

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

Project Number: DE-FE0006827

Nino Ripepi

Michael Karmis

Virginia Center for Coal and Energy Research at
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

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**

★ **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 MM&A
- 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, LLC
- Emory River, LLC
- Dominion Energy
- Alpha Natural Resources
- Flo-CO2

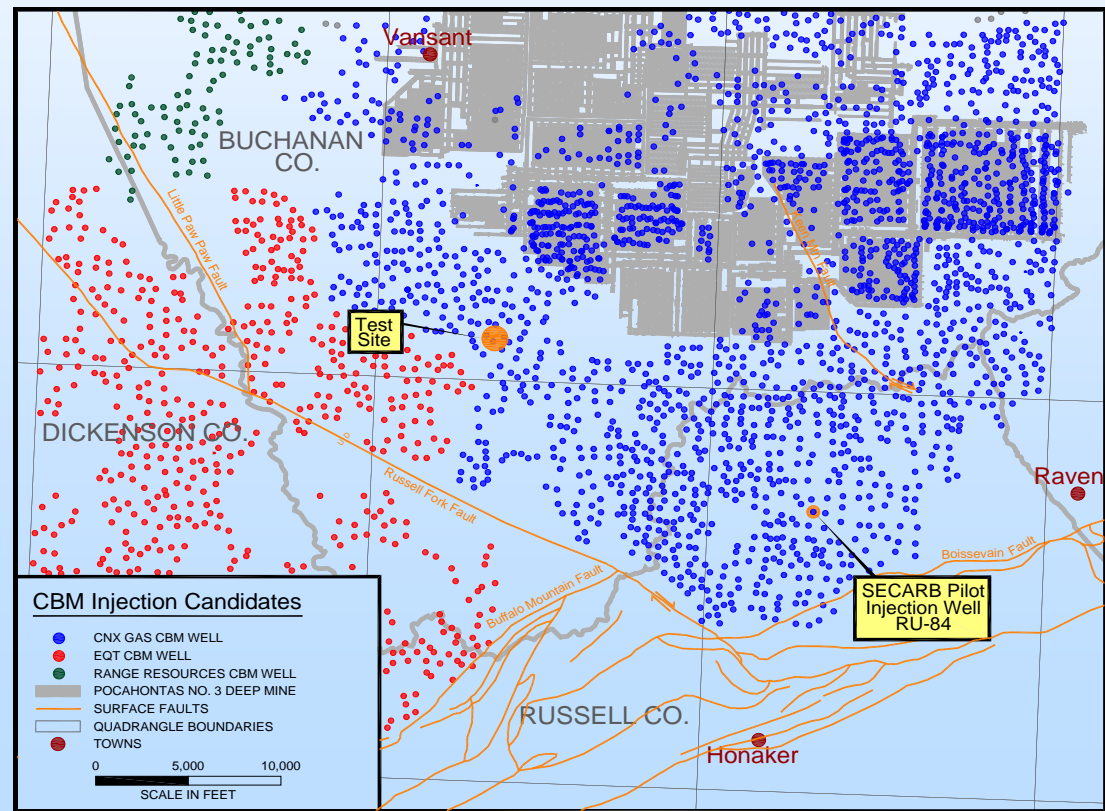
Collaborators

- Schlumberger
- Oak Ridge National Laboratory
- University of Tennessee
- University of Virginia

Pocahontas CBM Project

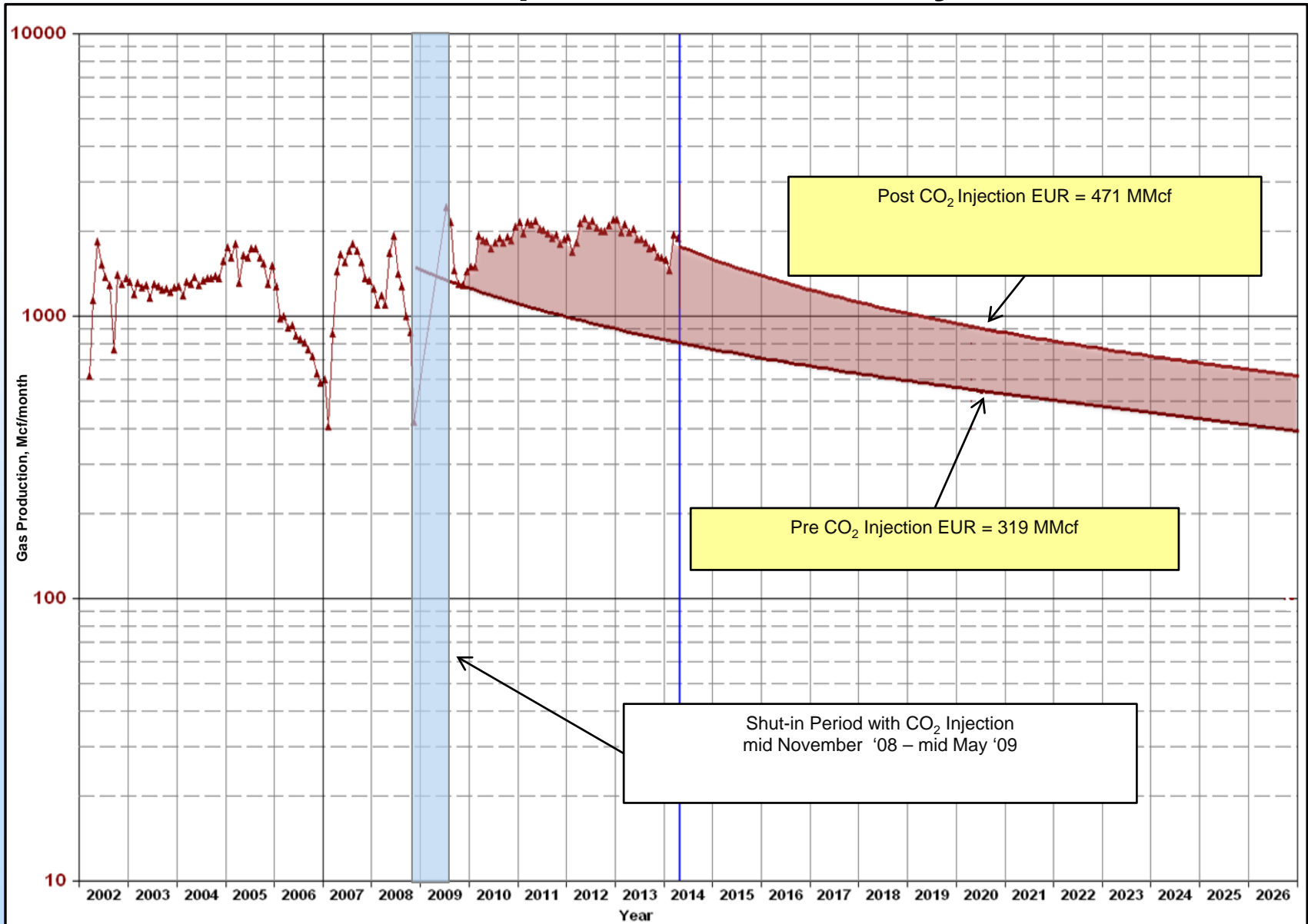
Buchanan County, VA (20,000 tons)

- Selected Three Wells for Injection: September, 2012
- Access Agreements: Jan. 2013
- Class II UIC Permit: Dec. 2013
- Drilling Permits Received
- CO₂ and Microseismic RFPs: July 2014
- Drilling Monitoring Wells: July 2014
- Desorbing Coals
 - Gas Content, Quality, Isotopes
- CO₂ Injection: October. 2014 – Sept. 2015
- Post-Injection Monitoring: Sept. 2016



