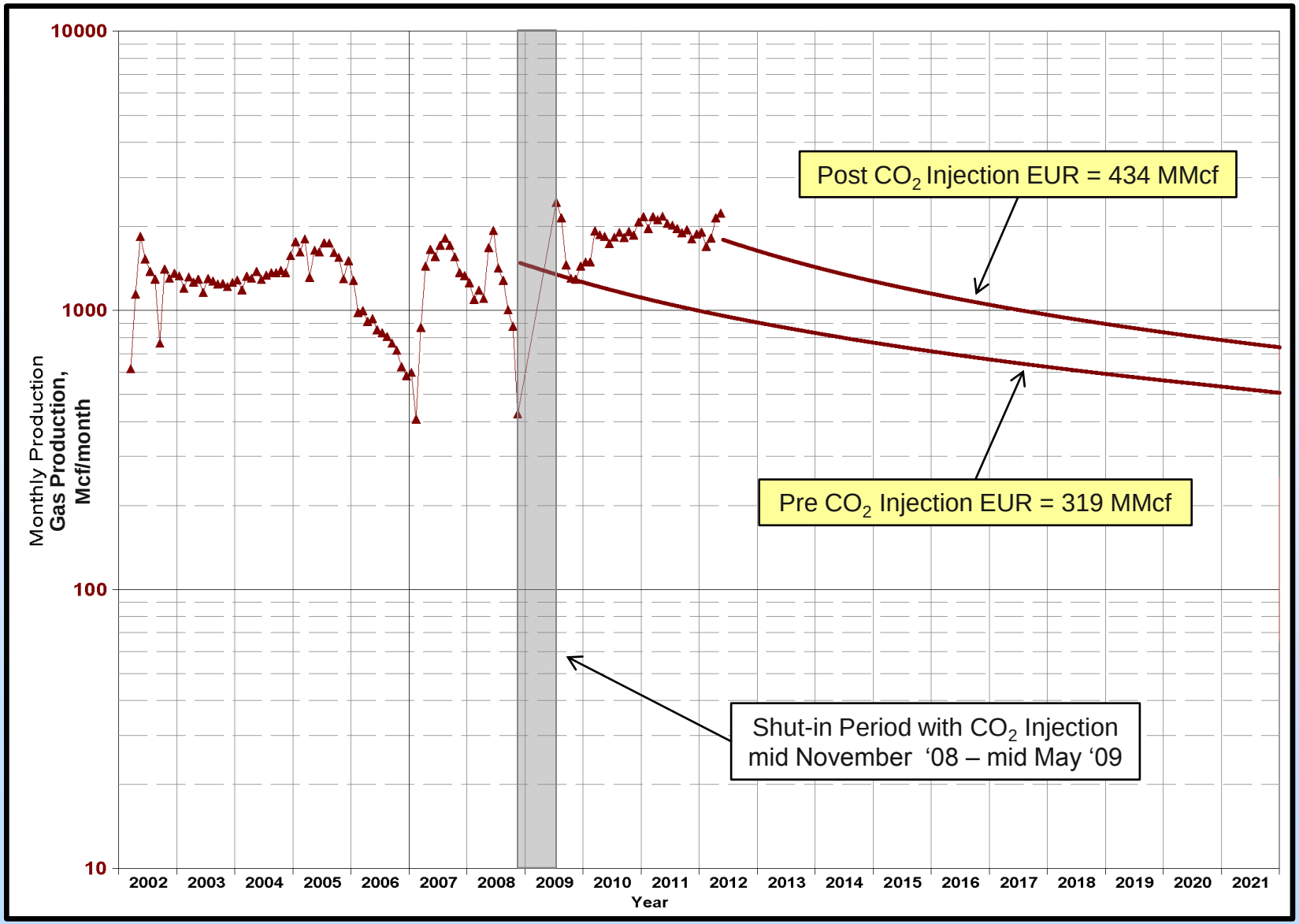
- CONSOL Operation
- Mineral and Surface Ownership
- Access
- Production
- EUR
- Depletion
- Depth
- Structure
- Continuity
- Regional Seals
- Faulting
- In-Fill Wells
- Perforations, Stimulation and Breakdown (Frac Records)

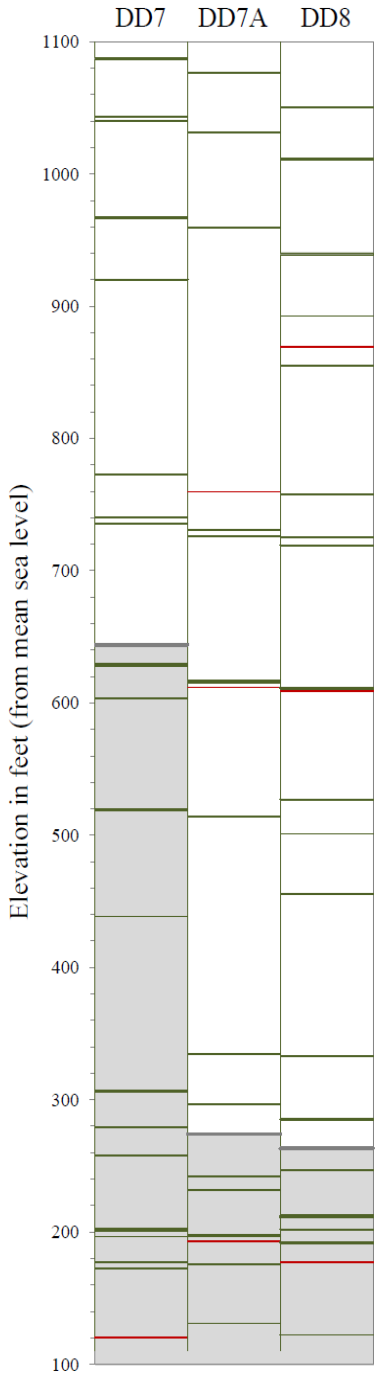


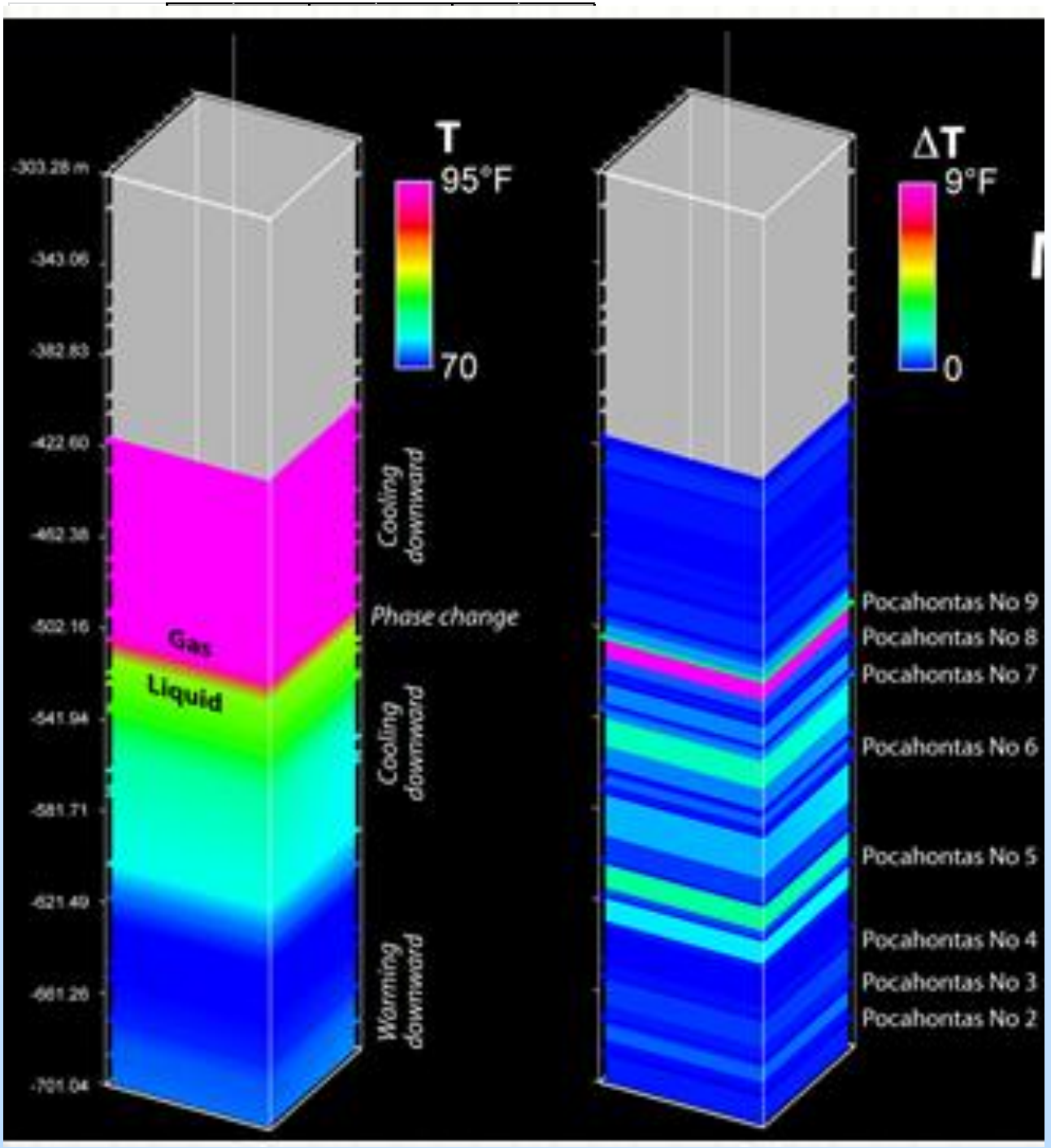
CBM Injection Test Sites
Russell and Buchanan Counties, VA



CO_2 Injection Decline-Curve Analysis
Phase II Injection Well RU-84 (BD-114)




DD7
DD7A
DD8
Elevation in feet (from mean sea level)
1100
1000
900
800
700
600
500
400
300
200
100


T
95°F
70
ΔT
9°F
0
-303.28 m
-343.06
-382.83
-422.60
-462.38
-502.16
-541.94
-581.71
-621.49
-661.26
-701.04
Cooling downward
Phase change
Gas
Liquid
Cooling downward
Warming downward
Pocahontas No 9
Pocahontas No 8
Pocahontas No 7
Pocahontas No 6
Pocahontas No 5
Pocahontas No 4
Pocahontas No 3
Pocahontas No 2

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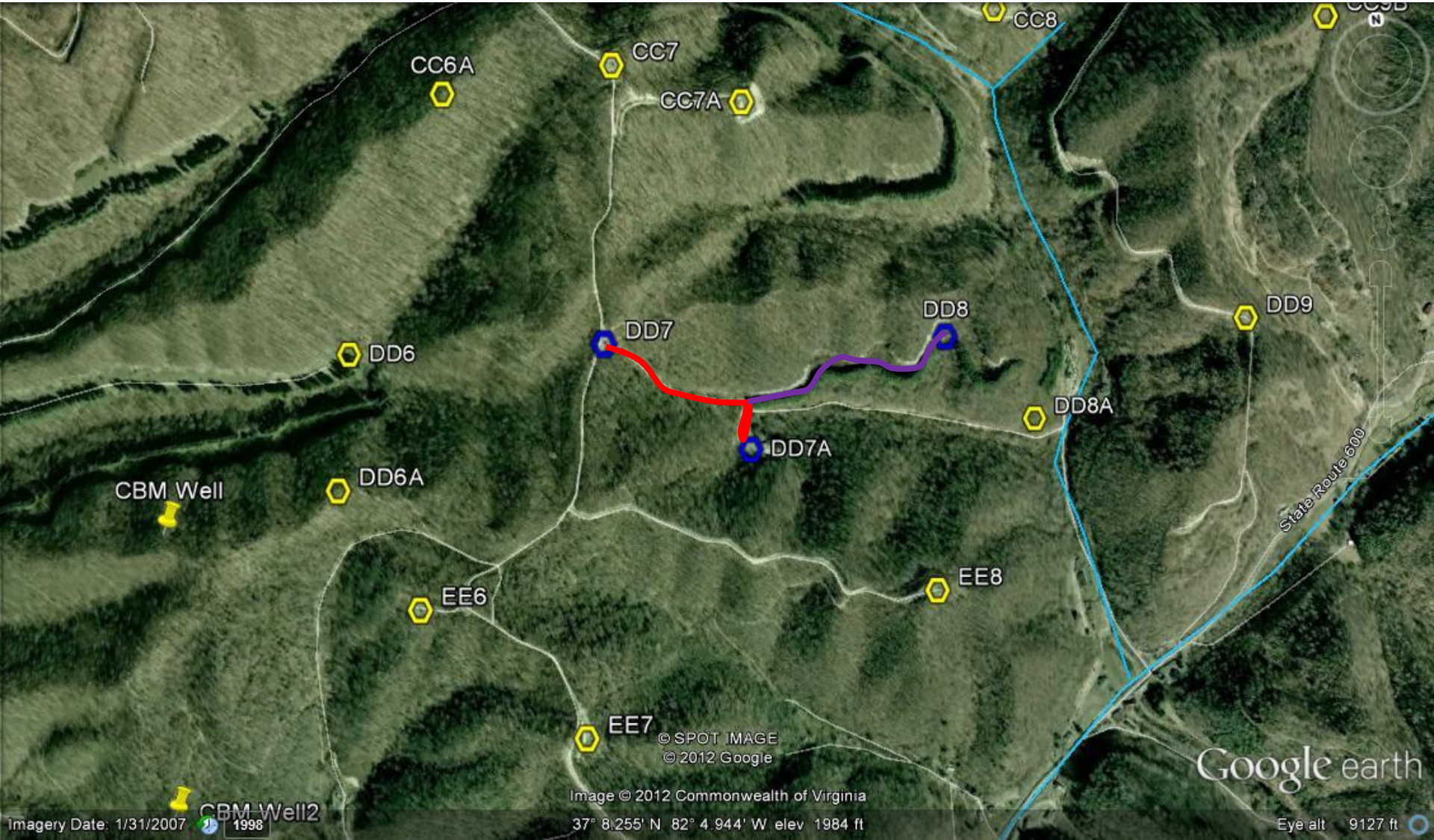
Aerial View of CBM Site and CO2 Transport Plans



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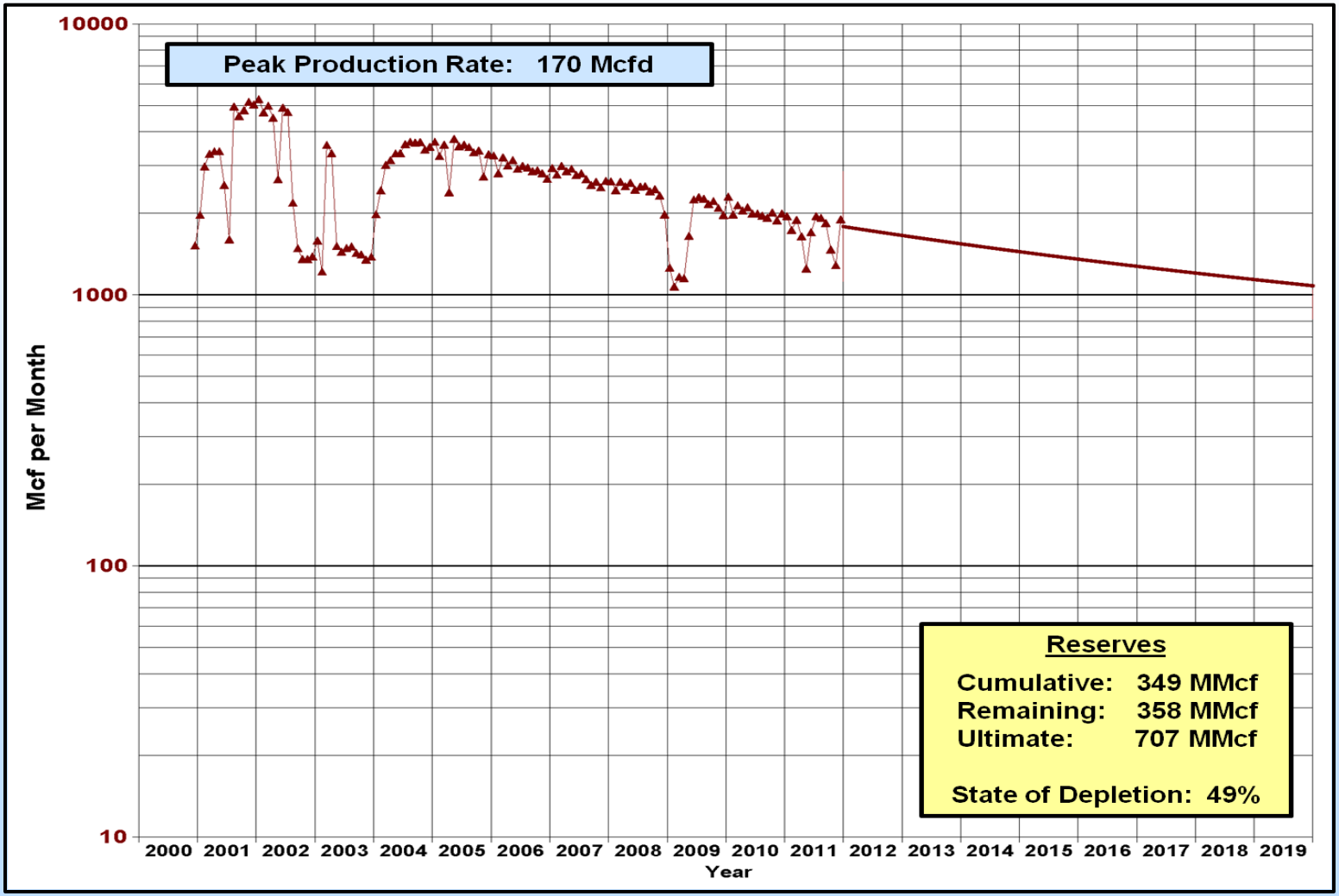
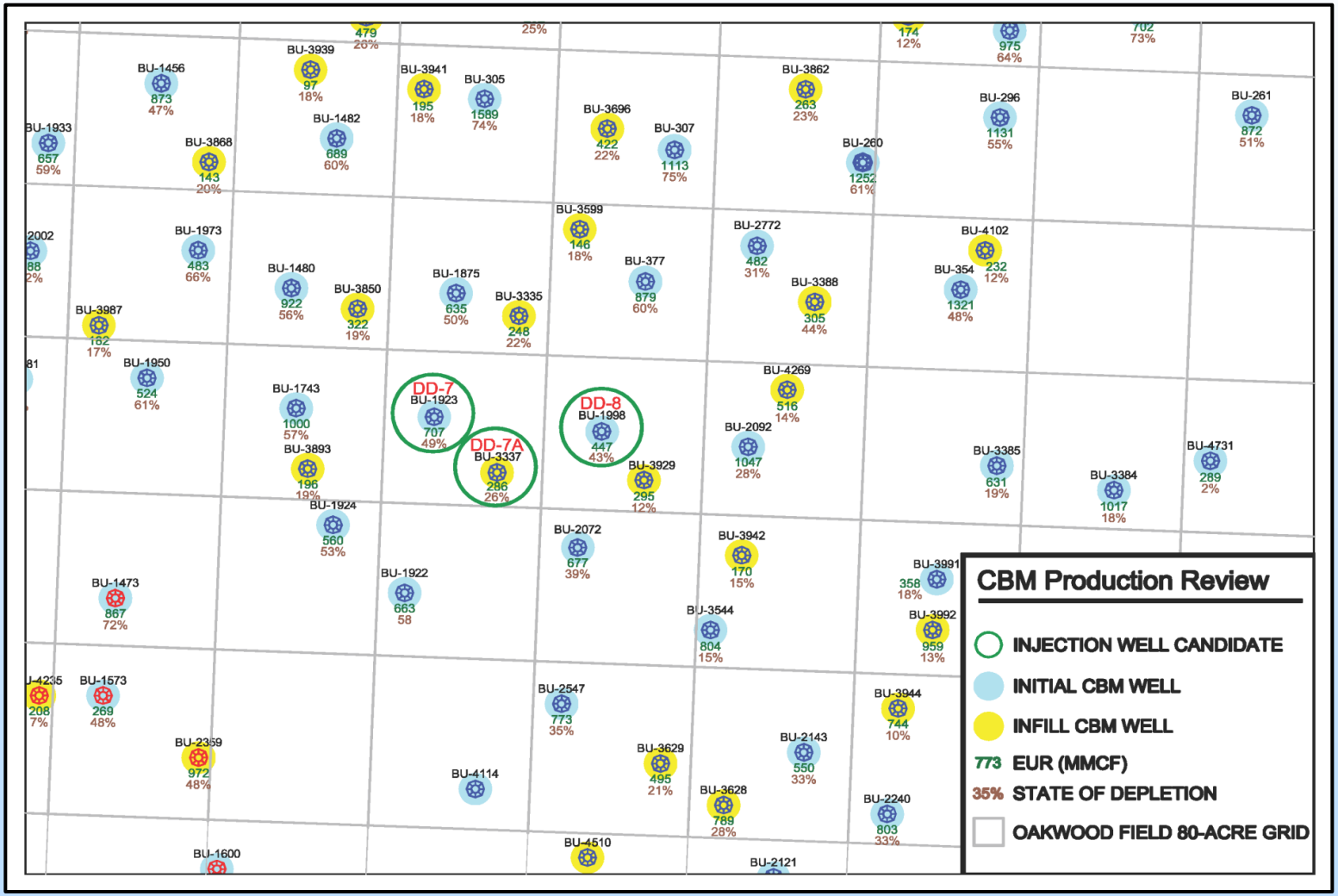
DD8

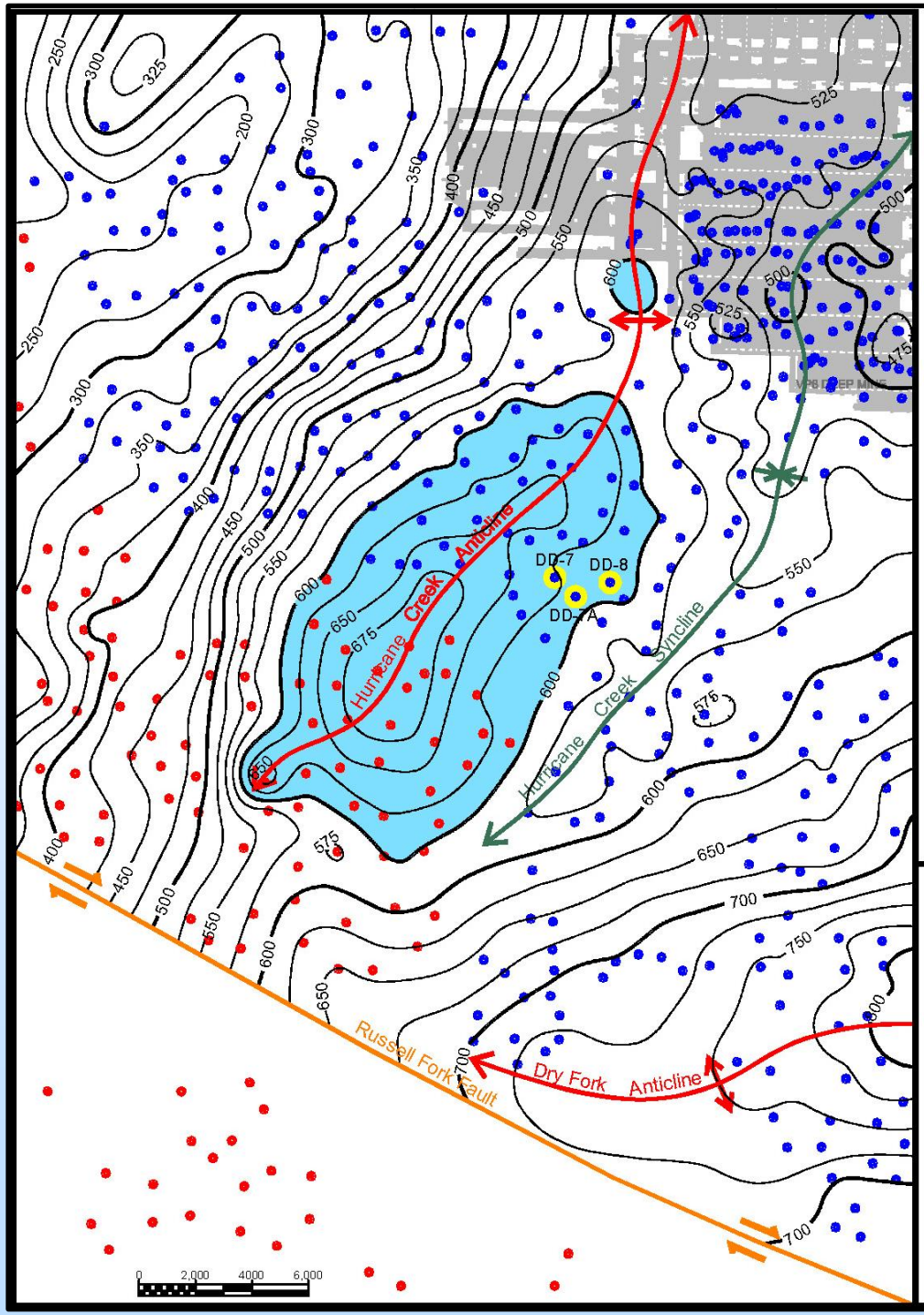
Decline Curve Analysis
BU-1923 (DD-7)



CBM Injection Test Site
Reserves and State of Depletion

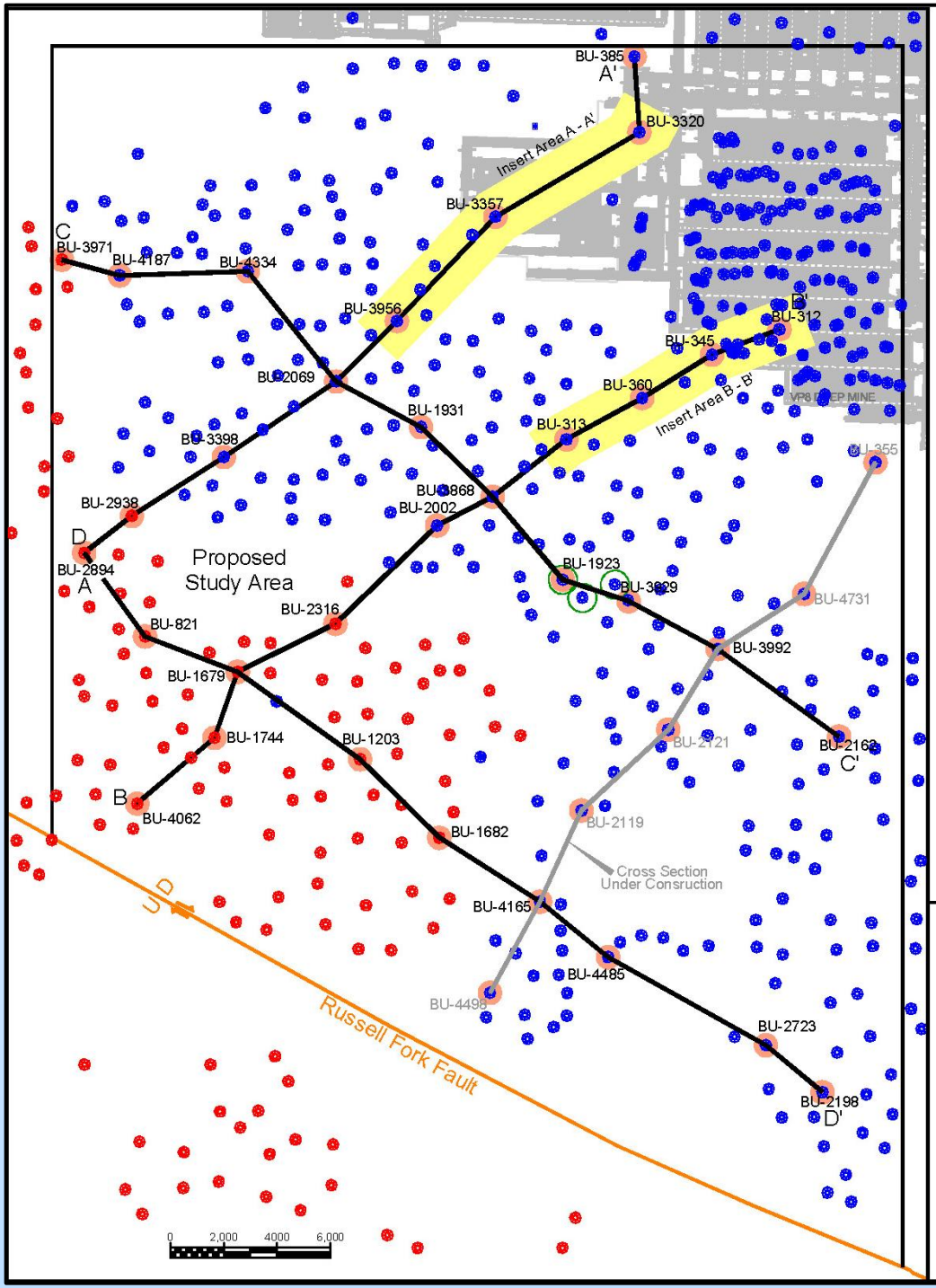


Pocahontas No. 9 Structure Map



Pocahontas No. 9 Structure

- POCAHONTAS NO. 9 STRUCTURE ISOLINE
  C. I. = 25 FEET
- SURFACE FAULT
- ANTICLINE
- SYNCLINE
- POCAHONTAS NO. 3 DEEP MINE
- CNX GAS CBM WELL
- EQUITABLE CBM WELL
- INJECTION WELL CANDIDATE