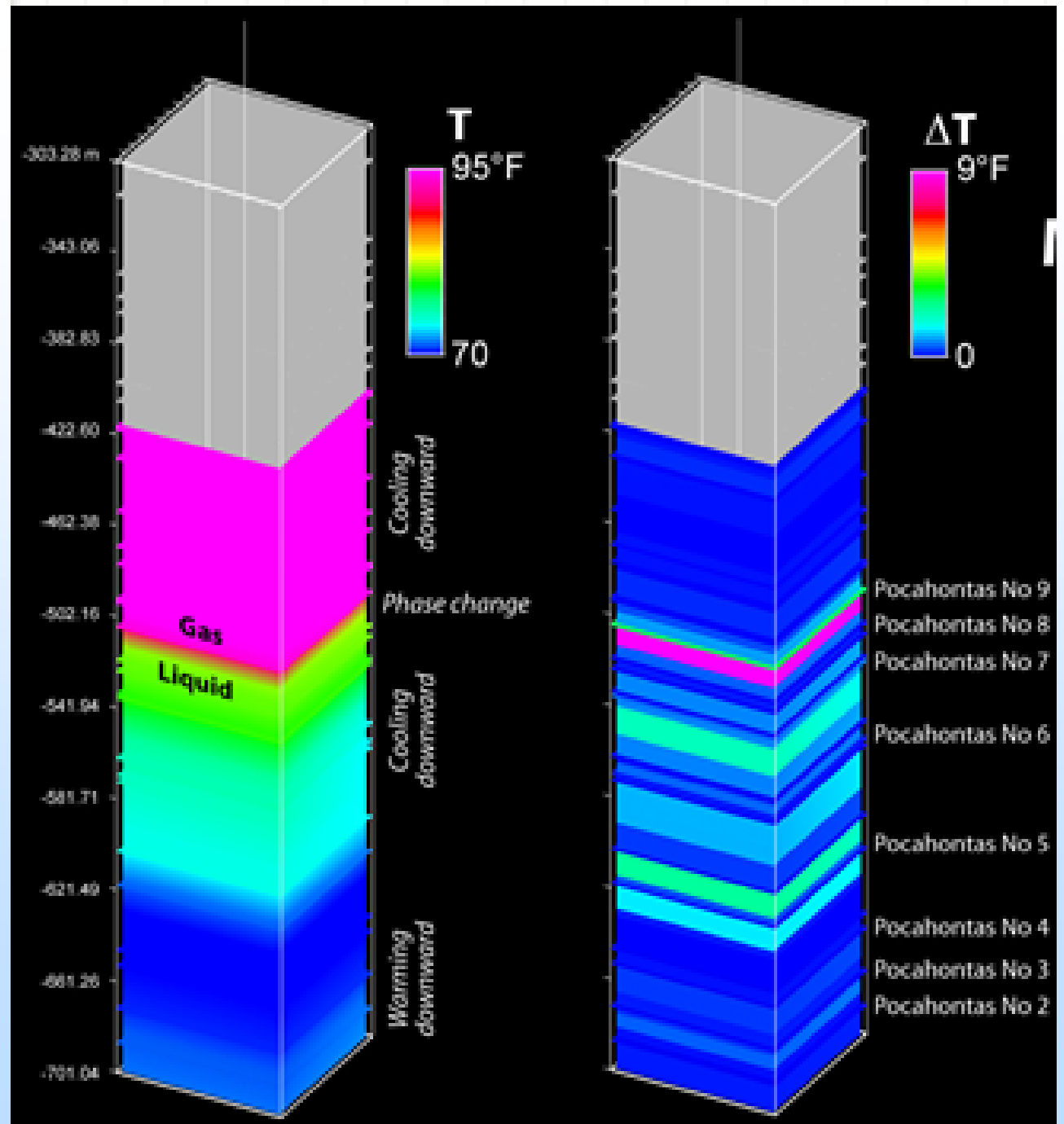
1,000 Ton ECBM Huff-n-Puff in VA

25% CO₂ produced in 5 years

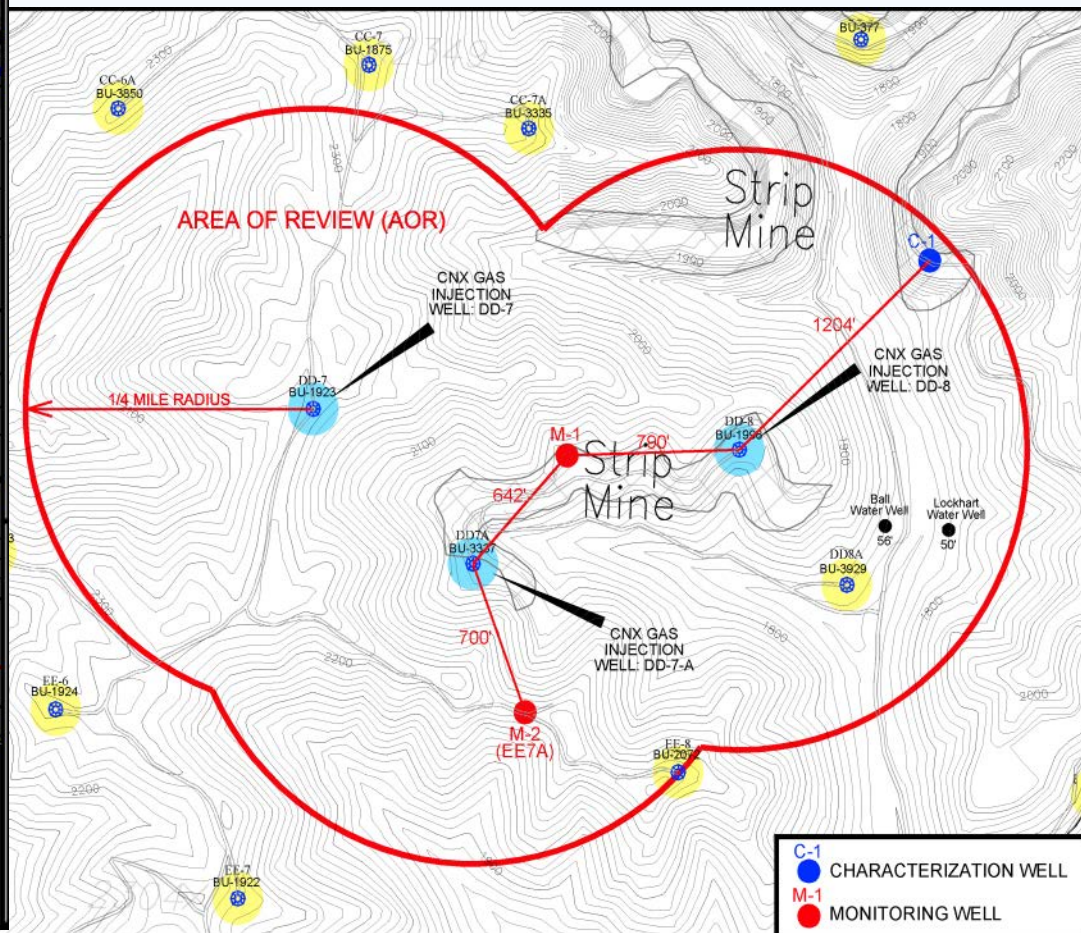
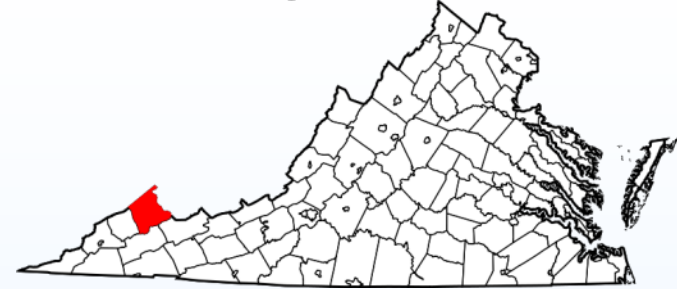
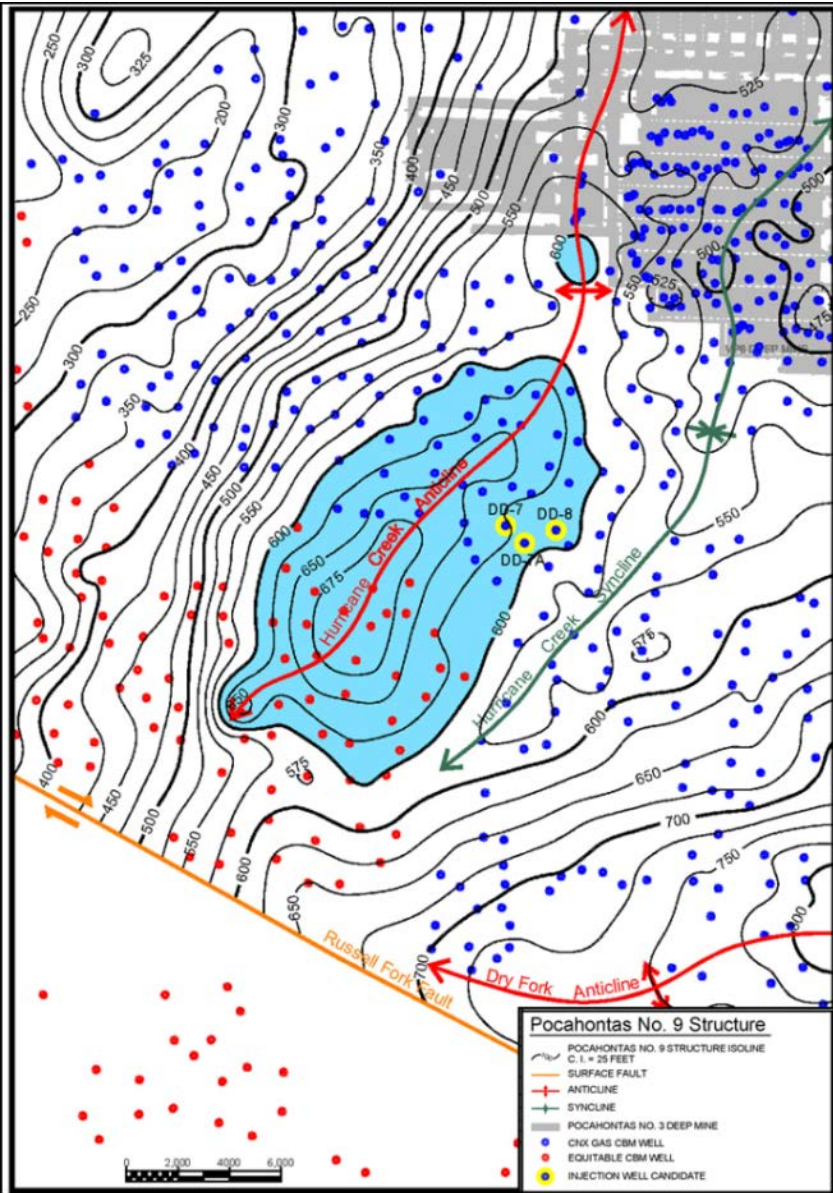


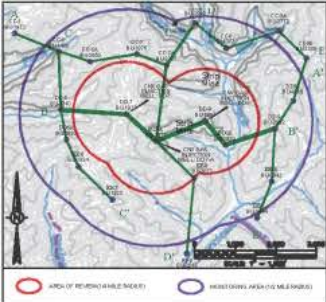
Injection Logging from Russell County

- Spinner
- Temperature
- Pressure



Buchanan County, VA – CBM Test





B-B'