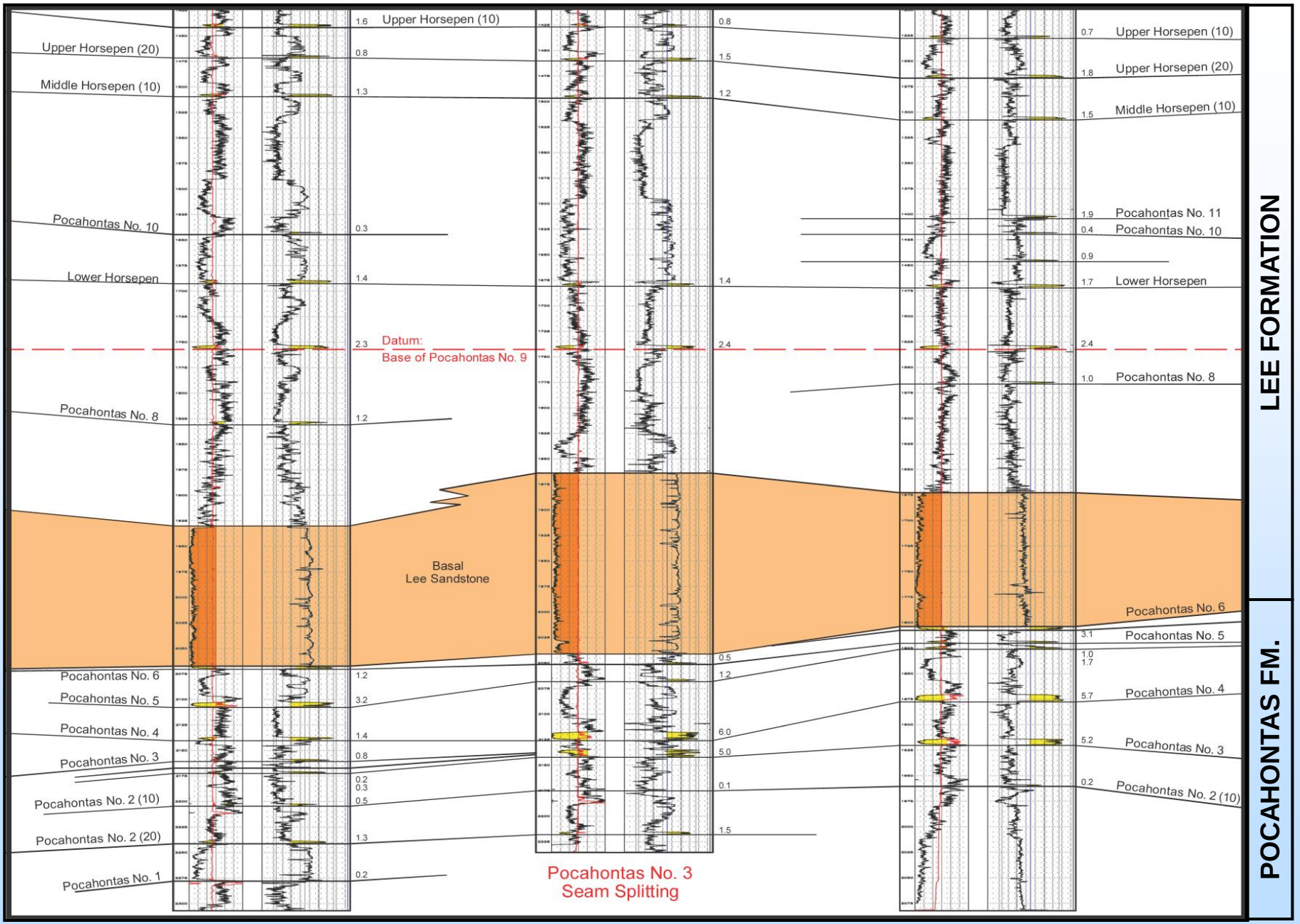


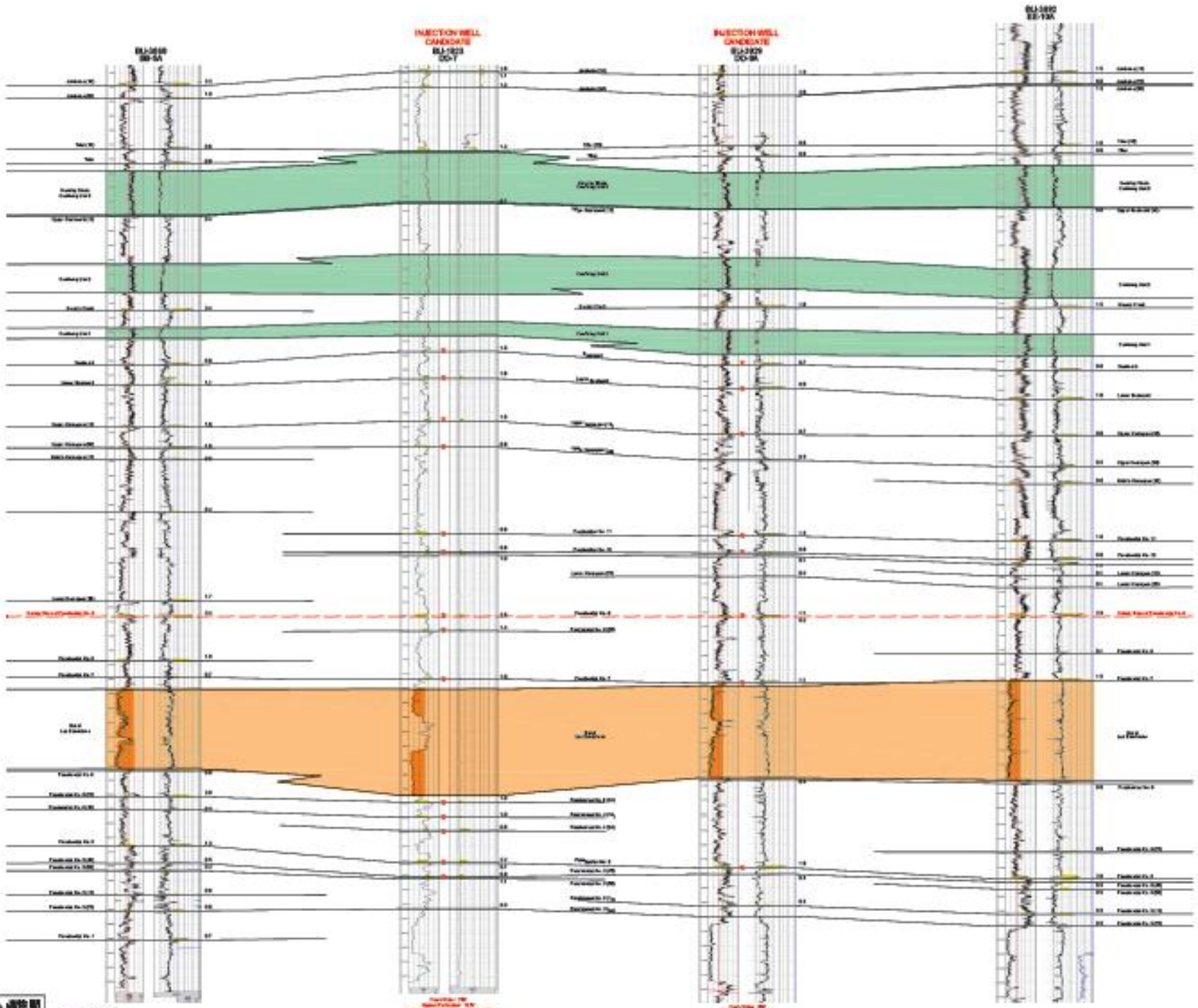
Cross Section Location Map

Cross Section Location

- A A' — LINE OF CROSS SECTION
- SURFACE FAULT
- POCAHONTAS NO. 3 DEEP MINE
- CNX GAS CBM WELL
- EQUITABLE CBM WELL
- GOB WELL
- INJECTION WELL CANDIDATE
- CROSS SECTION WELL

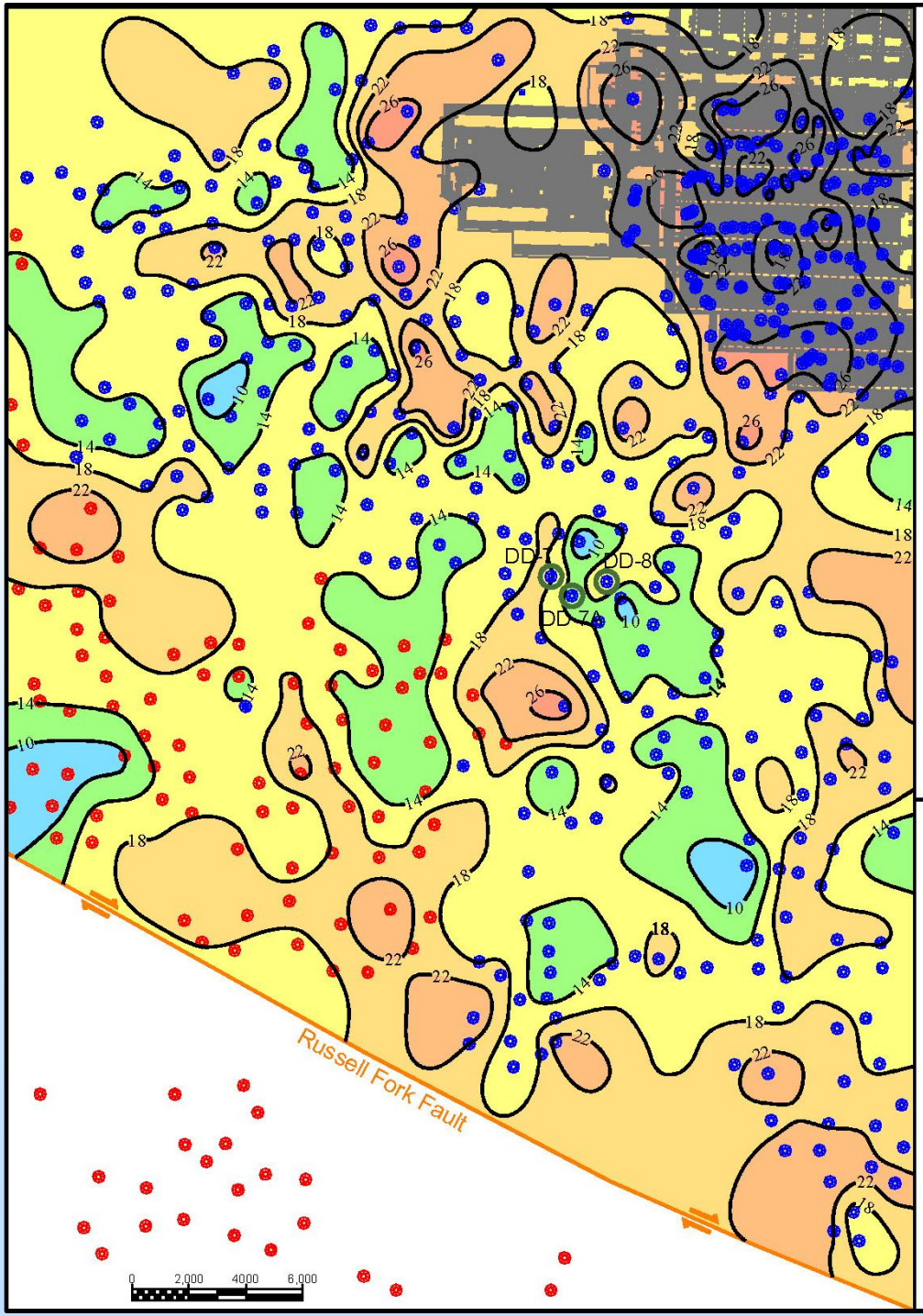
Cross Section Inset A – A’




INJECTION WELL CANDIDATE
INJECTION WELL CANDIDATE

Net Coal Isopach Map

(Upper Horsepen to Pocahontas No. 1)



Net Coal Isopach Map

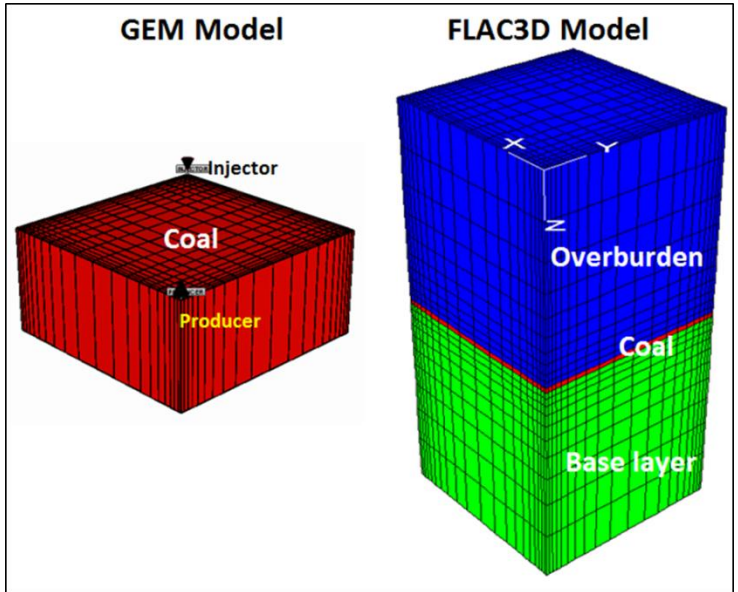
- NET COAL THICKNESS ISOLINE; CONTOUR INTERVAL = 4.0 FEET
- SURFACE FAULT
- POCAHONTAS NO. 3 DEEP MINE
- CNX GAS CBM WELL
- EQUITABLE CBM WELL
- GOB WELL
- DD-7 INJECTION WELL CANDIDATE

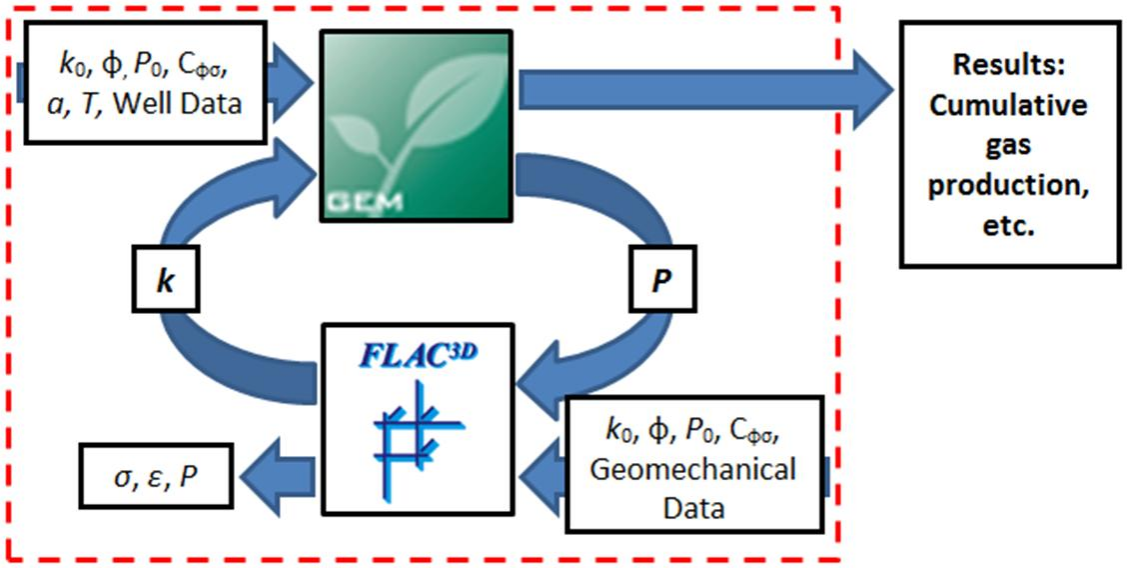
NET COAL THICKNESS

- < 10.0 FEET
- 10.0 - 14.0 FEET
- 14.0 - 18.0 FEET
- 18.0 - 22.0 FEET
- 22.0 - 26.0 FEET
- > 26.0 FEET

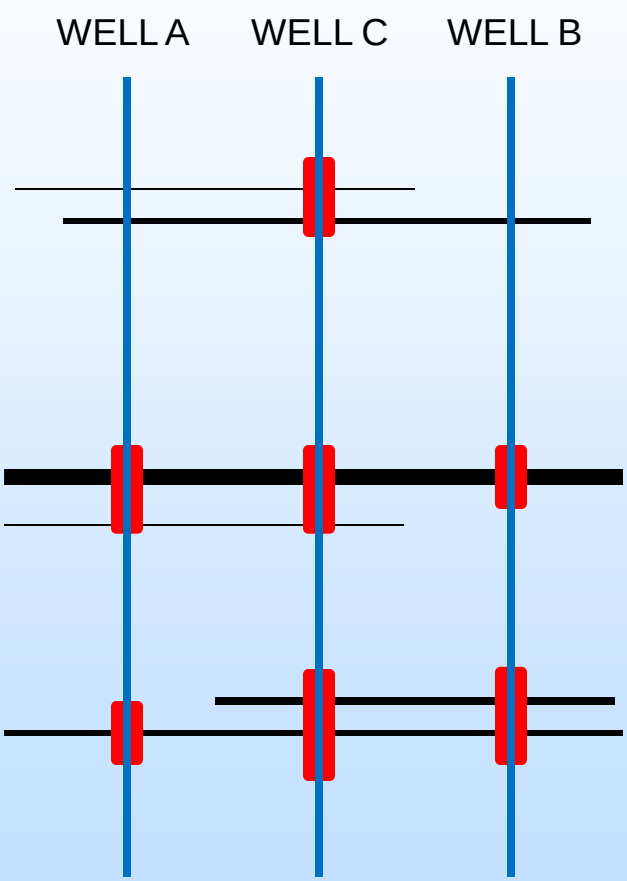
Overview of Reservoir Modeling

- **Preliminary Reservoir Modeling – Single Zone**
  - ARI's COMET3
- **Detailed Reservoir Modeling**
  - ARI's COMET 3 – Four Zones (3 Injection, 1 Production)
  - Computer Modeling Group's GEM Program – By Seam
- **Coupling GEM with FLAC3D for Geomechanical Modeling** (Poster Session)



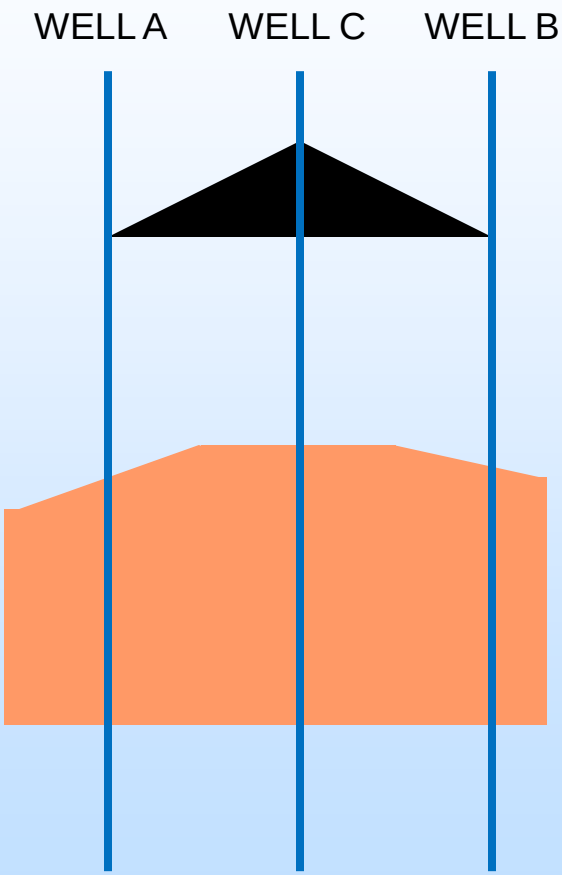


Thickness Modeling - Challenges

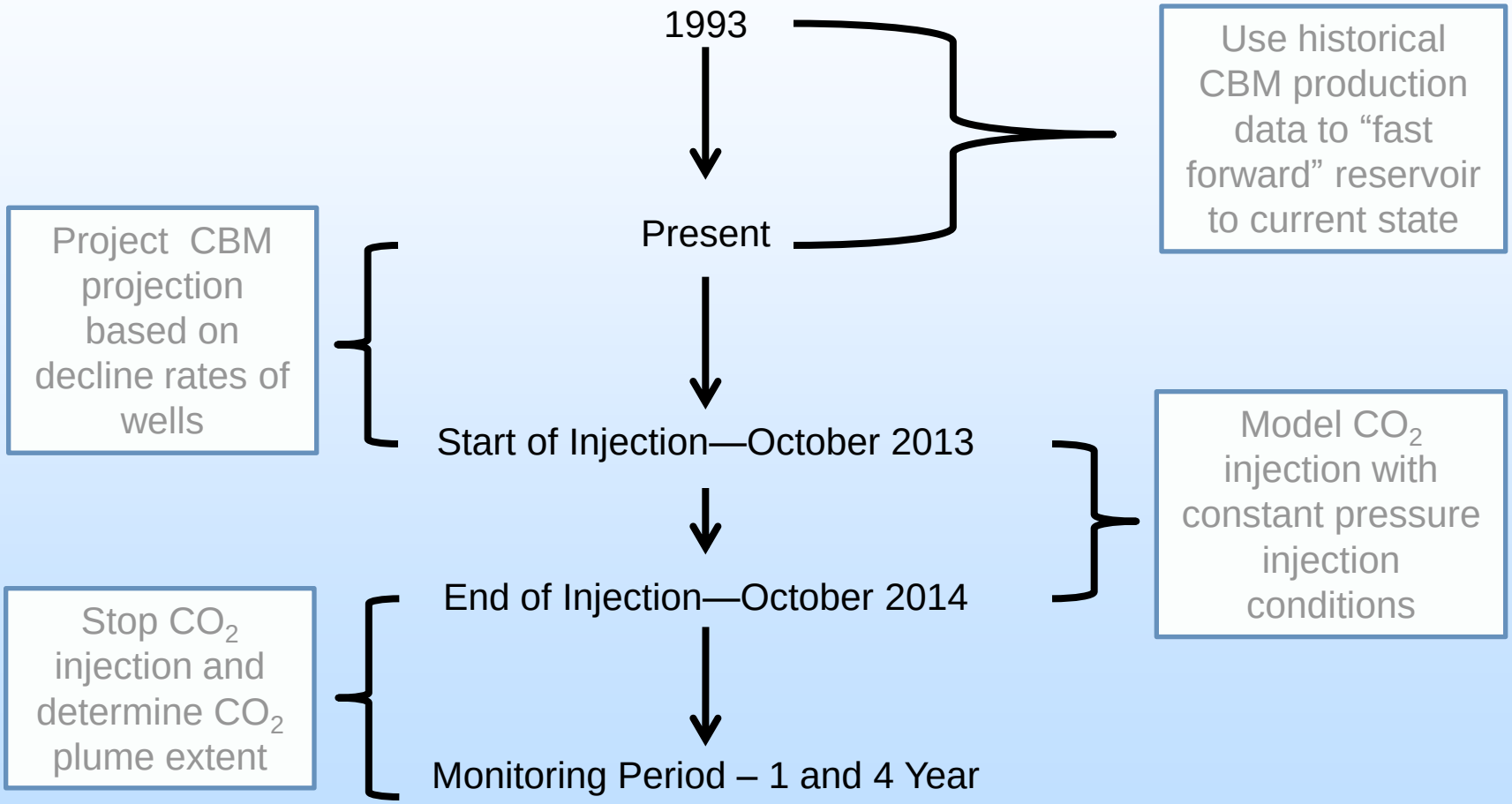


ZONE 1
Produced CH_4, No Injection of CO_2

ZONE 2
Produced CH_4, Injection of CO_2



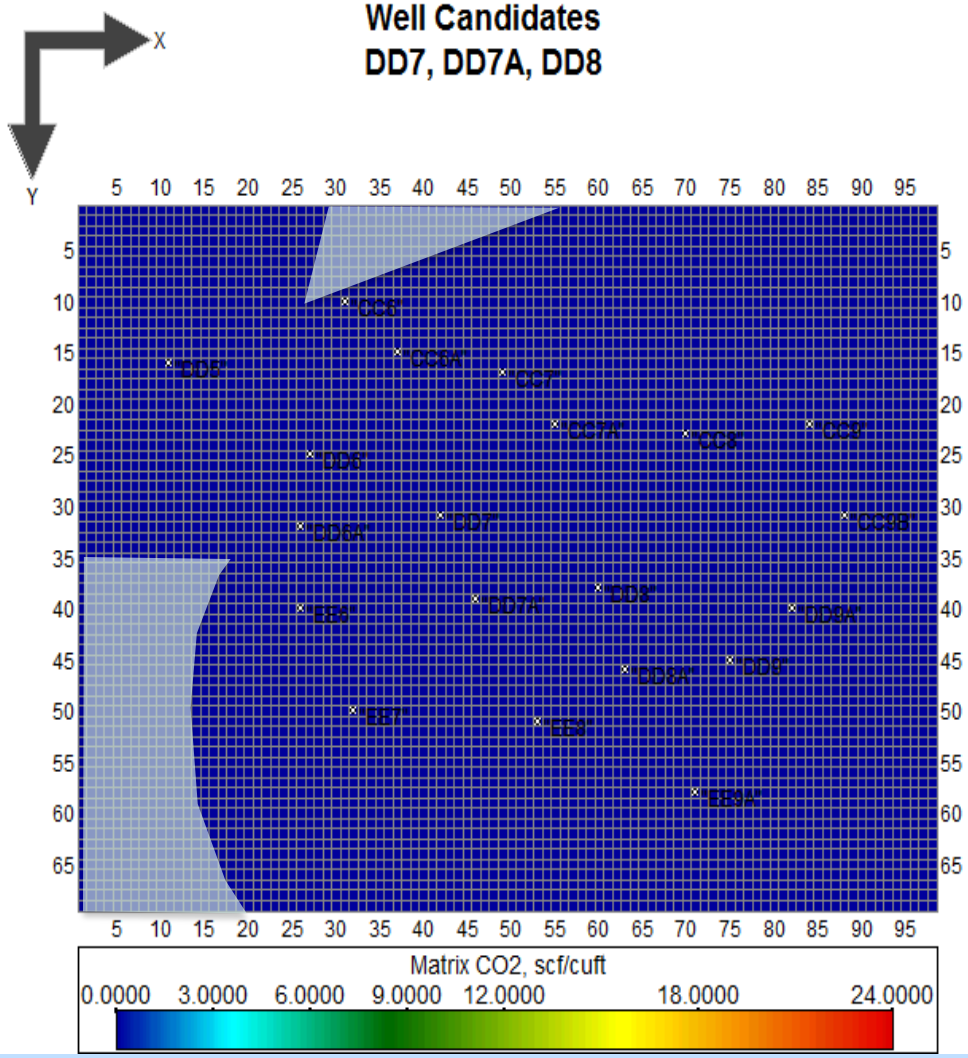
Modeling Methodology

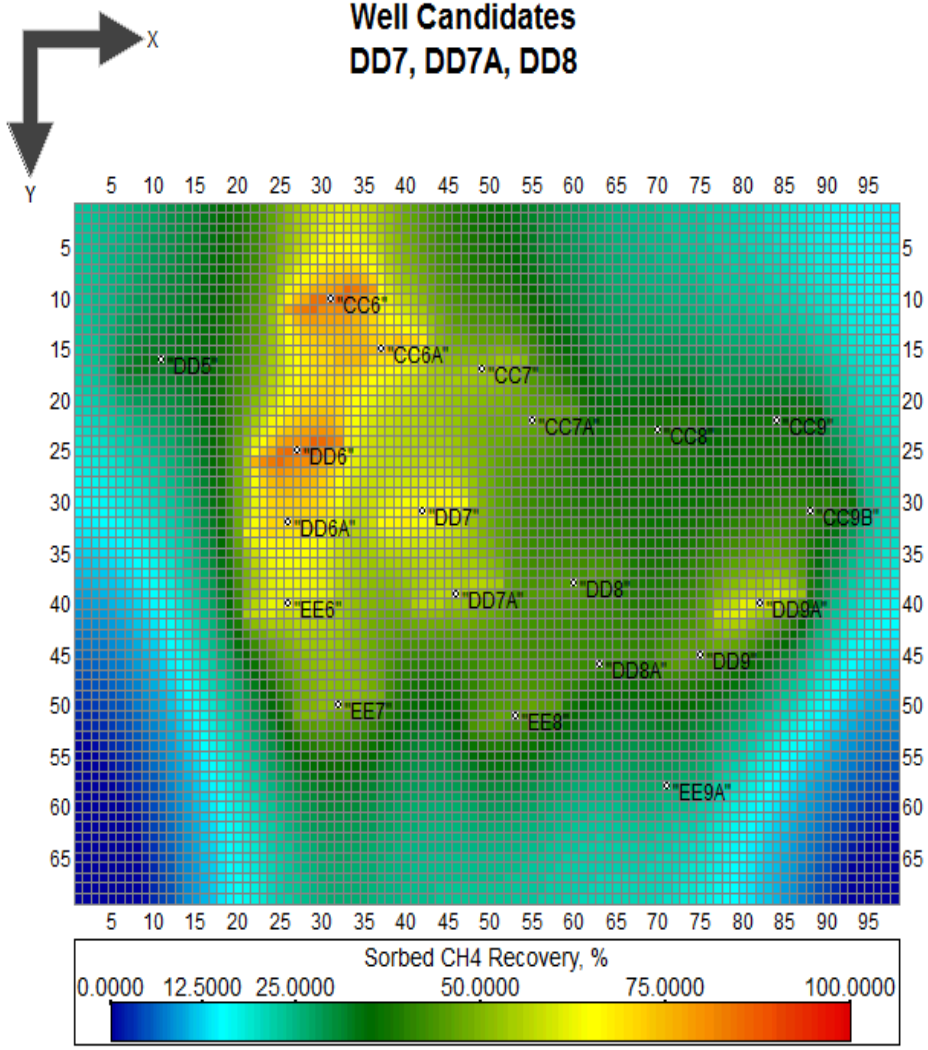


Key Reservoir Modeling Inputs for Preliminary Model

- Initial Gas Content = 400 ft^3/ton
- Initial Permeability = 8md/4md
- Pressure Gradient = 0.3 psi/ft
- Half Fracture Length = 650 ft
- Coal Porosity = 1%
- ***Producing Coal Depth = 1800 feet***
- ***Total Coal Thickness = 15 feet***