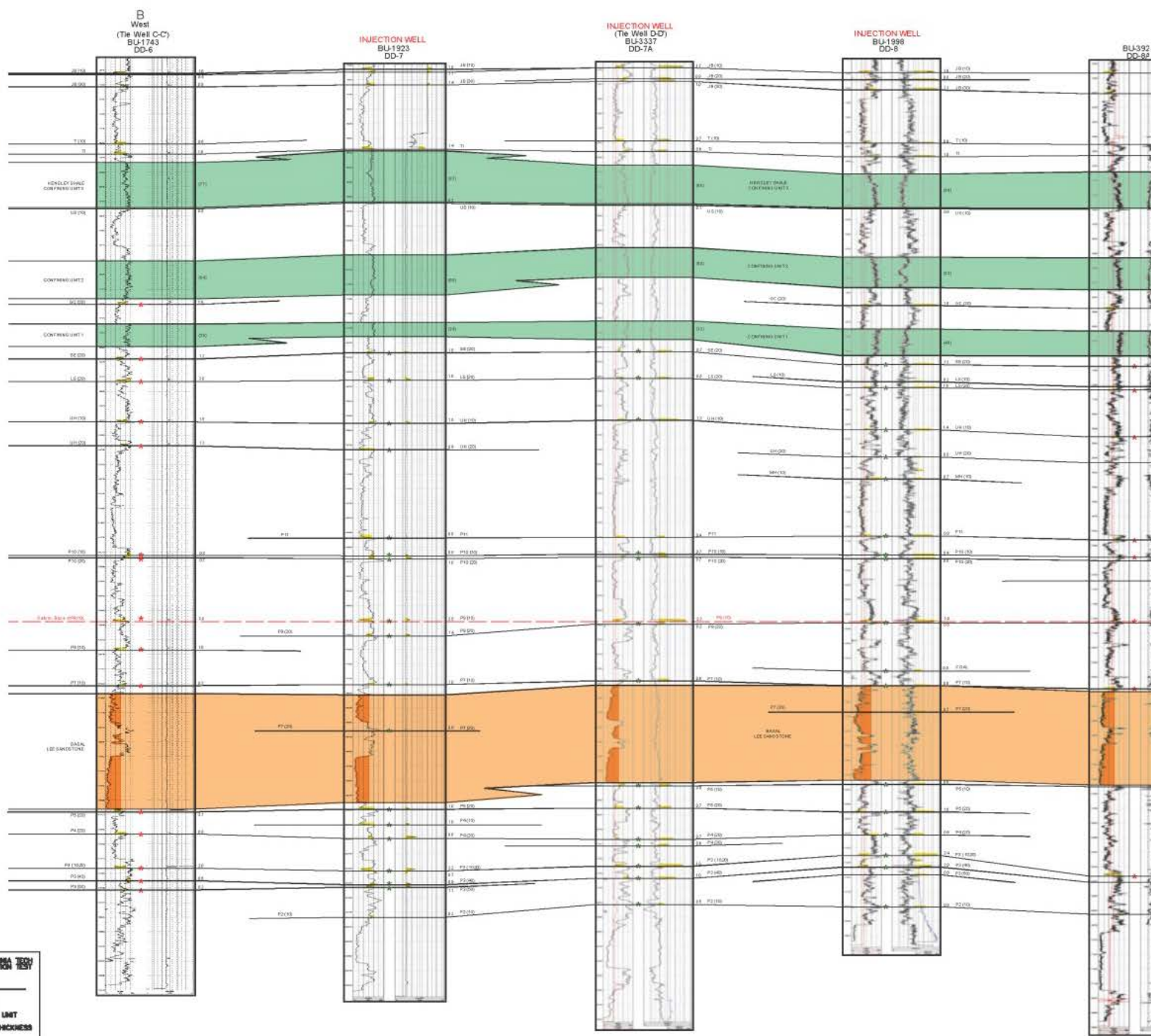


EXHIBIT 2 **SMALL SCALE CO₂ INJECTION TEST** **VIRGINIA TECH**

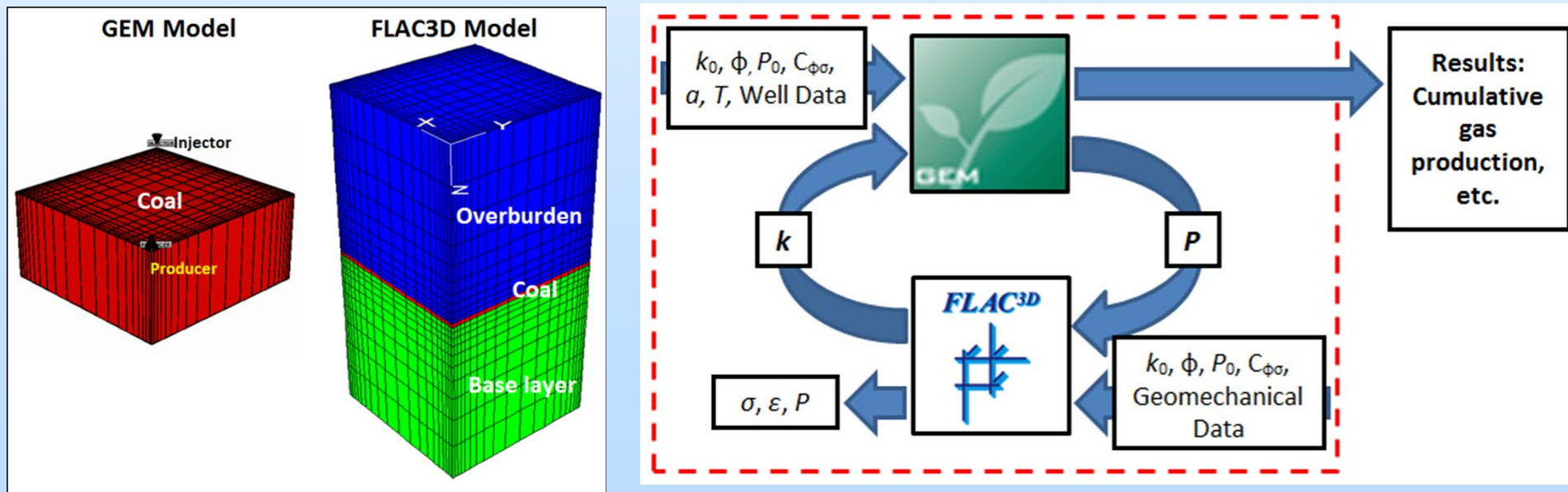
Injection Well Cross Section B - B'

VERTICAL SCALE: 1" = 50'
 HORIZONTAL SCALE: NOT TO SCALE
 DATUM: BASE OF P8 (10)
 * COMPLETED COAL SEAM
 * INJECTION ZONE

QUARTZ SANDSTONE
 SHALE CONFINING UNIT
 CONFINING UNIT THICKNESS (FEET)

Overview of Reservoir Modeling

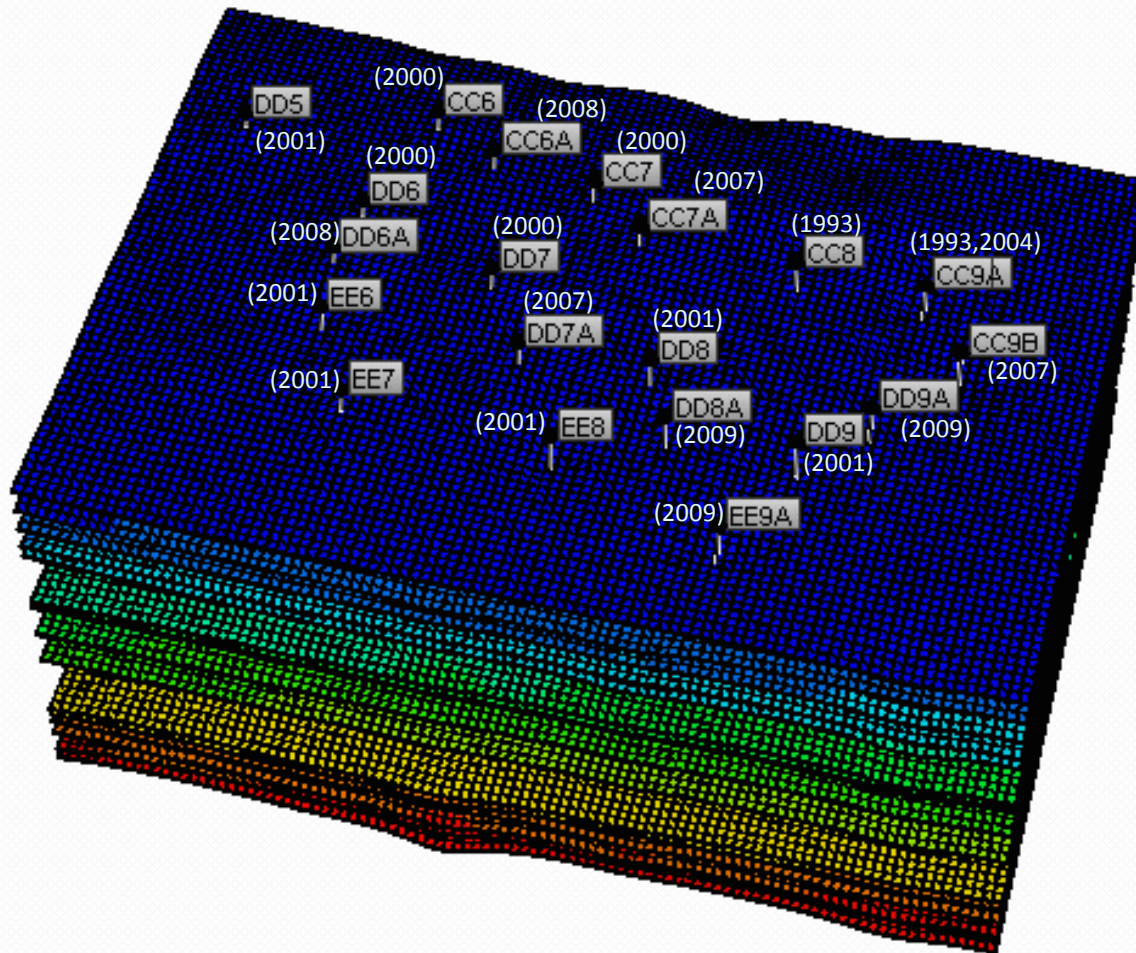
- Preliminary Reservoir Modeling – Single Zone
 - ARI's COMET3
- Detailed Reservoir Modeling
 - Computer Modeling Group's GEM Program – By Zone (5) and By Seam (15-20 seams)
 - Schlumberger's Eclipse – By Seam (15-20 seams)
- Coupling GEM with FLAC3D for Geomechanical Modeling



21 Well Buchanan County Modeling Area

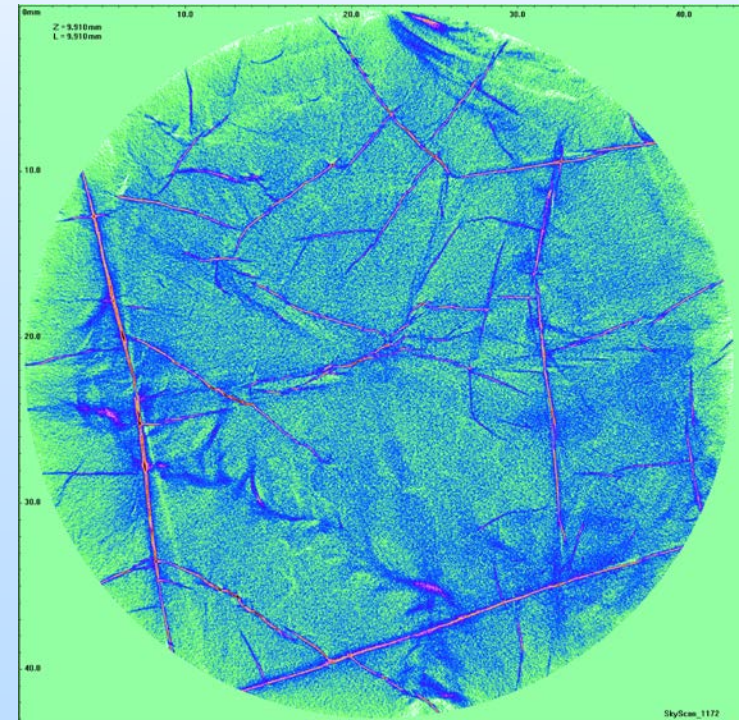
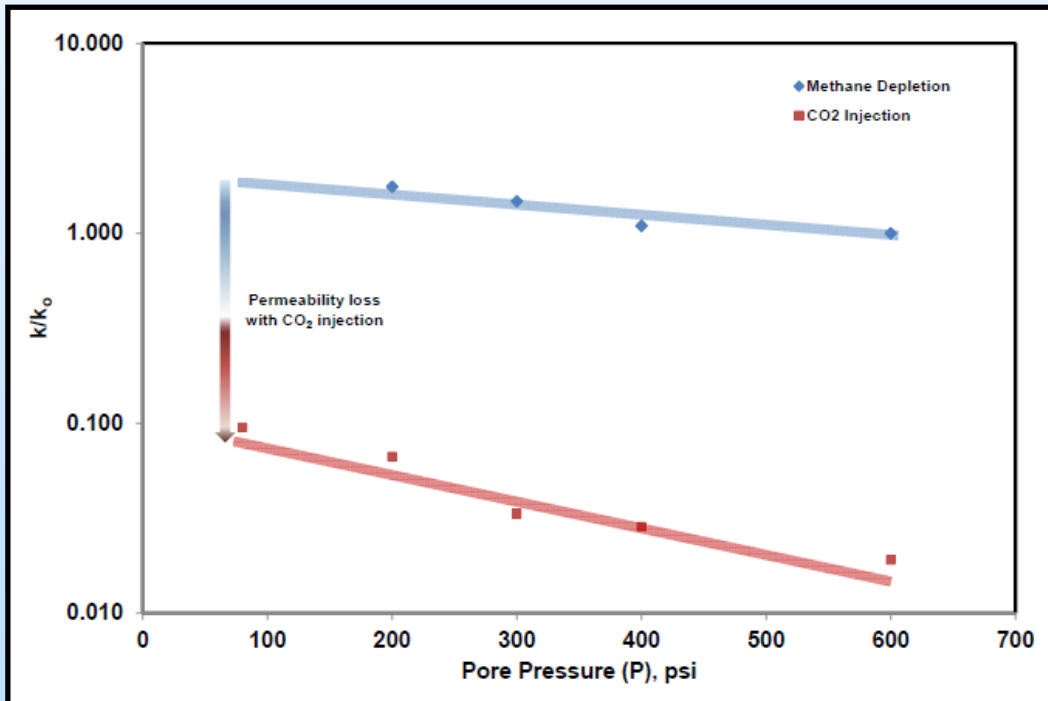
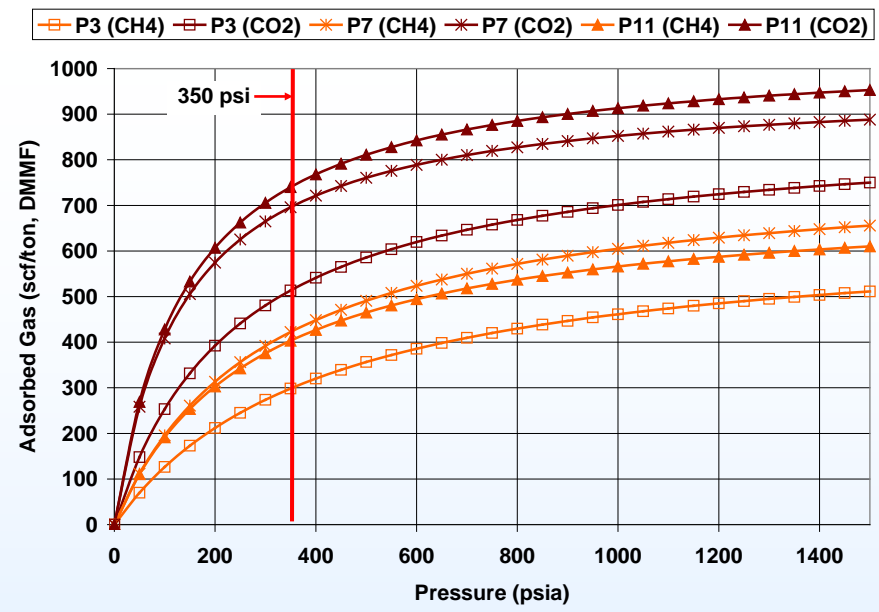
Production Start Date: 1993-2009 Year