Initiation of Injection, October 2013
Well Candidates: DD7, DD7A , DD8

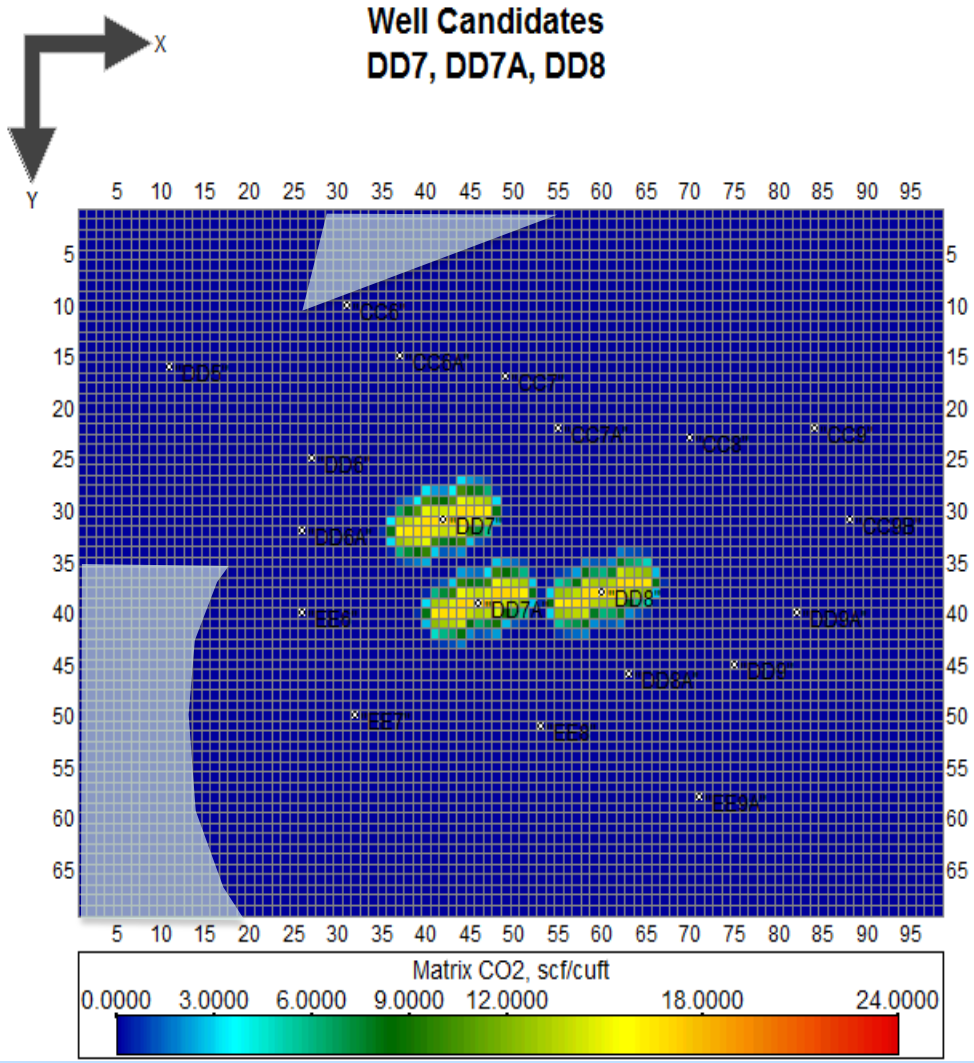


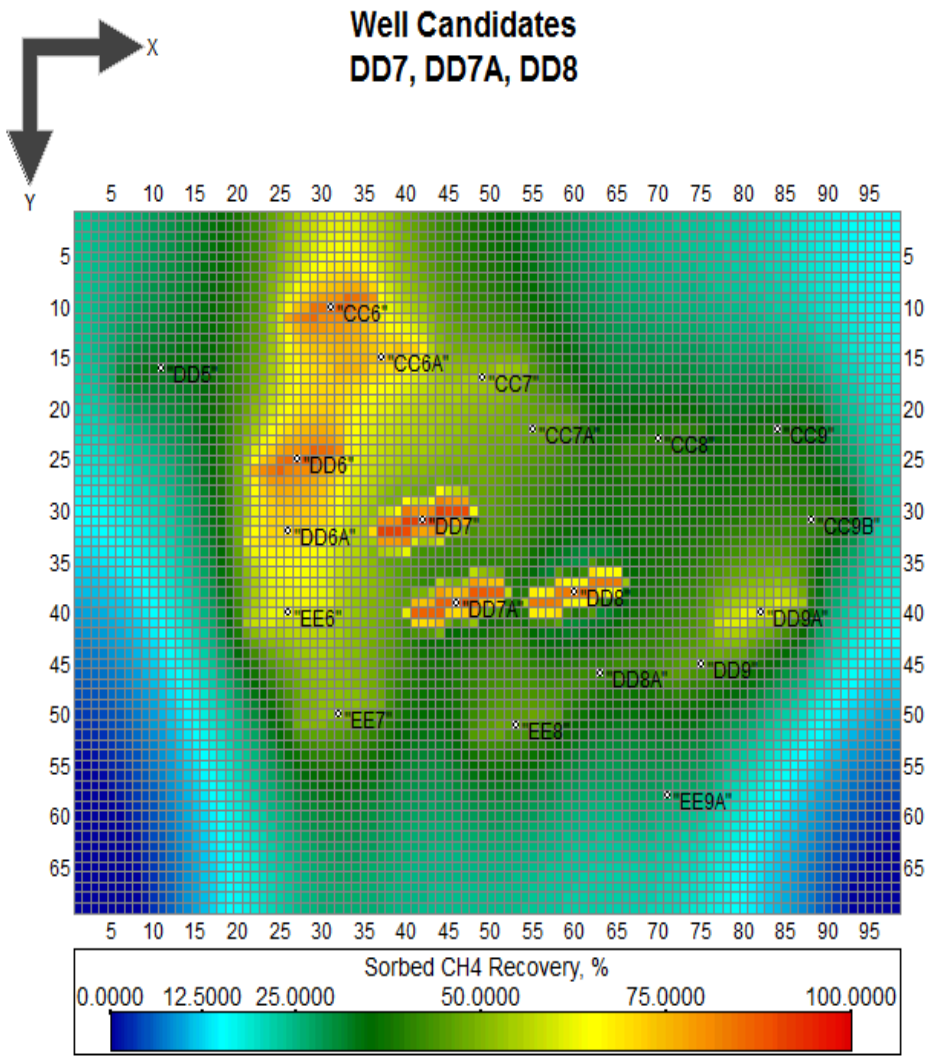


Matrix CO_2, scf/ cuft

Sorbed CH_4 Recovery, %

After 20,000 Tons Injected
Well Candidates: DD7, DD7A , DD8

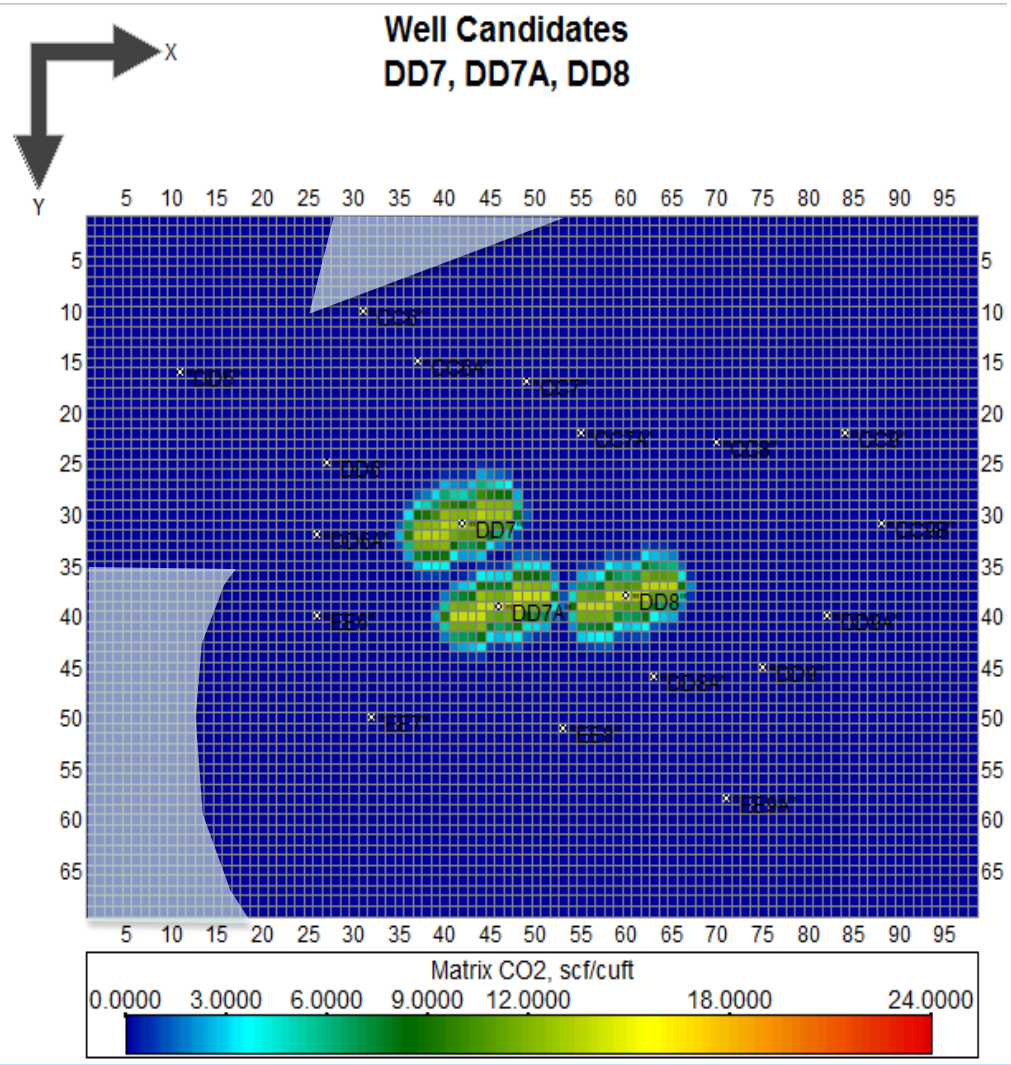


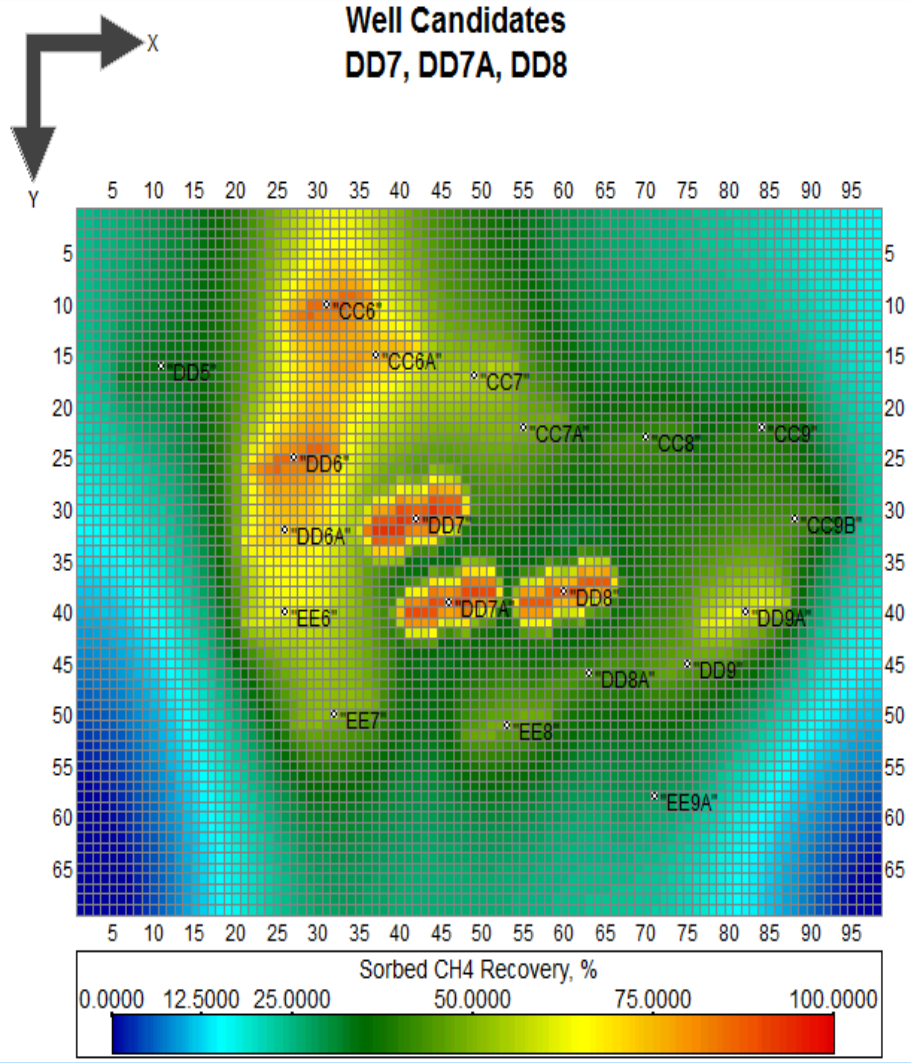


Matrix CO2, scf/ cuft

Sorbed CH_4 Recovery, %

End of Injection, October 2014
Well Candidates: DD7, DD7A , DD8

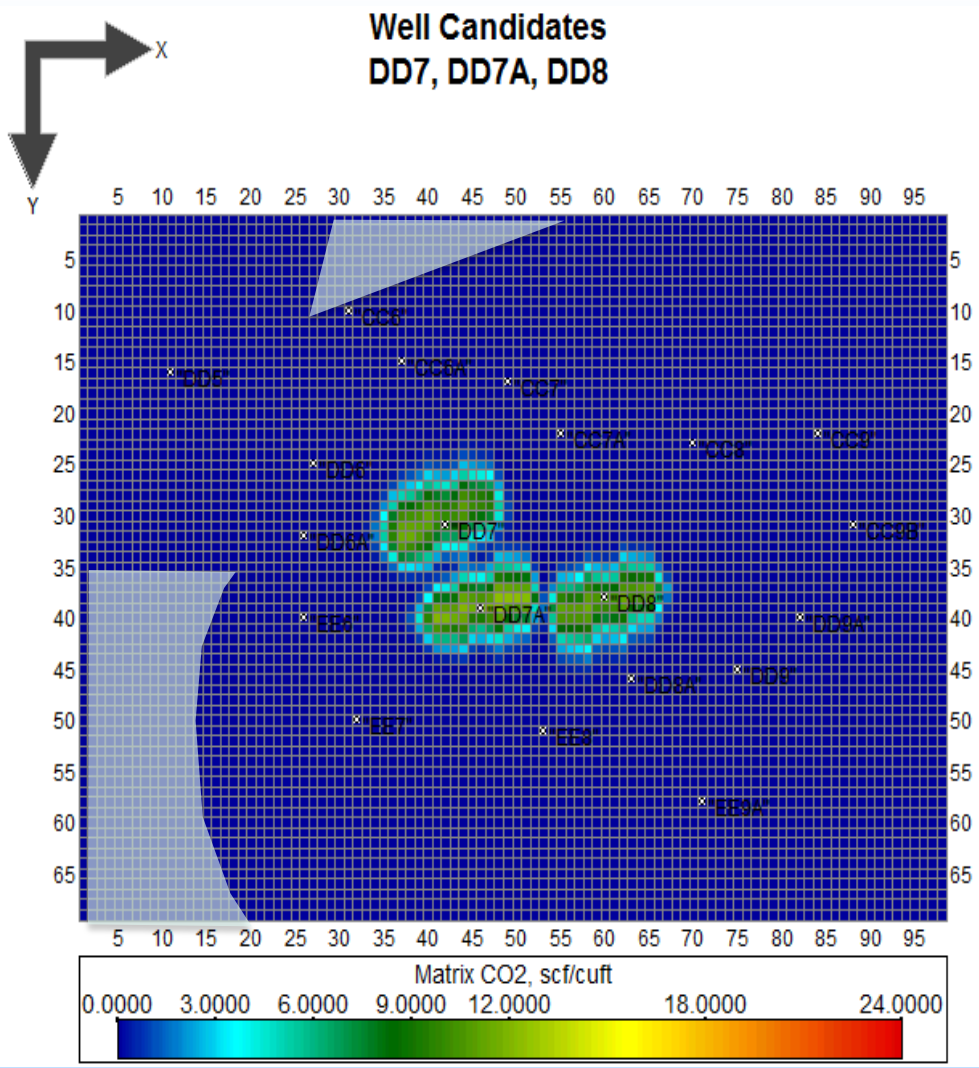


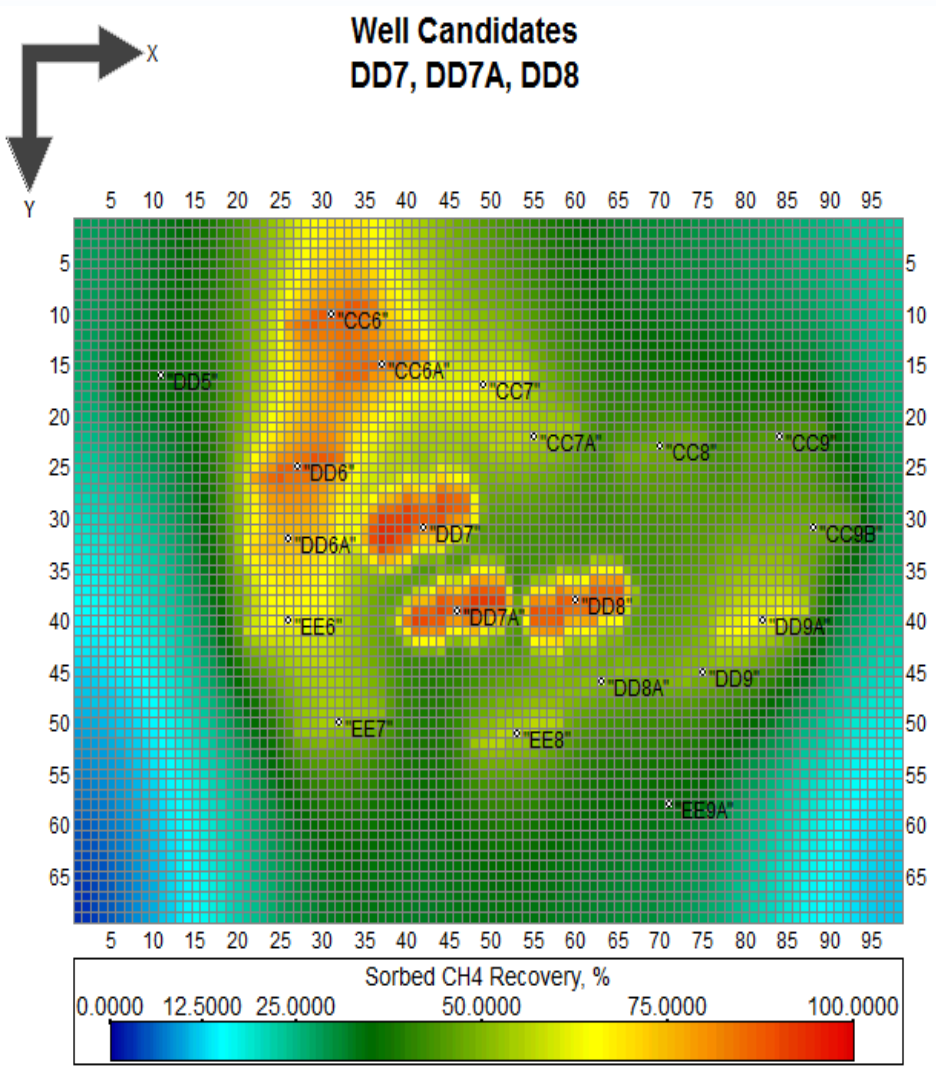


Matrix CO_2, scf/ cuft

Sorbed CH_4 Recovery, %

4 Years After the End of the Injection, October 2017
Well Candidates: DD7, DD7A , DD8

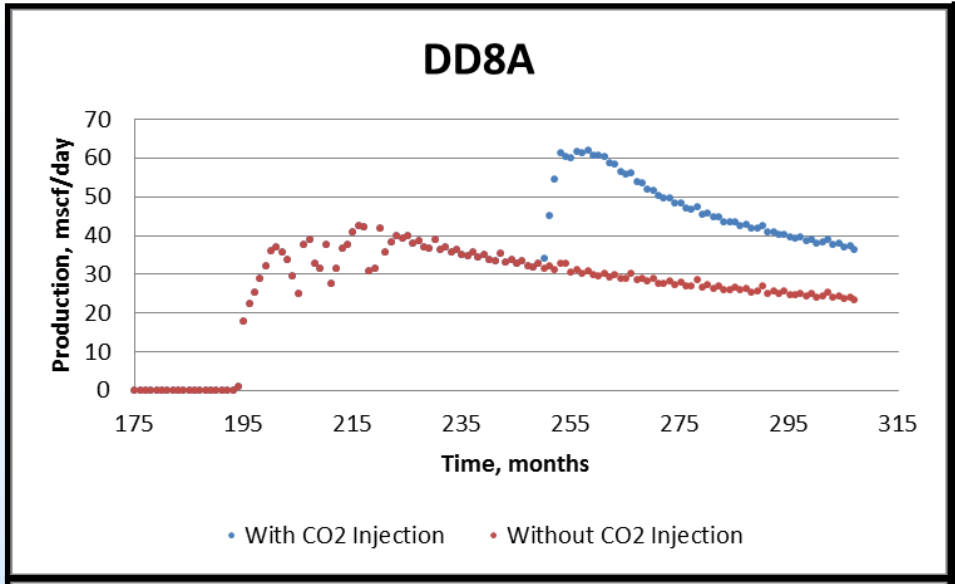


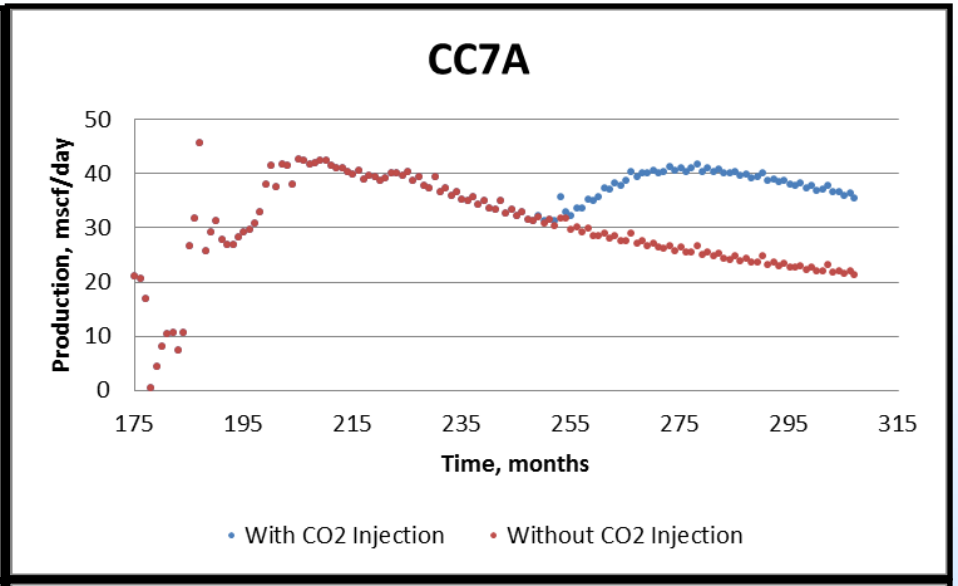


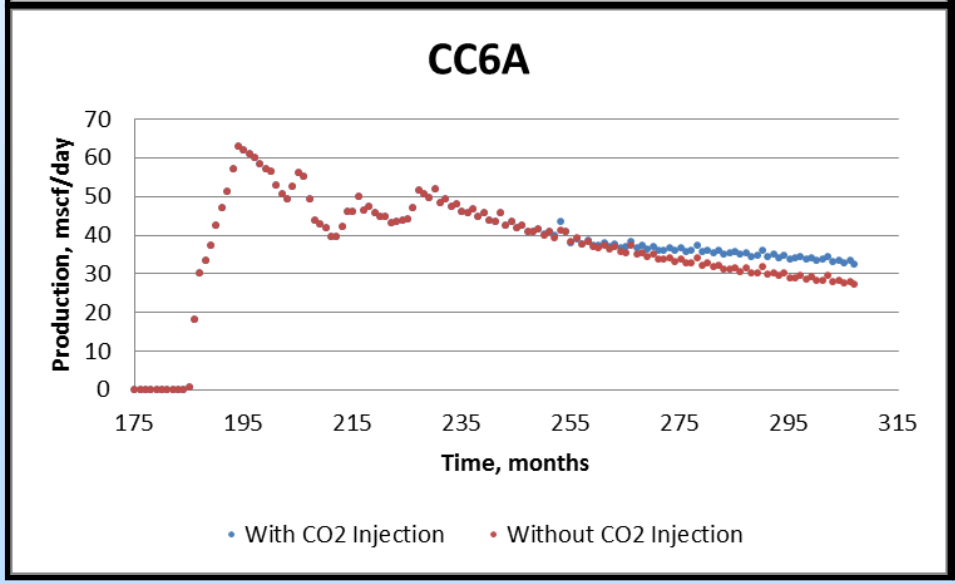
Matrix CO_2, scf/ cuft

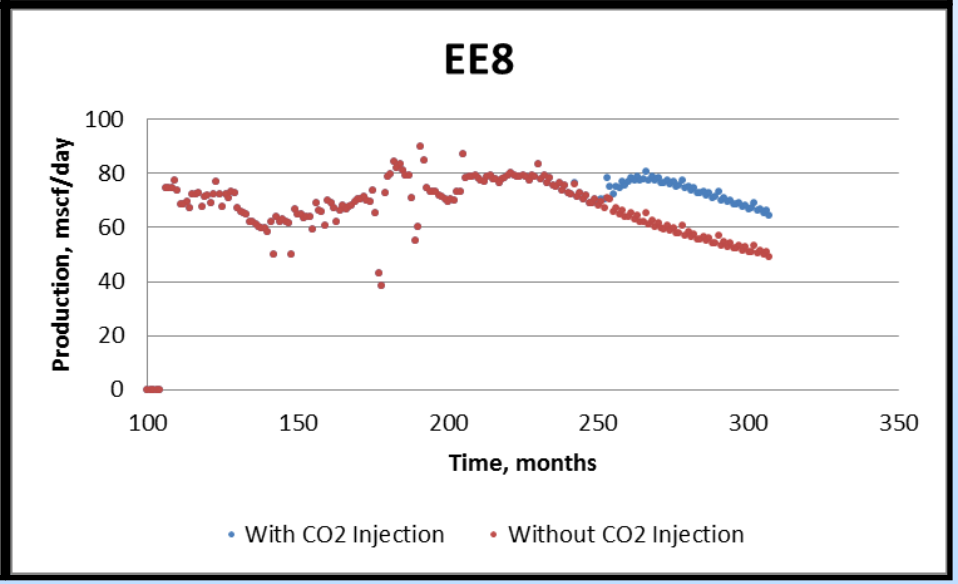
Sorbed CH_4 Recovery, %

ECBM after 1 and 4 Years Post-Injection: 22 – 106 MMcf

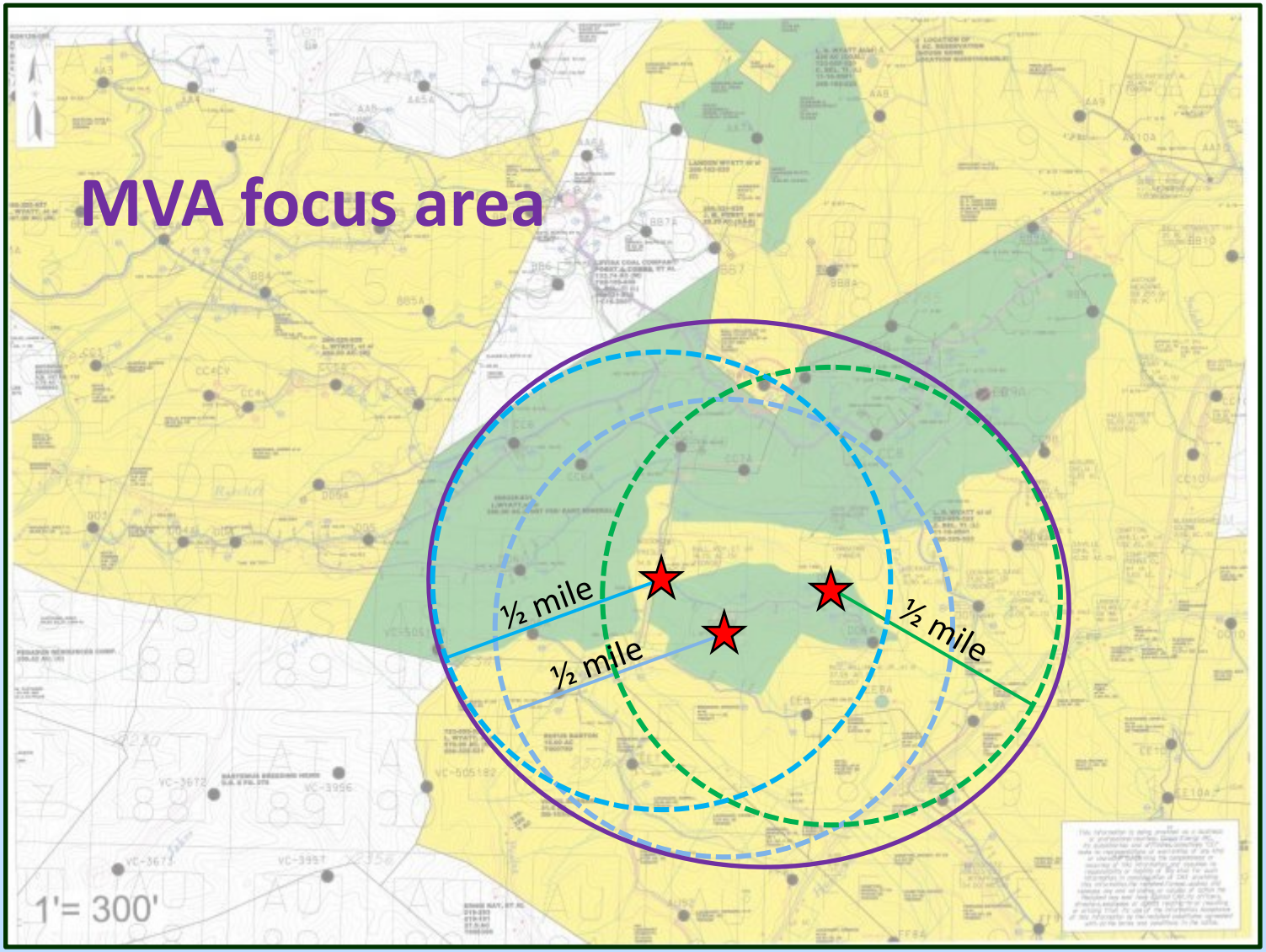








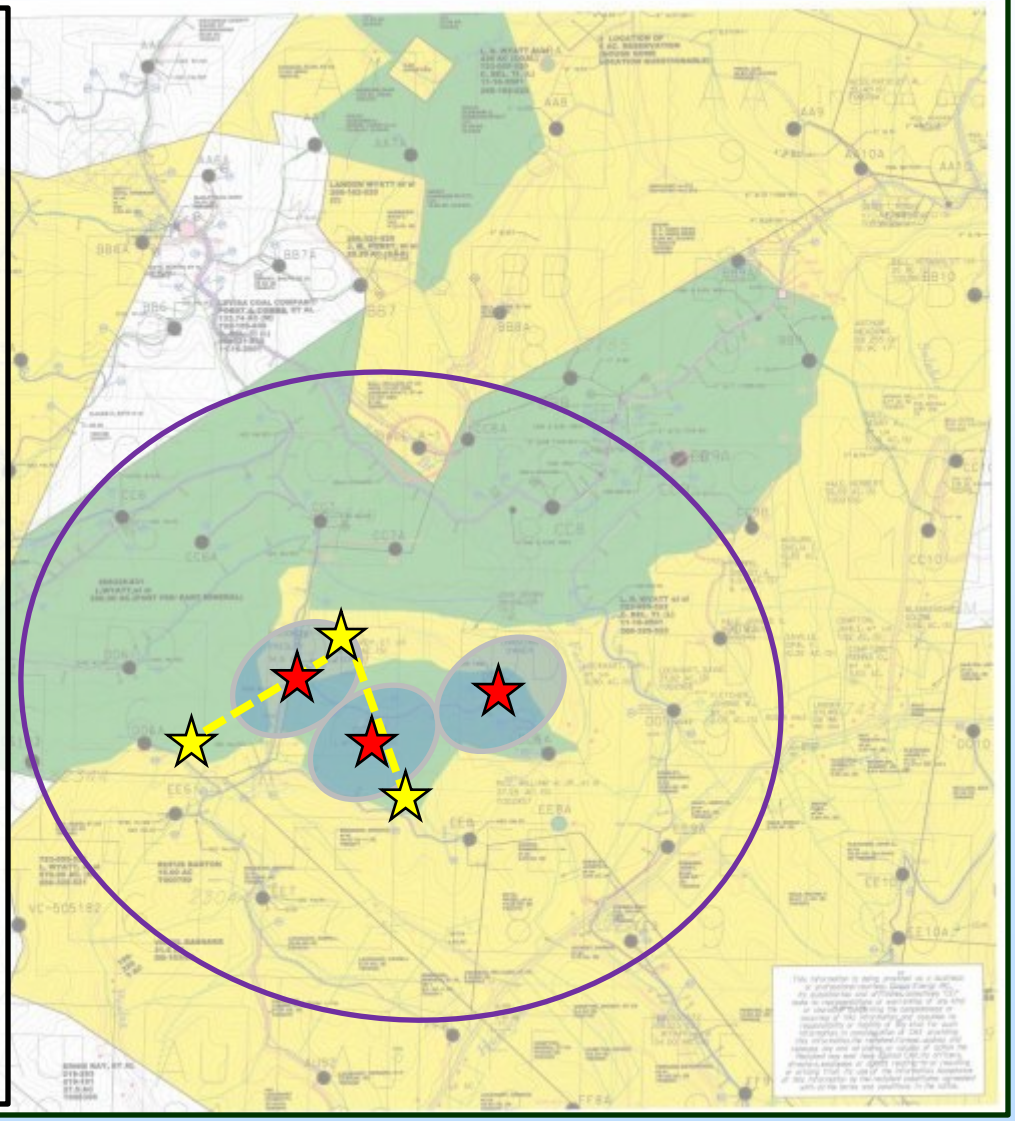
Monitoring, Verification and Accounting (MVA)



Monitoring Well Candidates

MVA program features

- 2-3 monitoring wells, depending on:
  - Access
  - Anticipated plume growth
  - Tests to be conducted (VSP/crosswell seismic)
  - Future well utilization (conversion or plugged)



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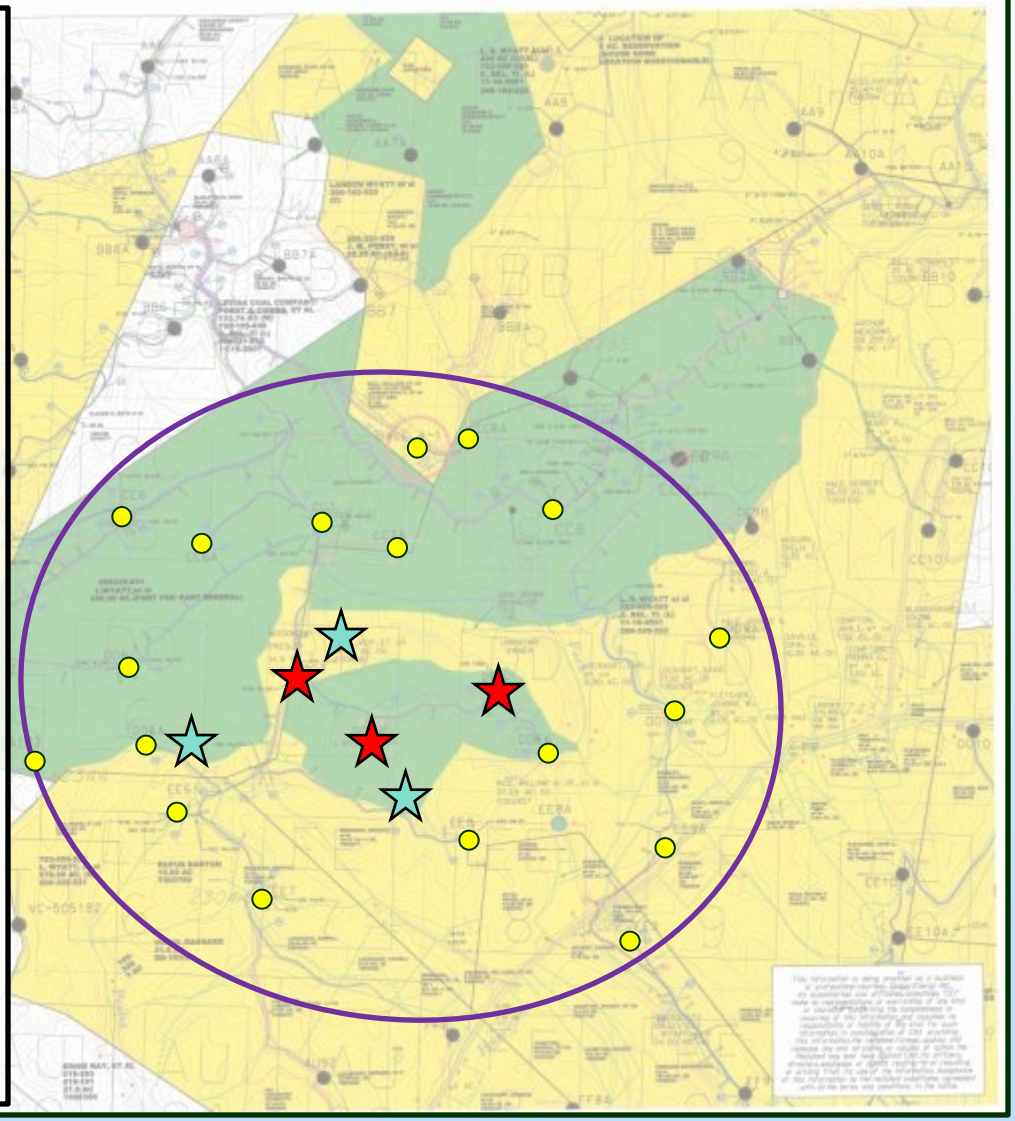
Offset Well Testing

MVA program features

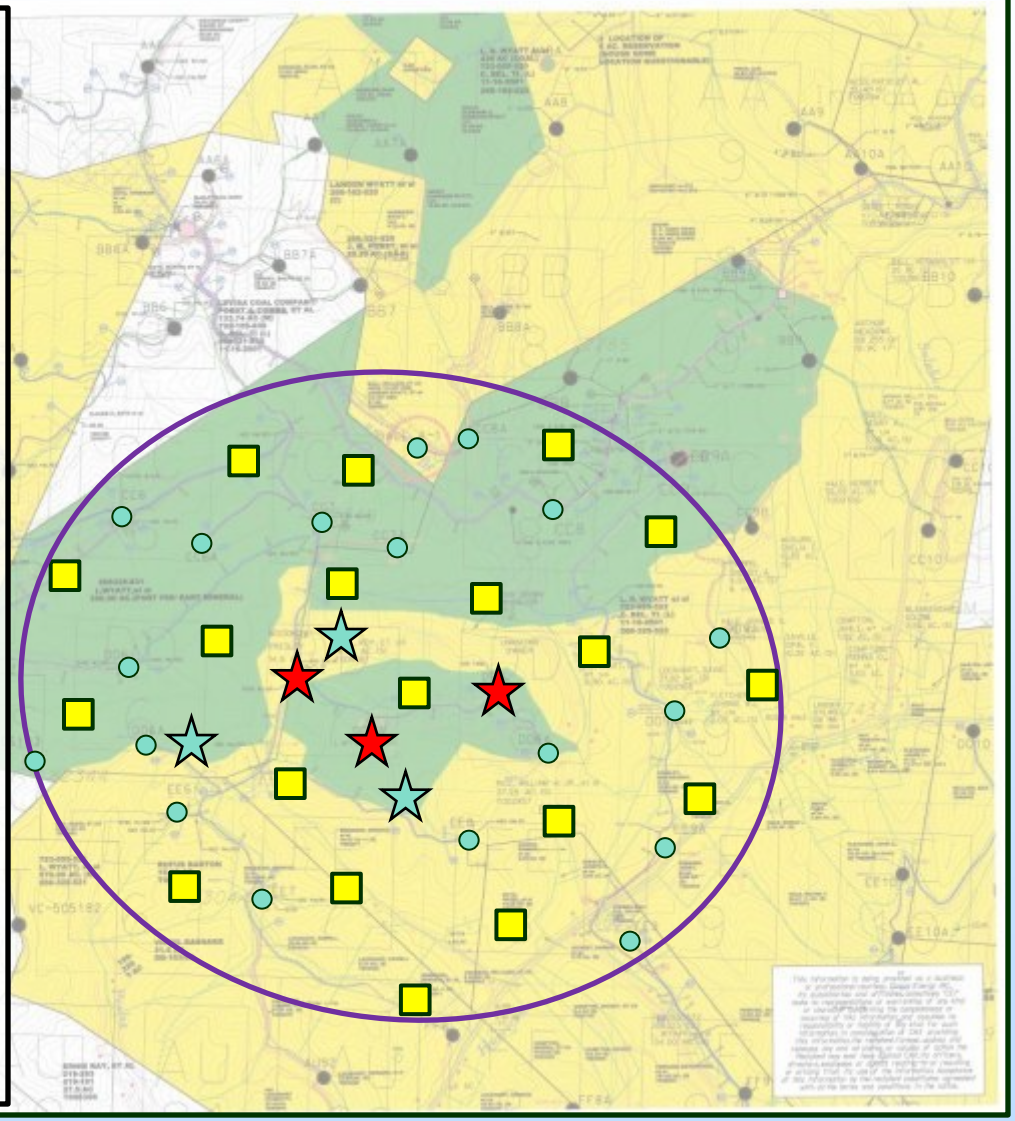
- 2-3 monitoring wells, depending on:
  - Access
  - Anticipated plume growth
  - Tests to be conducted (VSP/crosswell seismic)
  - Future well utilization (conversion or plugged)
- Offset well testing
  - Pressure
  - Gas content
  - Production
  - Temperature



Surface Monitoring Stations

MVA program features

- 2-3 monitoring wells, depending on:
  - Access
  - Anticipated plume growth
  - Tests to be conducted (VSP/crosswell seismic)
  - Future well utilization (conversion or plugged)
- Offset well testing
  - Pressure
  - Gas content
  - Production
  - Temperature
- Surface test stations
  - Soil gas composition
  - Groundwater tests
  - Microseismic array
  - Surface deformation measurement
  - Isotope and Tracers



Monitoring, Verification and Accounting (MVA)