Study Area	
Drainage Area (Acres)	1552
Surface Elevations (ft)	1,685-2,364
Top Seams Elevations (ft)	29-1,201
Thicknesses (ft)	0.01-4.20



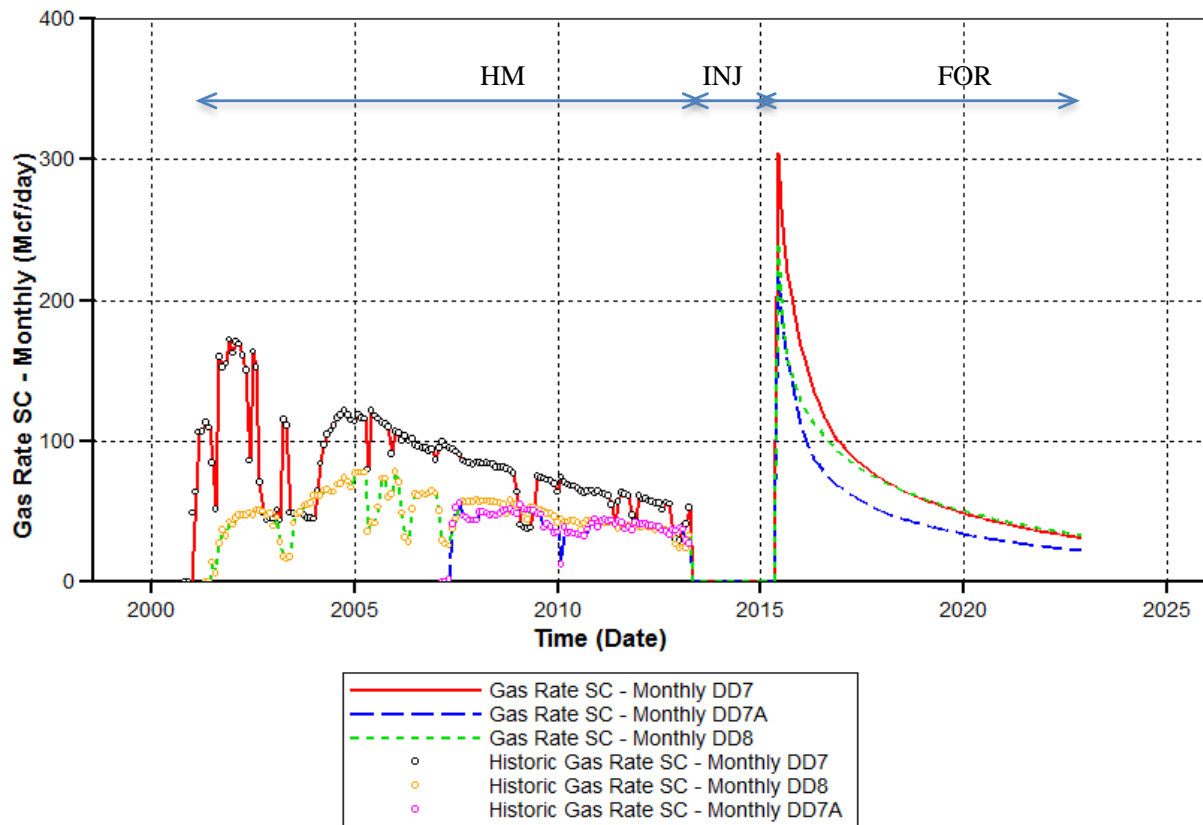
Modeling Inputs:

Isotherms, Gas Content, Permeability, Cleats, Fracture development are all variable by seam, depth and/or structural location



Buchanan County Modeling Scenarios

History Match, Injection Period and Forecast for Wells DD7, DD7A, DD8

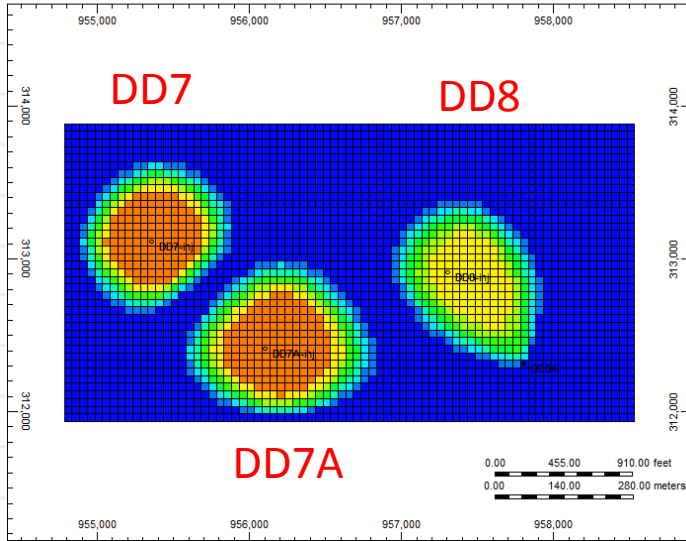


Injection	
Start Date	1 st May, 2013
End Date	1 st May, 2014
CO ₂ Injection Rate per Well	18.26 tons/day
Shut In Period Post Injection	1 Year
Forecast Year	2023

Scenarios (S) Models	
S1	Perforations, No Well Stimulation
S2	Negative Skin Factor, -4
S3	Hydraulic Fractures, 40% per Stage, Thickest Seams, 350 ft half-length

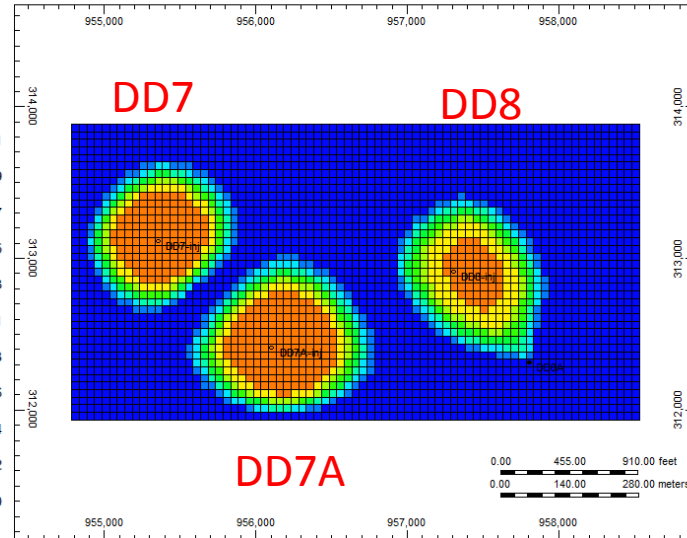
Buchanan County Modeling Scenario Results

Adsorption(CO2) (gmole/ft3) 2015-04-01 K layer: 4



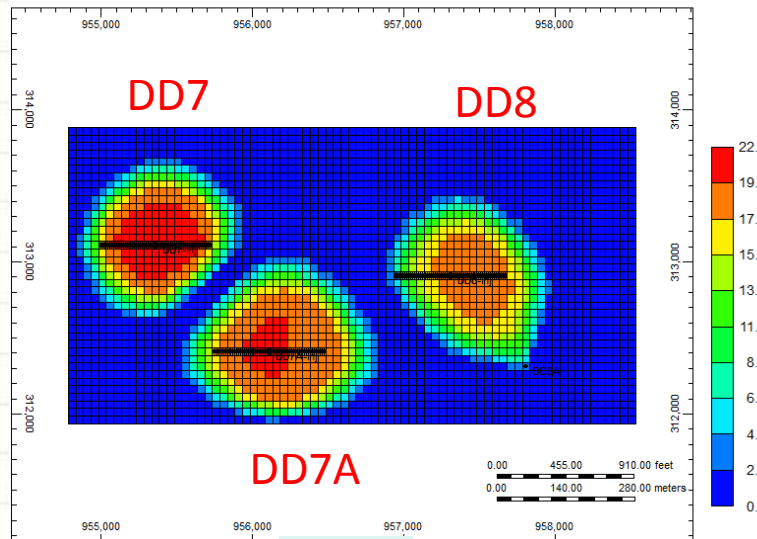
S1

Adsorption(CO2) (gmole/ft3) 2015-04-01 K layer: 4



S2

Adsorption(CO2) (gmole/ft3) 2015-04-01 K layer: 4

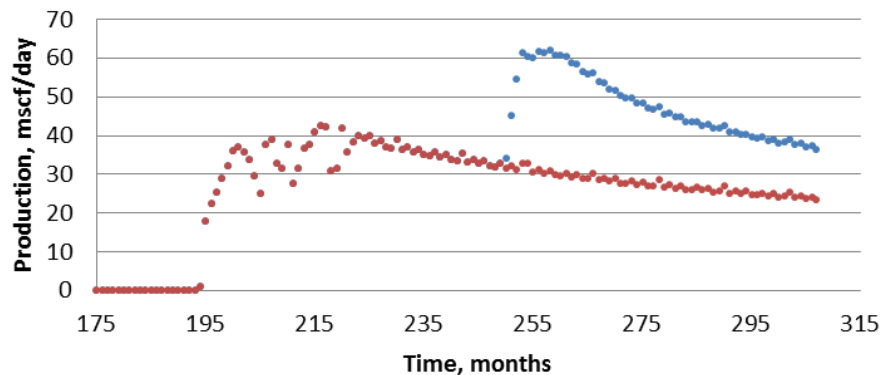


S3

CO₂ Adsorption
(gmole/ft³)
Date: 04/01/2015
Layer 4

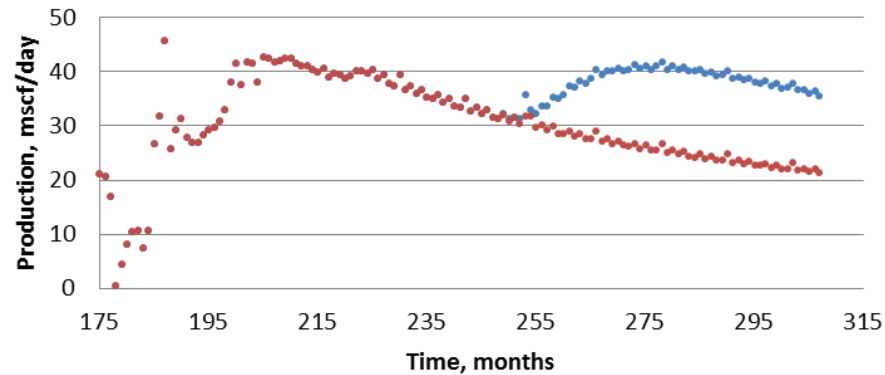
ECBM after 1 and 4 Years Post-Injection: 22 – 106 MMcf