MVA program features

- 2-3 monitoring wells, depending on:
  - Access
  - Anticipated plume growth
  - Tests to be conducted (VSP/crosswell seismic)
  - Future well utilization (conversion or plugged)
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  - Pressure
  - Gas content
  - Production
  - Temperature
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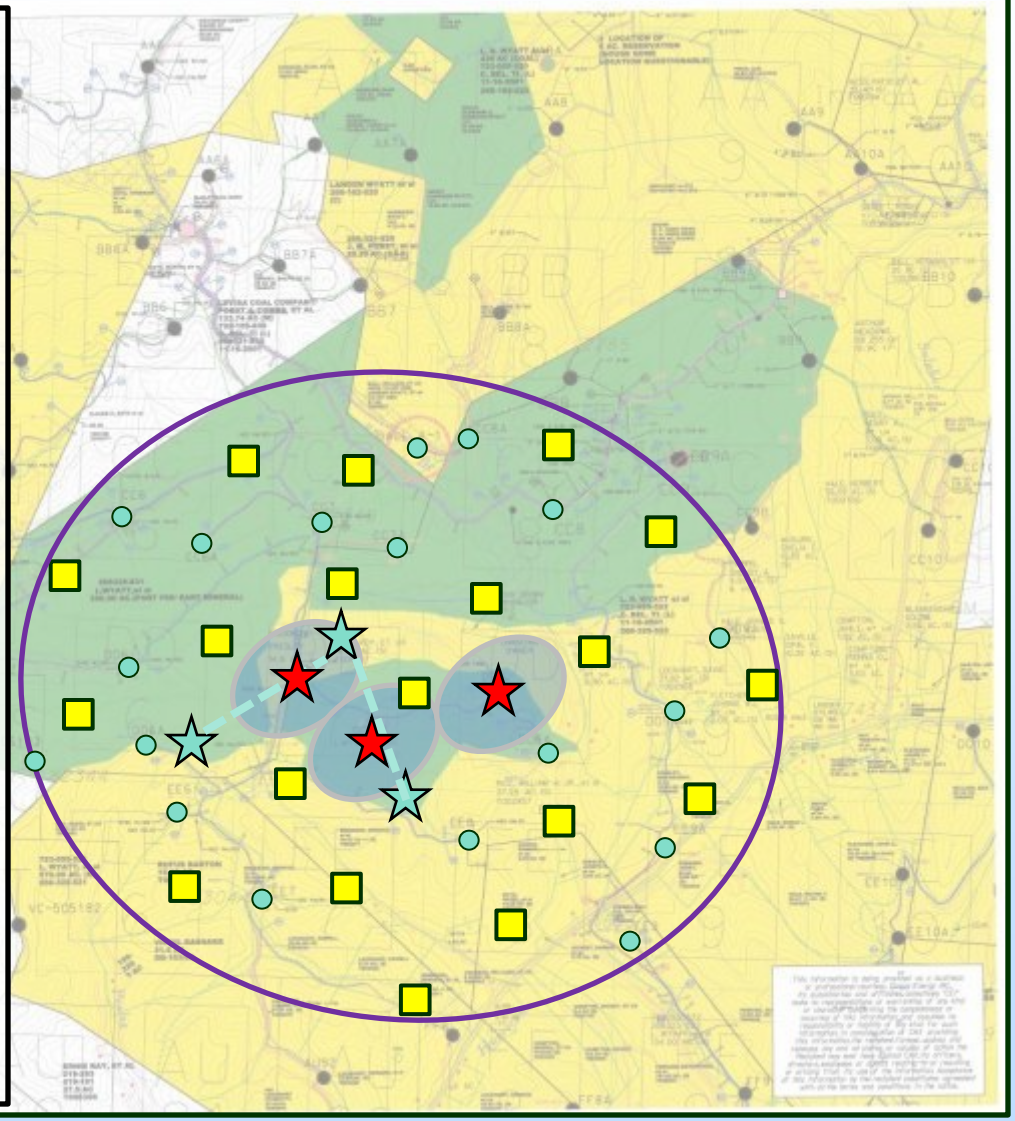
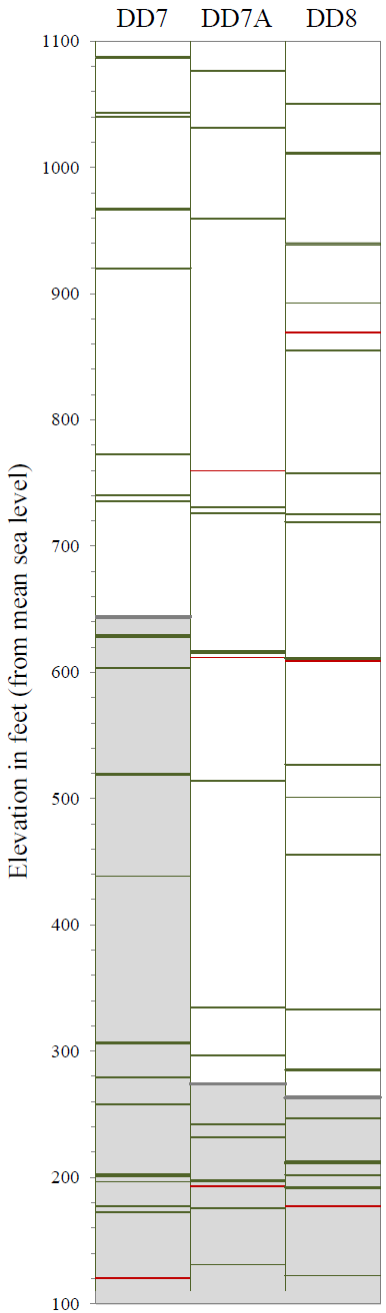
  - Isotope and Tracer




DD7
DD7A
DD8
Elevation in feet (from mean sea level)
1100
1000
900
800
700
600
500
400
300
200
100


Hydraulic fracture direction: N55E
Injection well
250’
M1
50’
Src well
50’
M2
232 ft
© 2012 Google
37°08'17.35" N 82°04'38.63" W elev 0 ft

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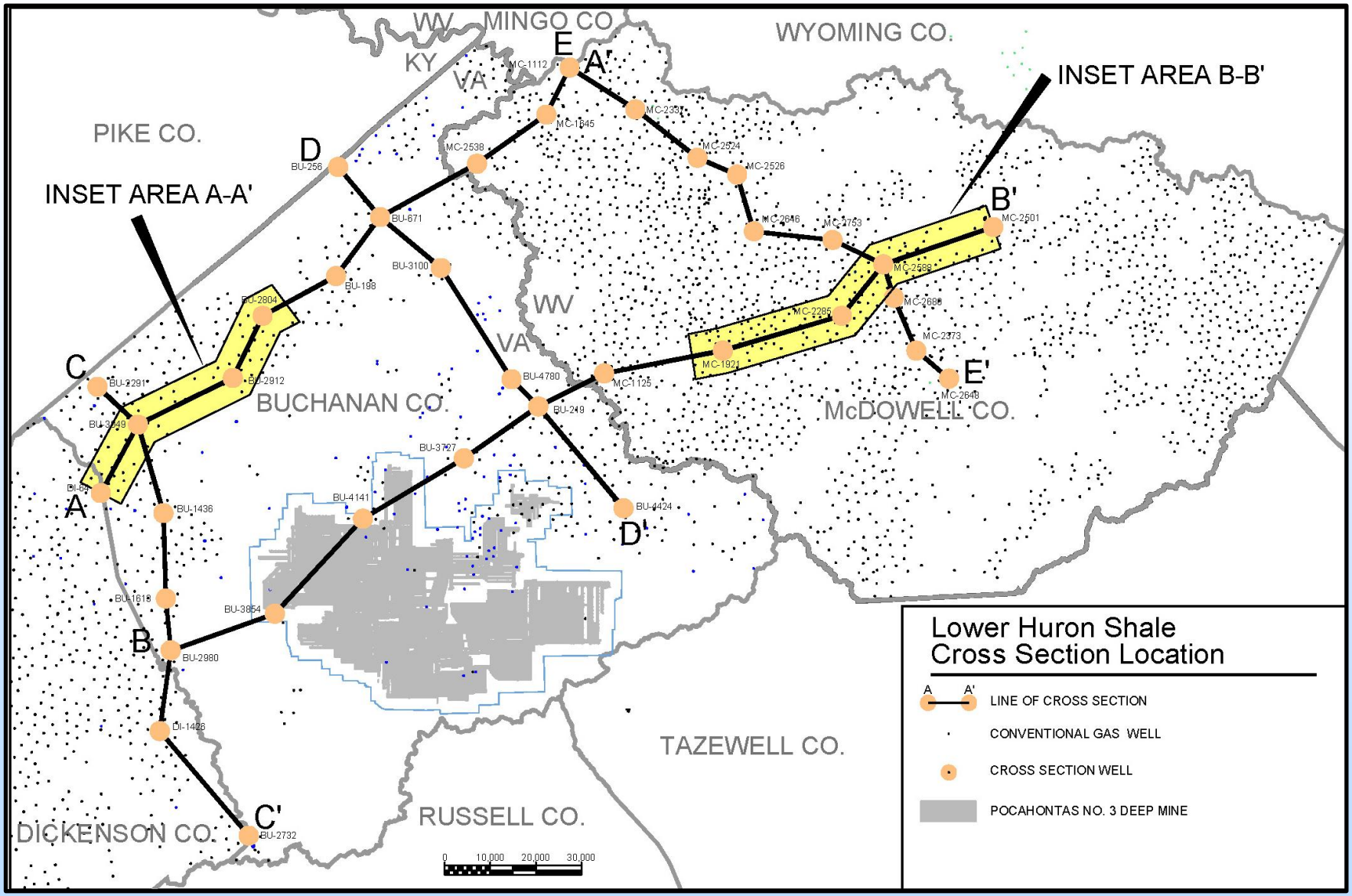
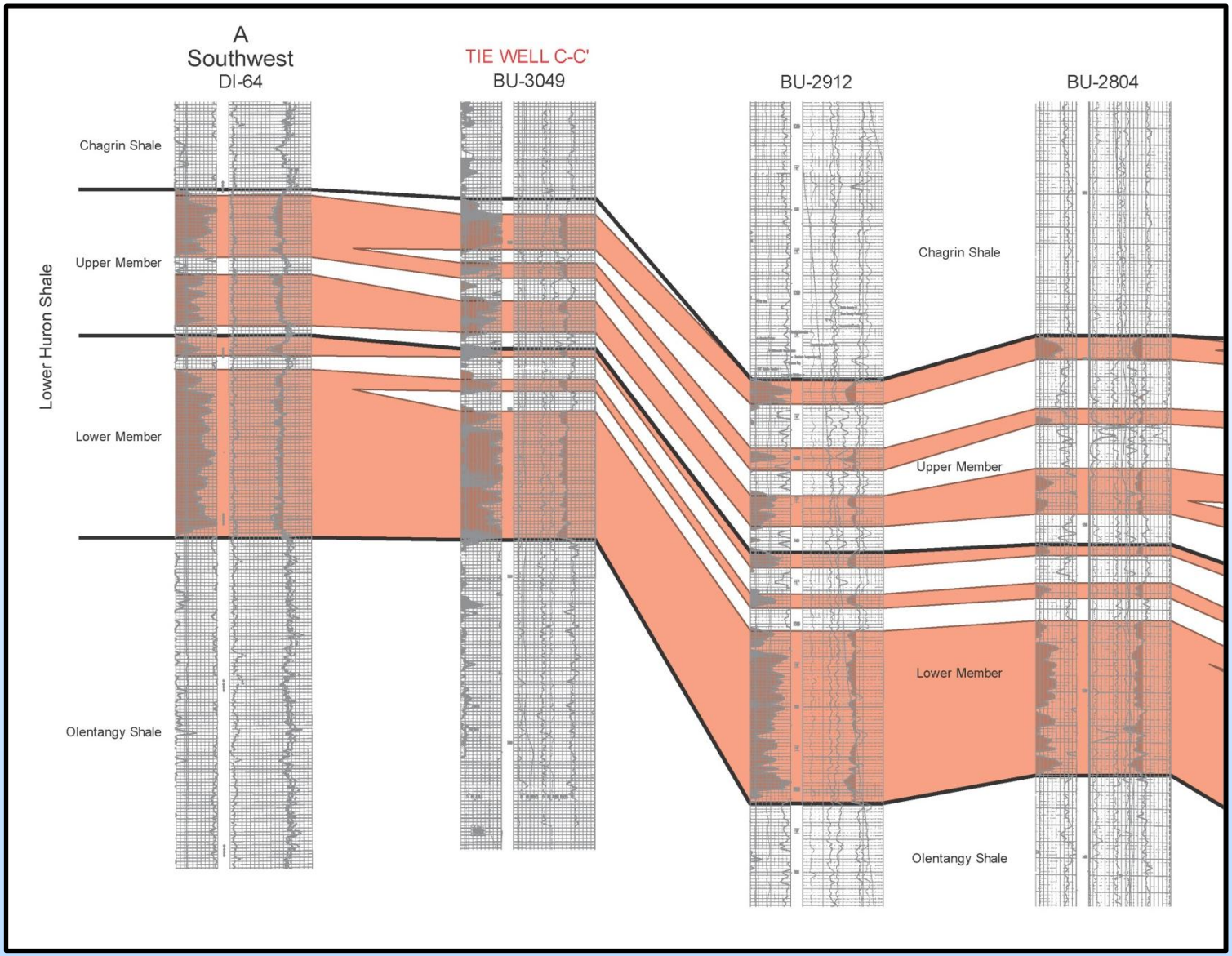
Shale Test

- 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

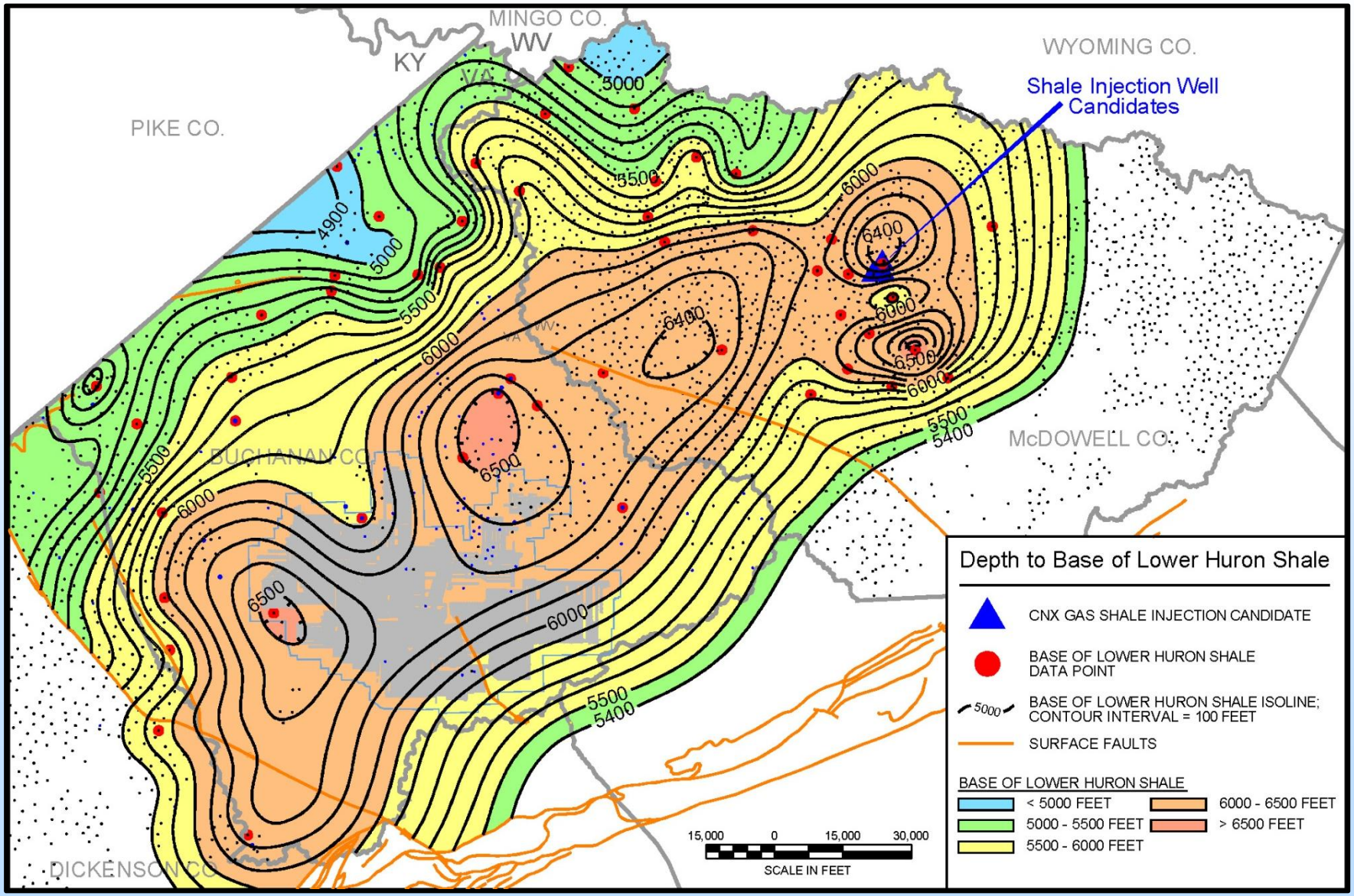
Lower Huron Shale
Cross Section Location Map