DD8A



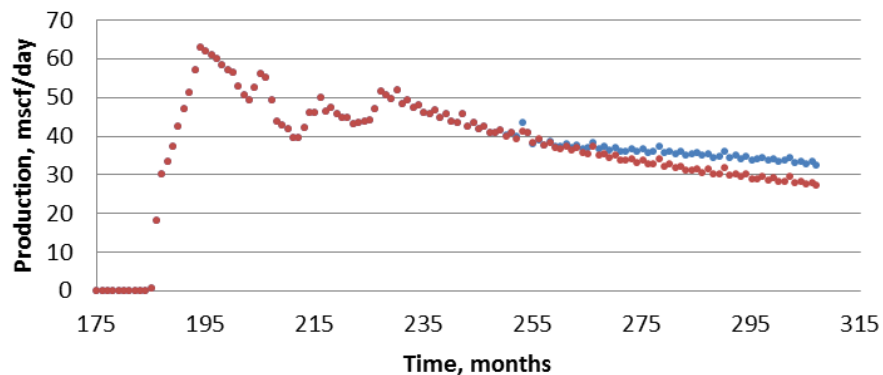
• With CO2 Injection • Without CO2 Injection

CC7A



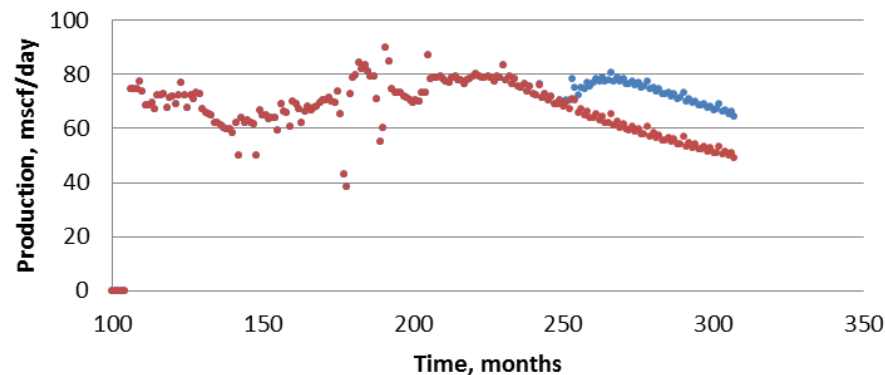
• With CO2 Injection • Without CO2 Injection

CC6A



• With CO2 Injection • Without CO2 Injection

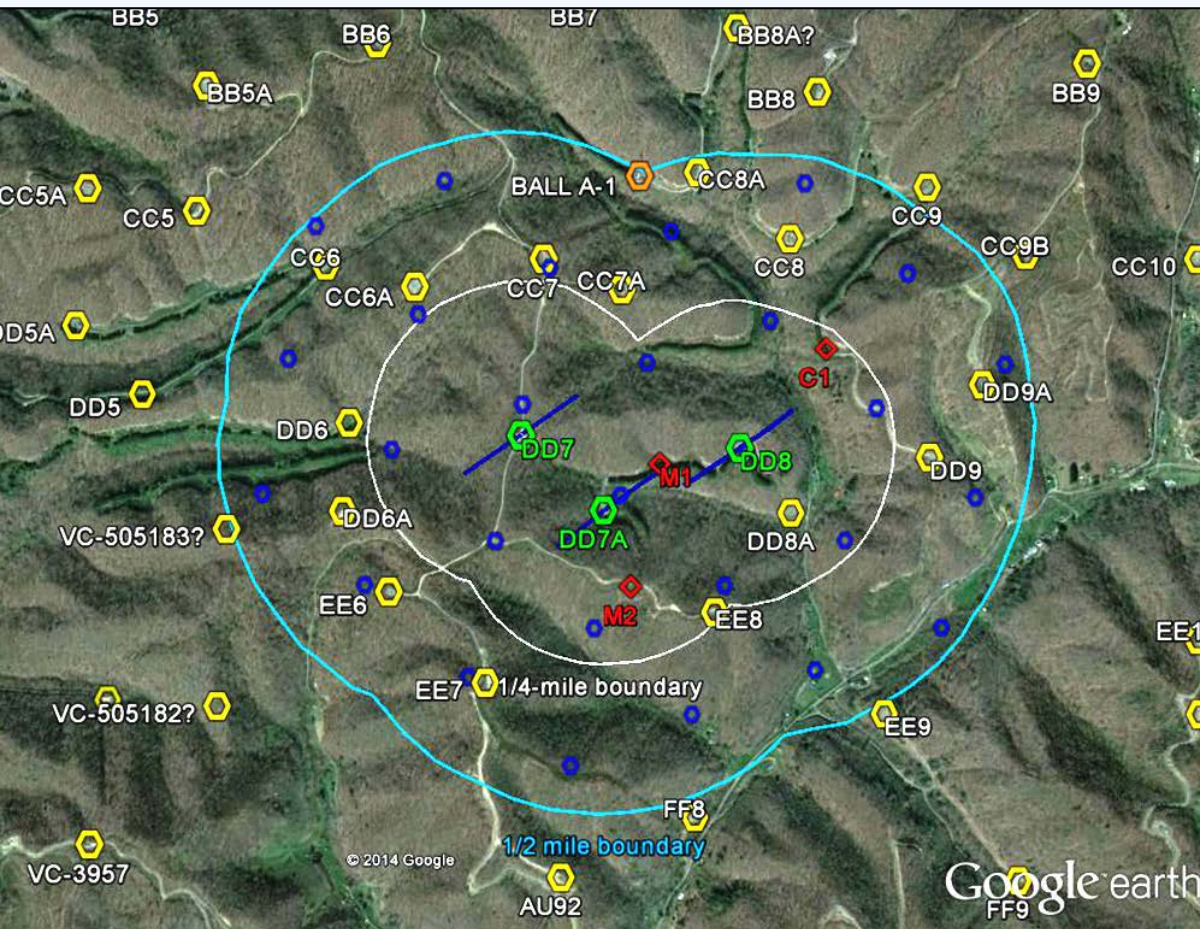
EE8



• With CO2 Injection • Without CO2 Injection

MVA program for CBM 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)

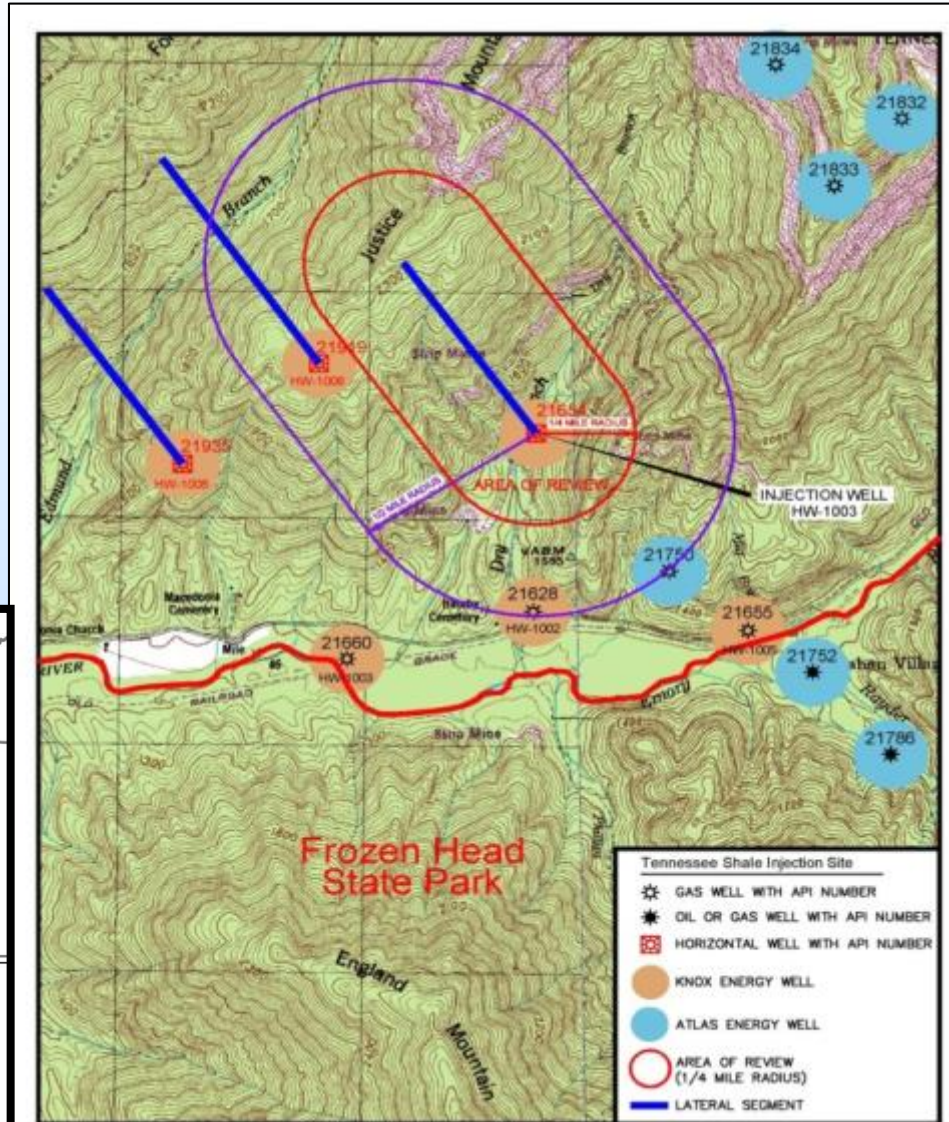
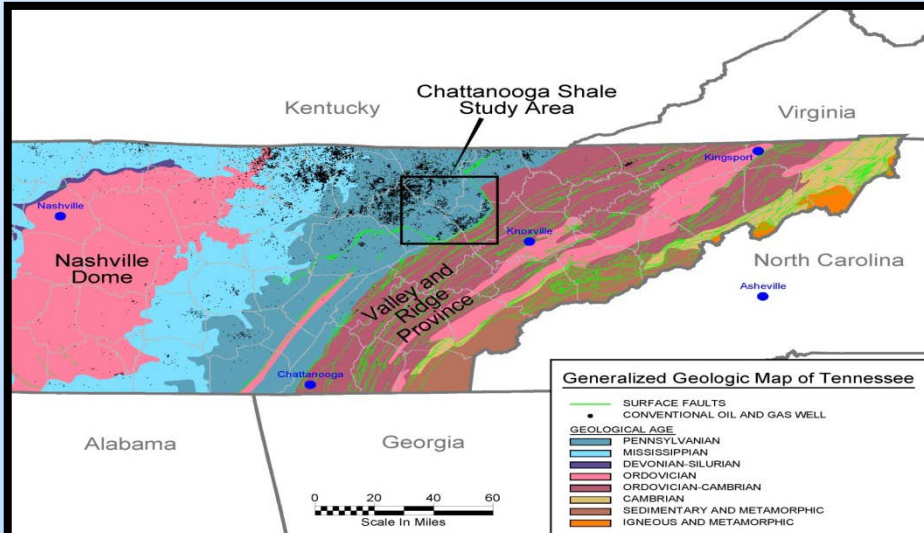
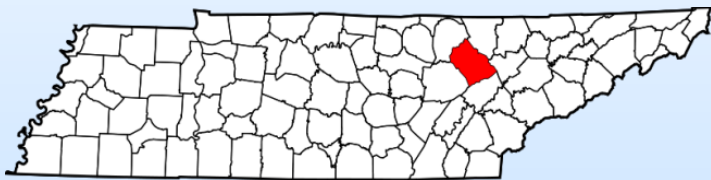


- Multiple tracer injection
- CO₂ and CH₄ Isotopic Analysis
- 3 monitoring wells by zone
- Surface deformation measurement
 - InSar and GPS
- Microseismic Monitoring
 - Passive measurement of seismic energy emissions

Emory River Project: "Huff and Puff"

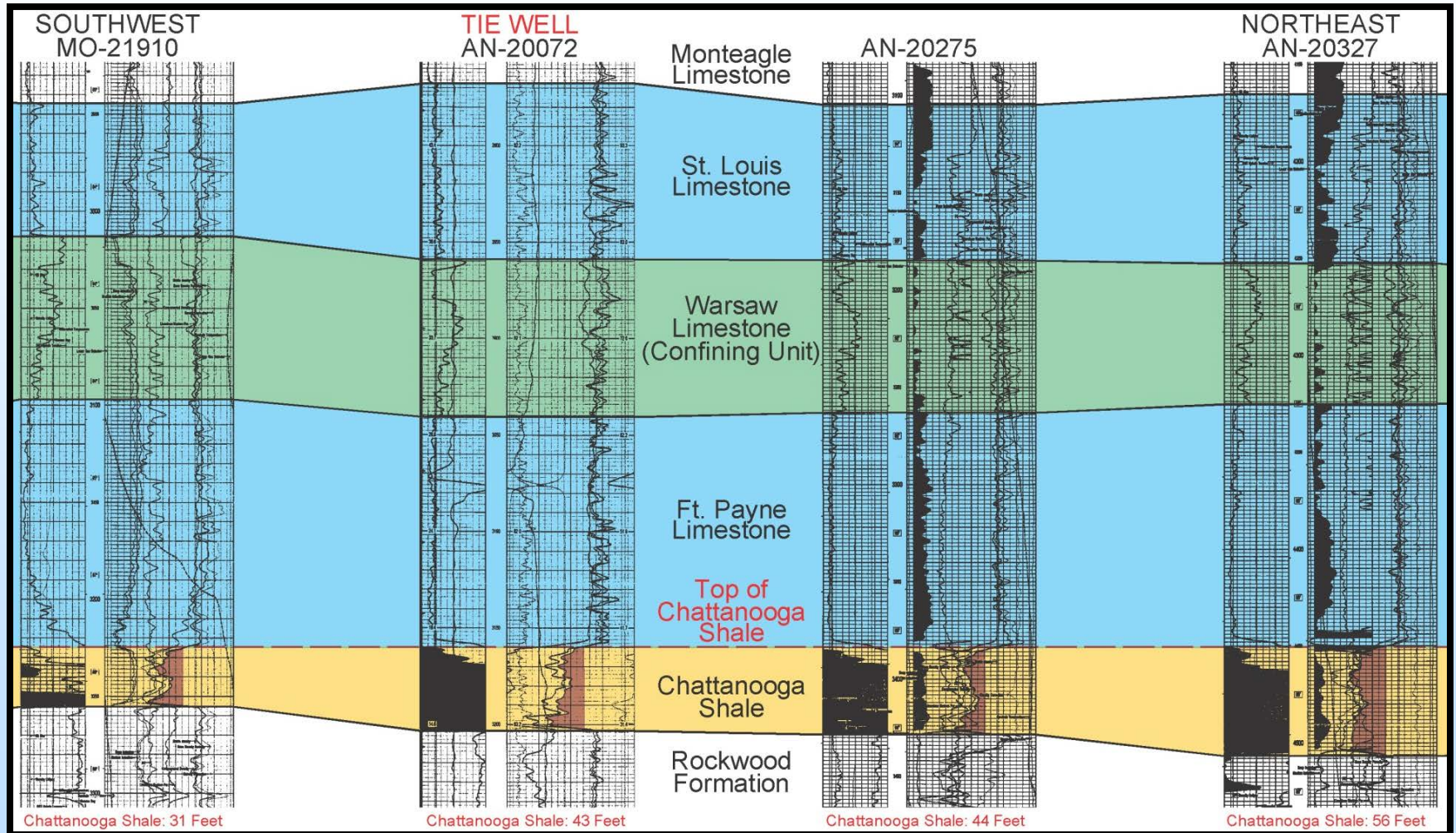
Horizontal Shale Gas Well in Morgan County, TN

- ❑ Well Stimulation Permit from TDEC
- ❑ Vendor Selected for injection (FloCO₂)
- ❑ Risk Management Registry: Completed
- ❑ Injection Well Conversion: Mar. 2014
- ❑ CO₂ Injection: Mar. 19-31, 2014
- ❑ Return to Production: July 29, 2014
- ❑ Post-Injection Monitoring: Mar. 2015