Cross Section A-A’ Inset
McDowell County, West Virginia



Depth to Lower Huron Shale



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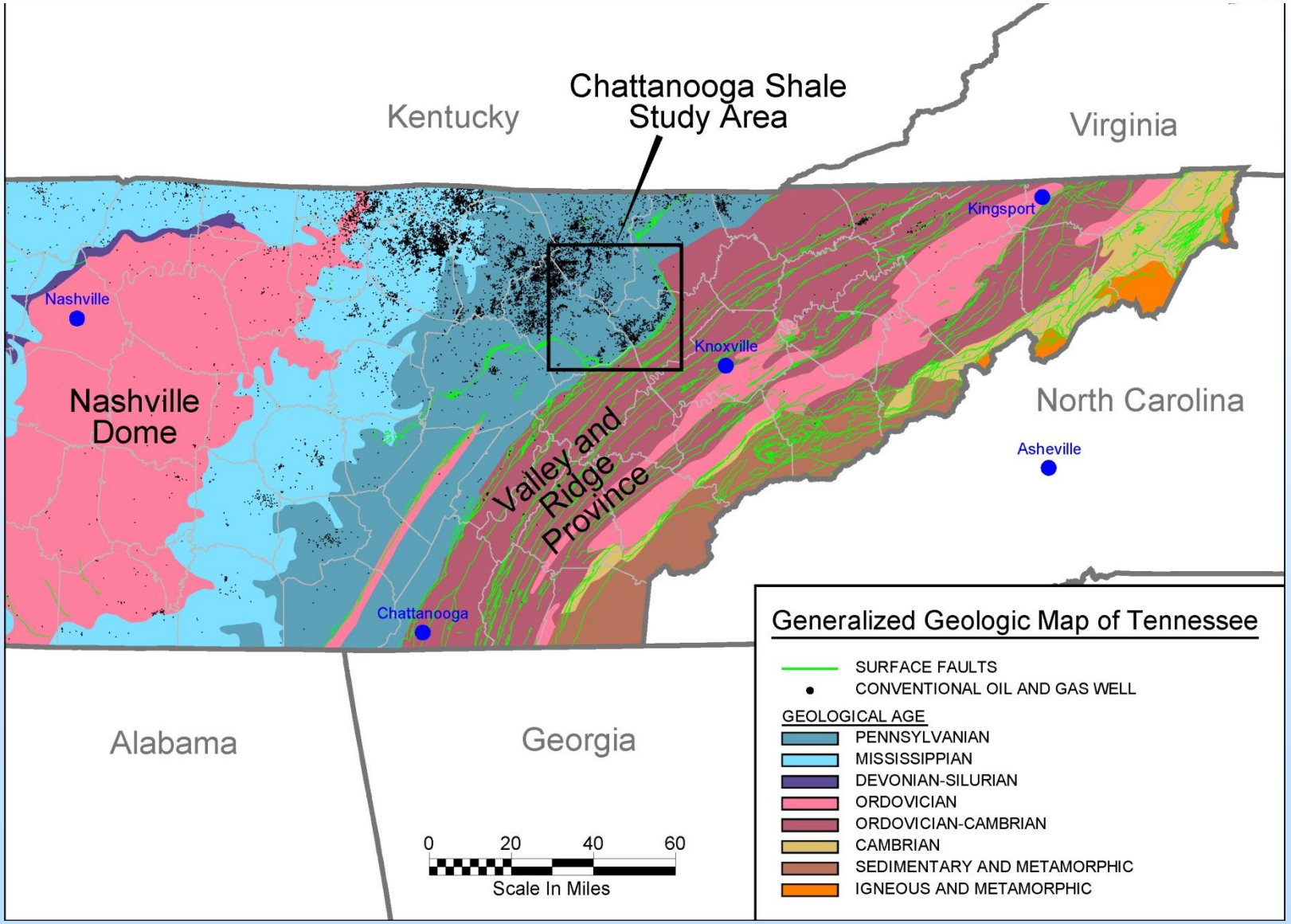
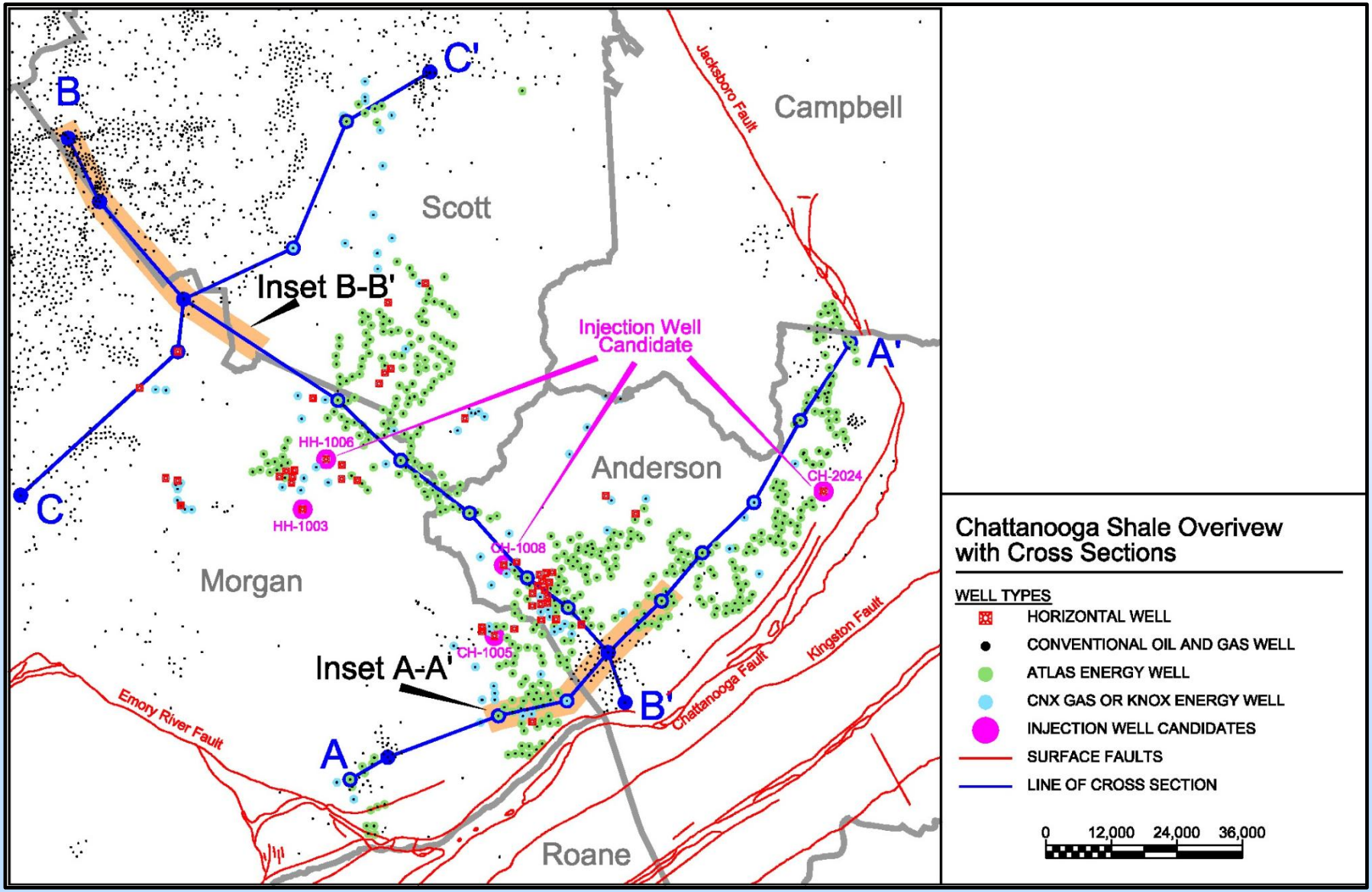
Chattanooga Shale Study Area

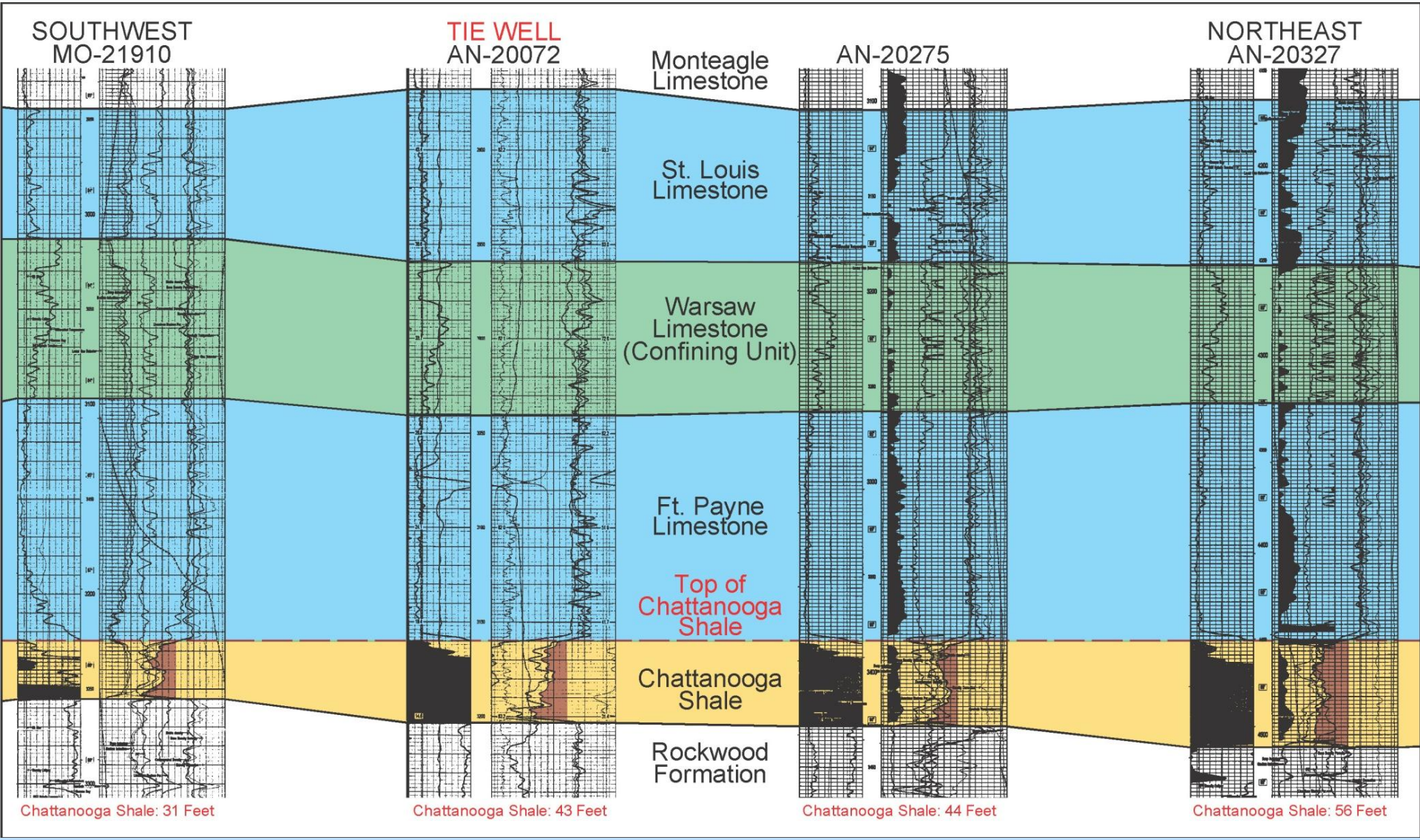


VirginiaTech
Invent the Future

Chattanooga Shale
Cross Section Location

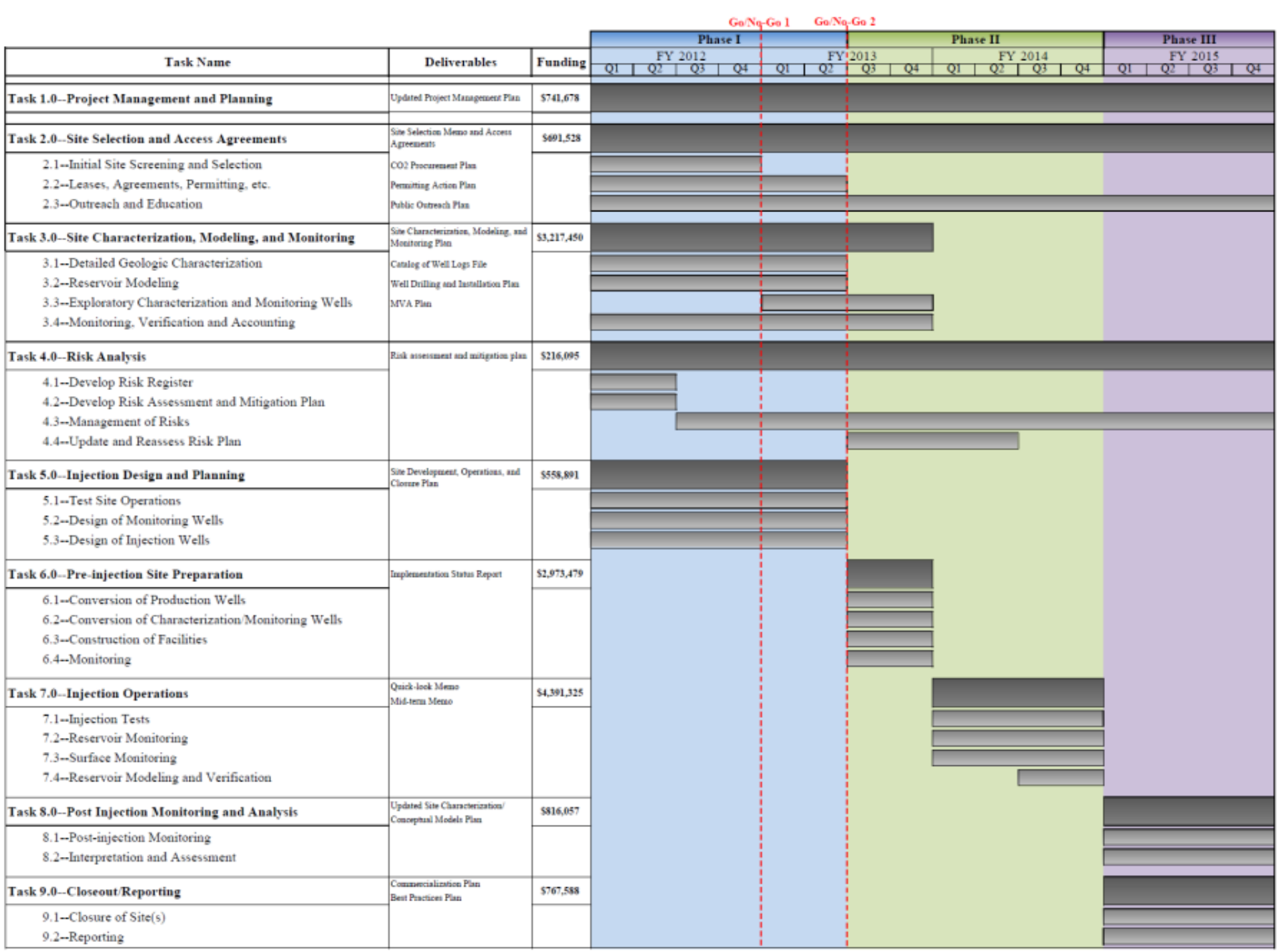


Cross Section A-A' Inset
Morgan & Anderson Counties, TN



Accomplishments to Date

- Completed Geologic Characterization for CBM Test Site
- Preliminary Geologic Characterization for Shale Test Site
- Site Selection of 3 CBM Wells for Injection
- Access Agreements for CBM Test completed
- Access Agreements for Shale Test under review
- Conducted Risk Workshop and developed Risk Register
- Performed preliminary reservoir modeling analysis and assessment
- Initiated Core Testing Program
- Initiated Public Outreach Plan



Task Name	Deliverables	Funding
Task 1.0--Project Management and Planning	Updated Project Management Plan	$741,678
Task 2.0--Site Selection and Access Agreements	Site Selection Memo and Access Agreements	$691,528
2.1--Initial Site Screening and Selection	CO_2 Procurement Plan	
2.2--Leases, Agreements, Permitting, etc.	Permitting Action Plan	
2.3--Outreach and Education	Public Outreach Plan	
Task 3.0--Site Characterization, Modeling, and Monitoring	Site Characterization, Modeling, and Monitoring Plan	$3,217,450
3.1--Detailed Geologic Characterization	Catalog of Well Logs File	
3.2--Reservoir Modeling	Well Drilling and Installation Plan	
3.3--Exploratory Characterization and Monitoring Wells	MVA Plan	
3.4--Monitoring, Verification and Accounting		
Task 4.0--Risk Analysis	Risk assessment and mitigation plan	$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	Site Development, Operations, and Closure Plan	$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	Implementation Status Report	$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	Quick-look Memo Mid-term Memo	$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	Updated Site Characterization/ Conceptual Models Plan	$816,057
8.1--Post-injection Monitoring		
8.2--Interpretation and Assessment		
Task 9.0--Closeout/Reporting	Commercialization Plan Best Practices Plan	$767,588
9.1--Closure of Site(s)		
9.2--Reporting		