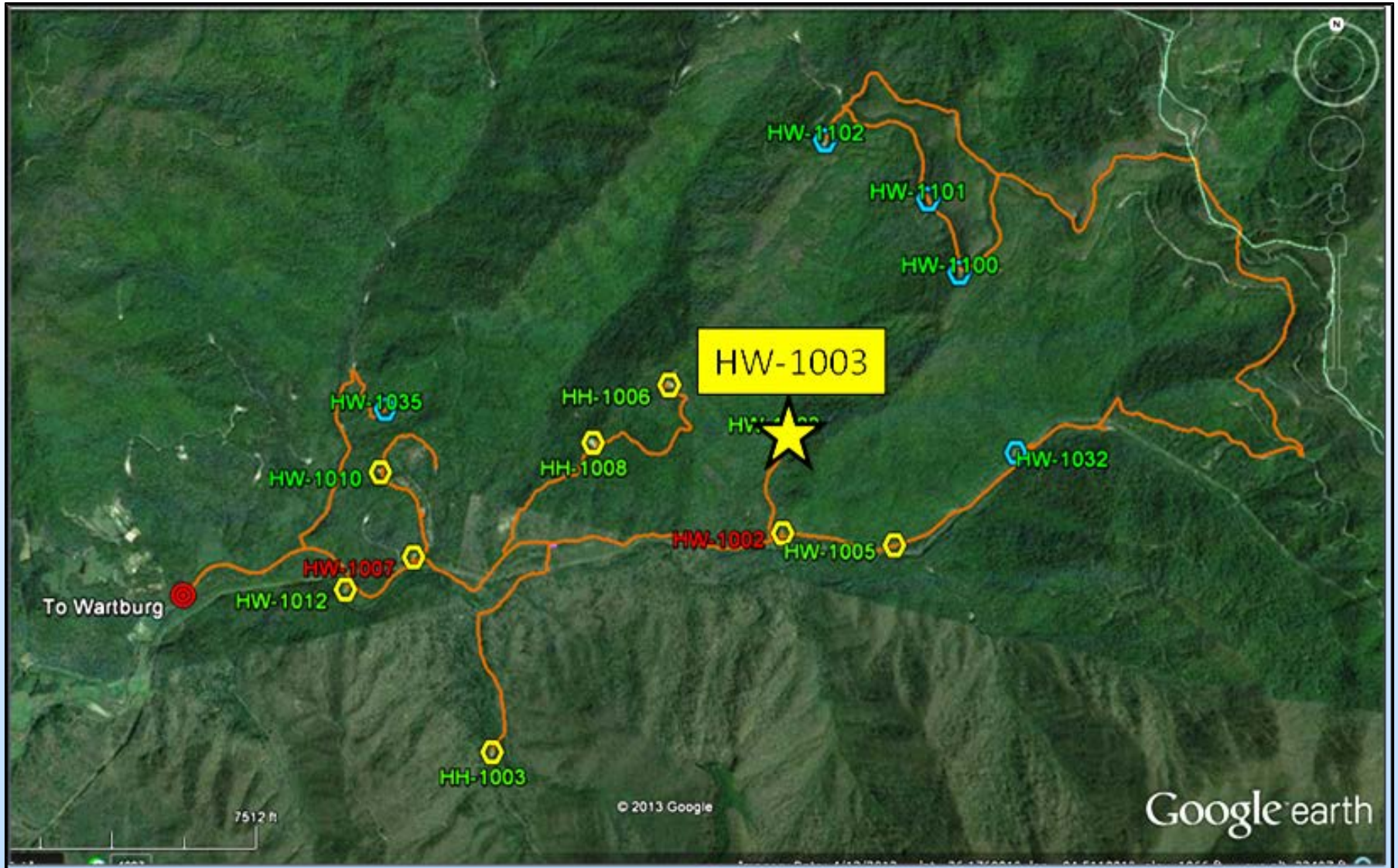


Chattanooga Shale Cross-Section

30-50 feet thick, 2500-4000 feet deep

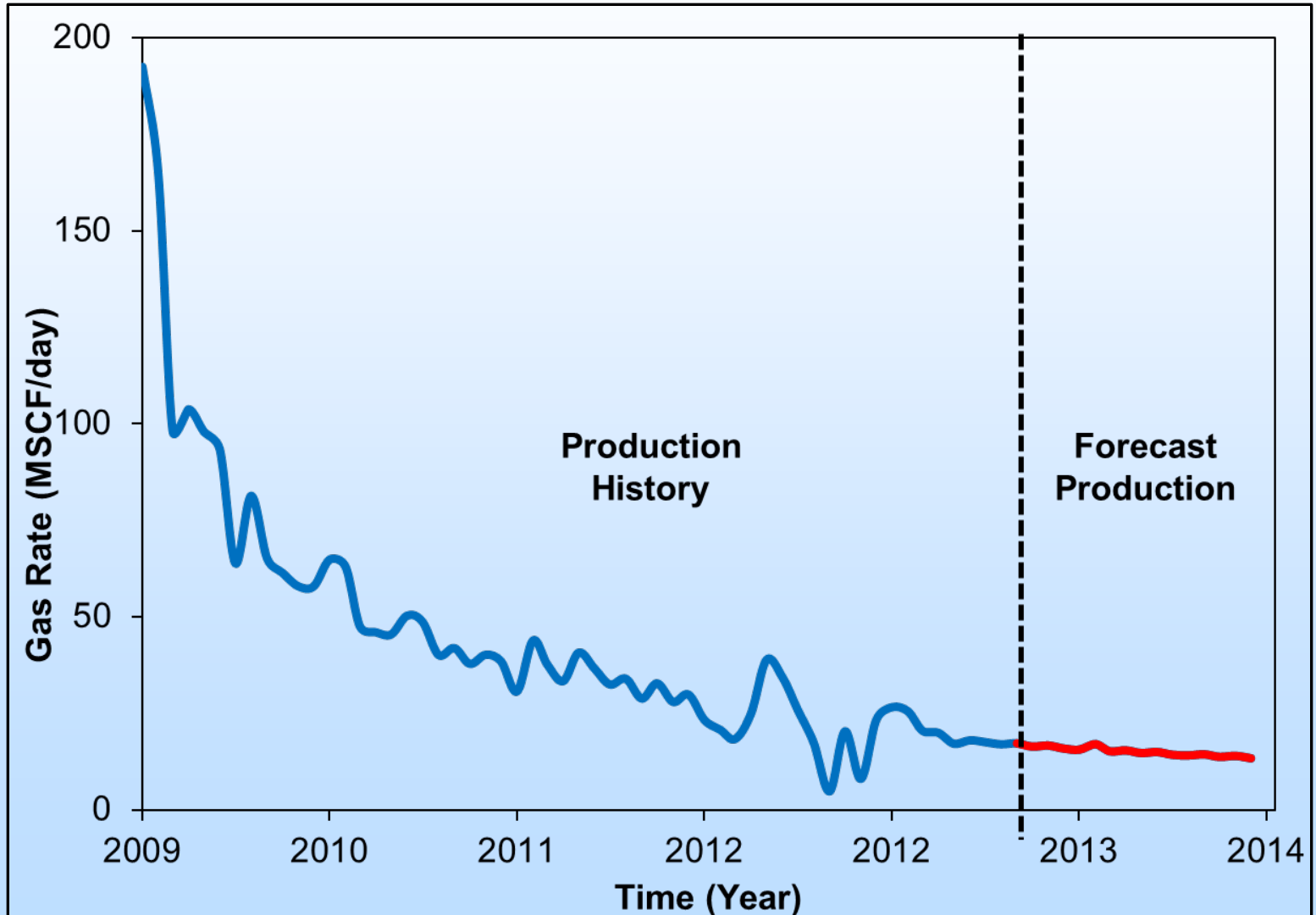


Injection Well (HW-1003) and Off-set Monitoring Wells

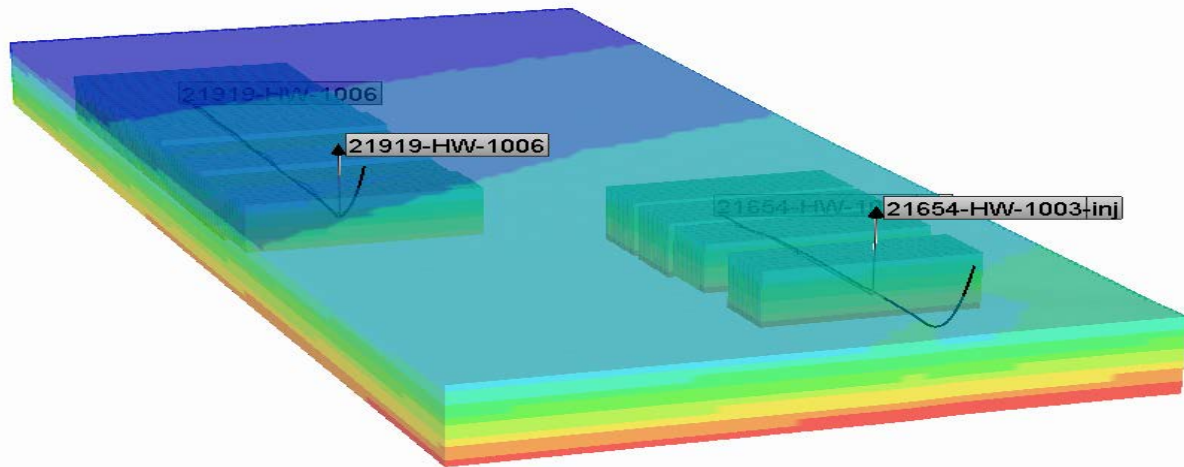


Production History

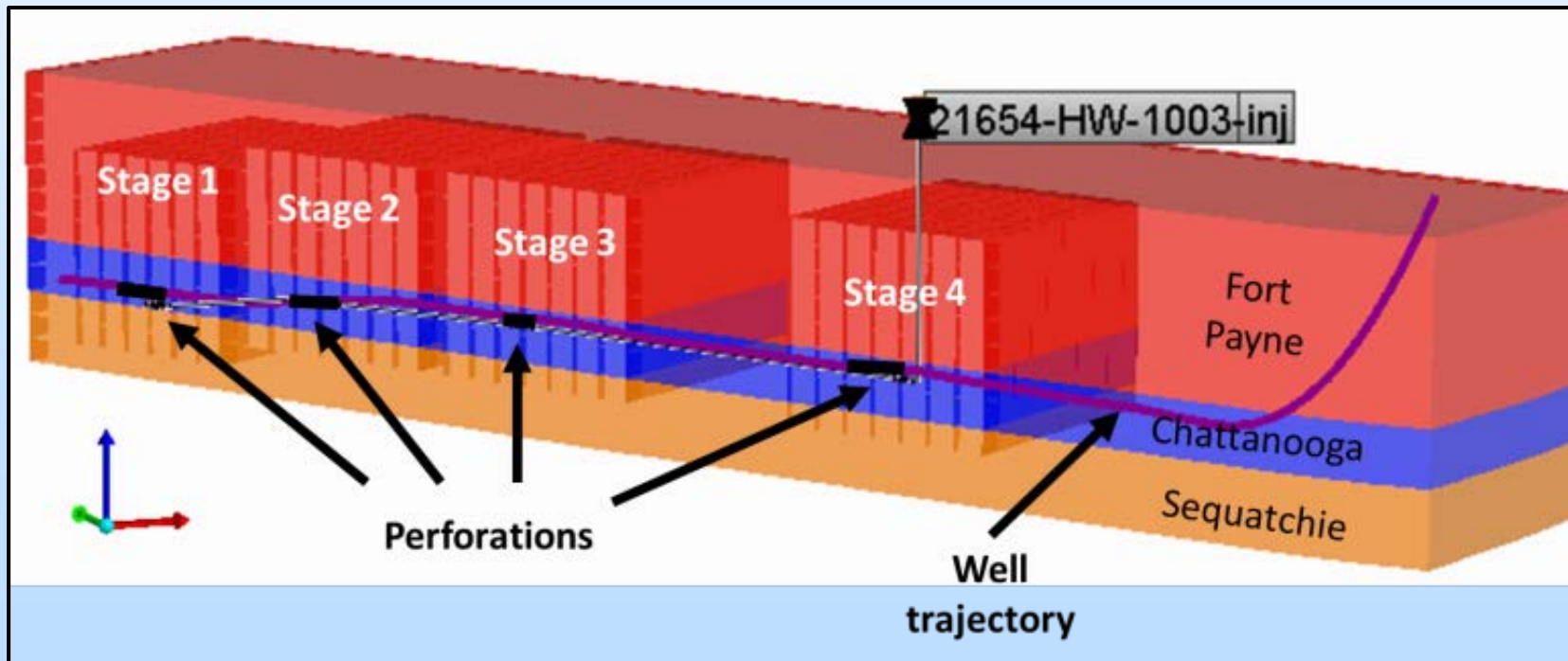
HW 1003 Injection Well



Reservoir Modeling

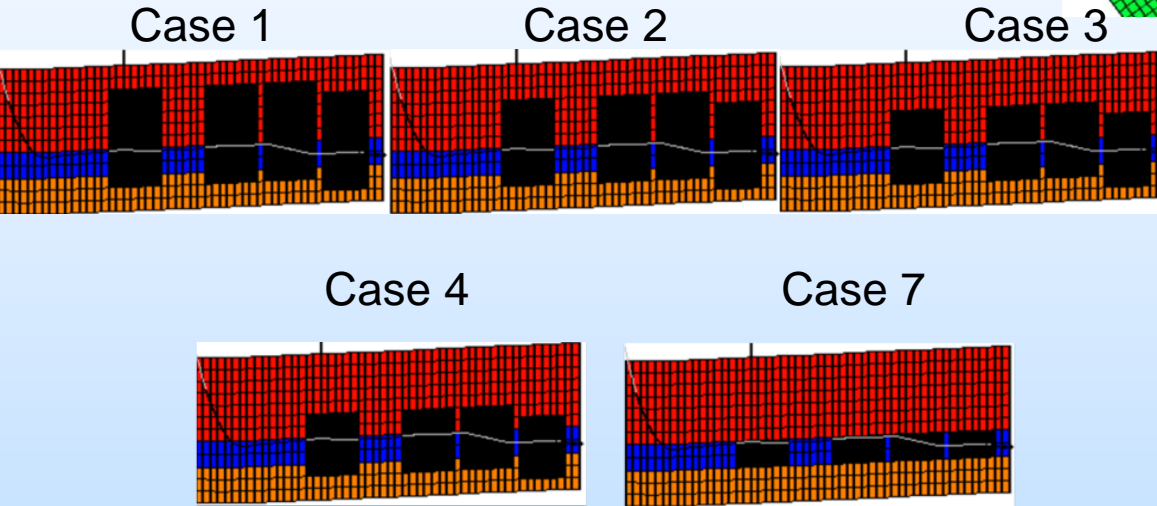
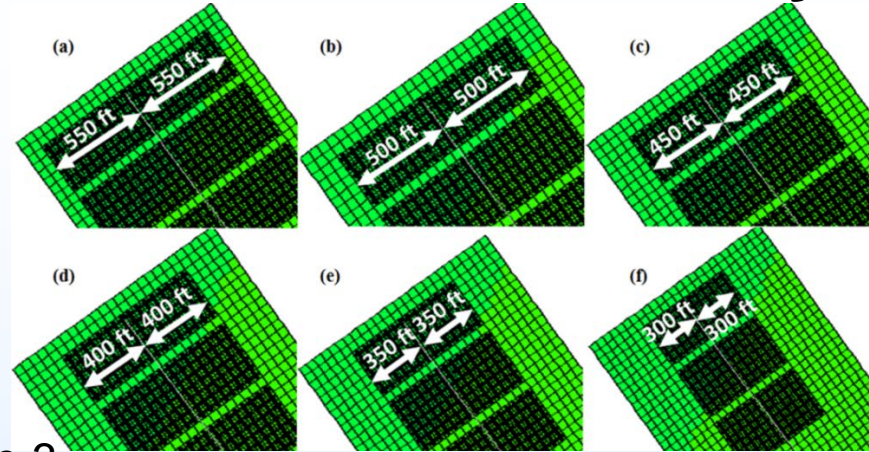


- Computer Modeling Group Ltd.'s GEM software
 - A dual porosity-dual permeability model with porosity & permeability defined in both matrices and fractures

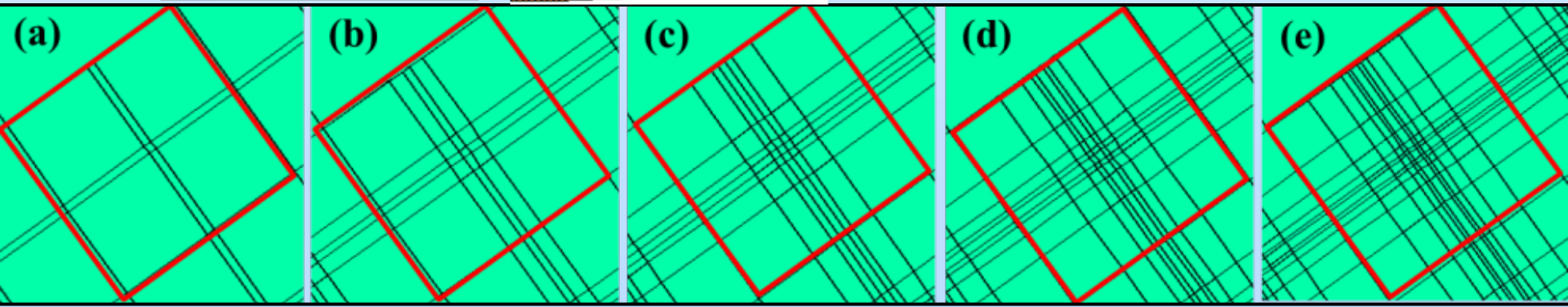


Sensitivity Analysis to Match Production History

- Utilization of Microseismic
- Half-length of HF
- Vertical-height of HF



- Grid Refinement in SRV

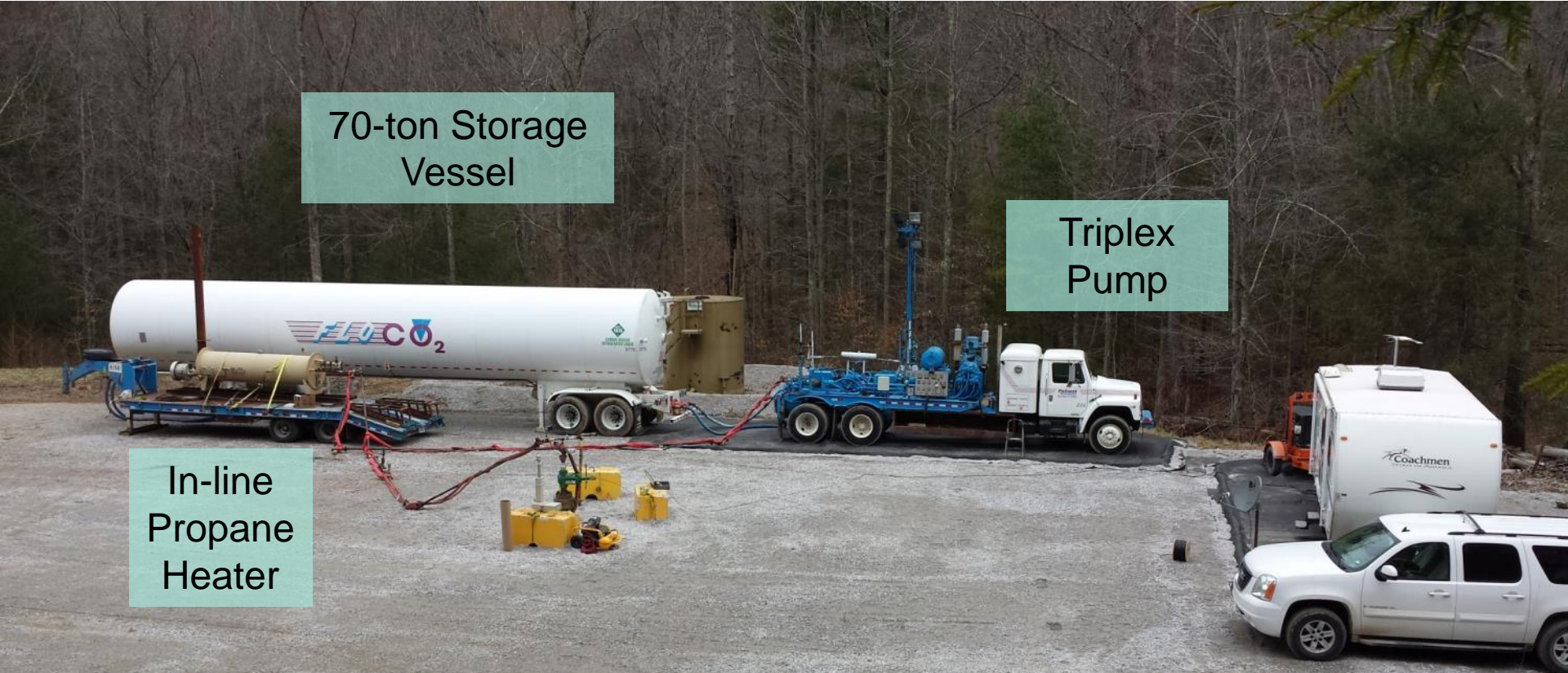


Site Layout

70-ton Storage Vessel

Triplex Pump

In-line Propane Heater



Injection Commenced



Injection Commenced on March 19, 2014 at 9:00 AM with a heated slug of 15-tons of CO₂

Tracer injection:

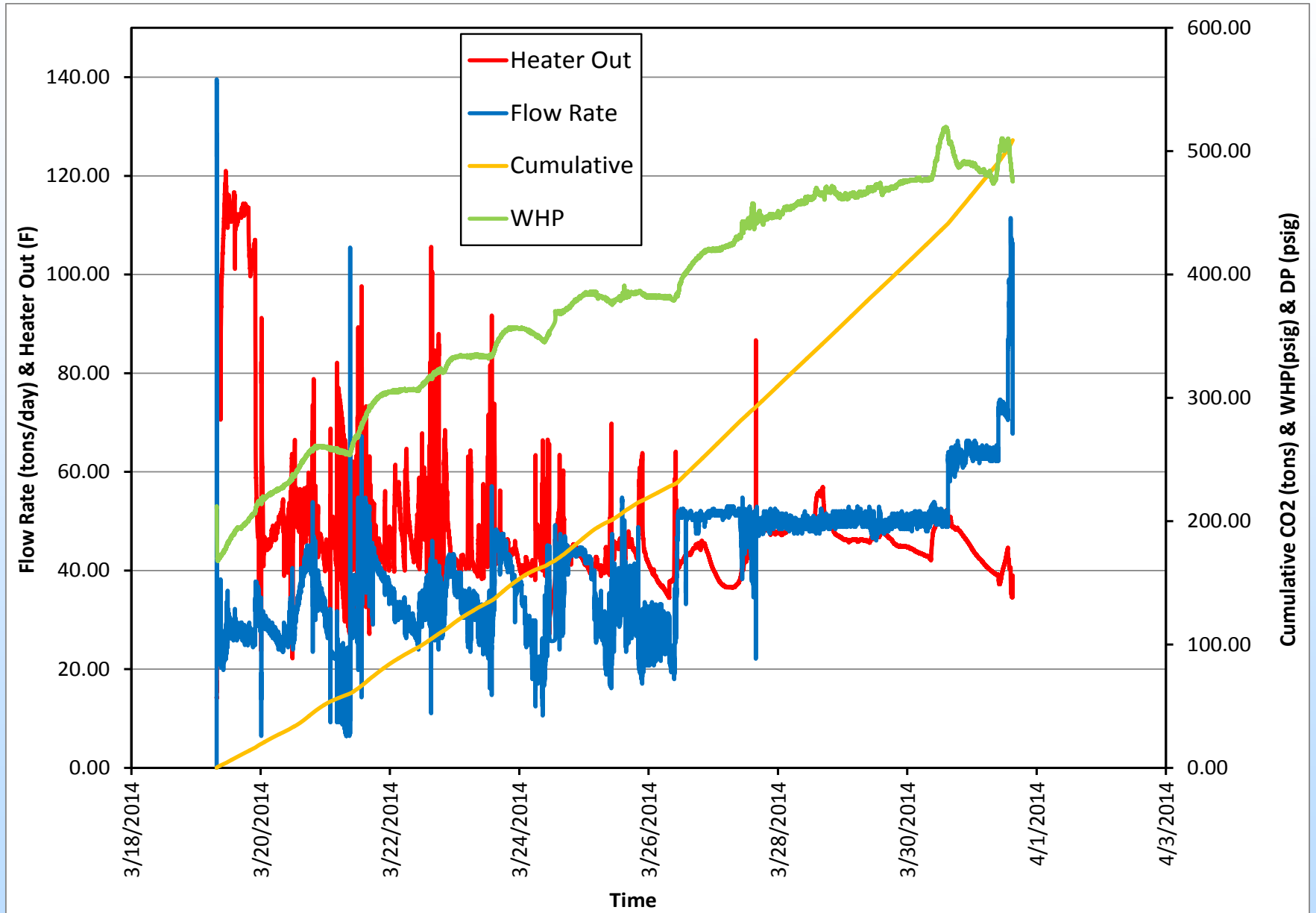
- **Perfluoromethylcyclopentane (PMCP)**
500 mL over 8 hrs on March 20 at 30 tons
- **Sulfur Hexafluoride (SF6)**
5.84 kg slug on March 20 at 30 tons
- **Perfluoromethylcyclohexane (PMCH)**
500 mL over 6 hrs on March 28 at 330 tons



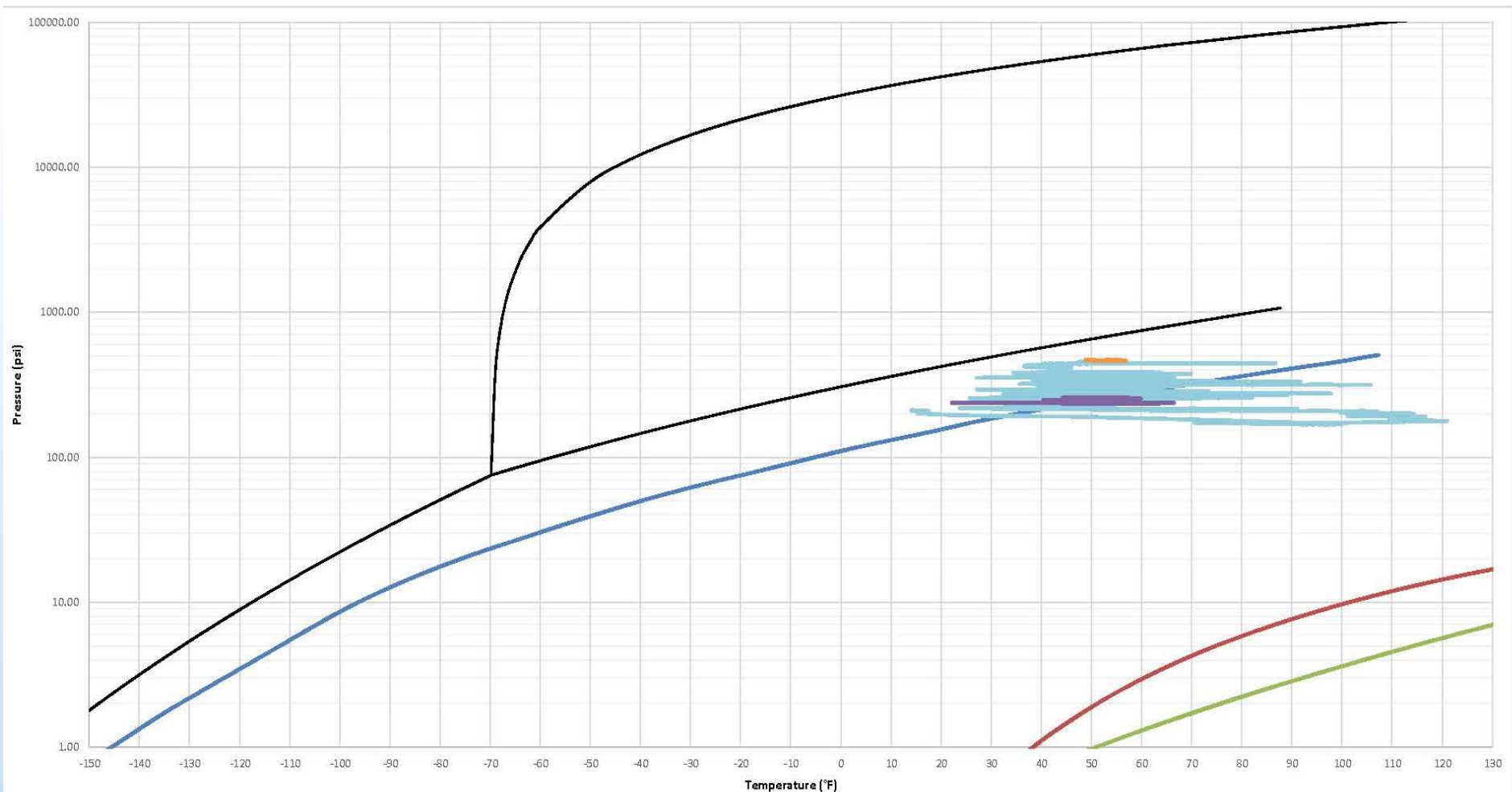
Monitoring Activities



Injection Data



CO2 – gas; SF6 - gas/liquid; PFTs - liquid



— CO2 Phase

— SF6 Phase

— PMCP Phase

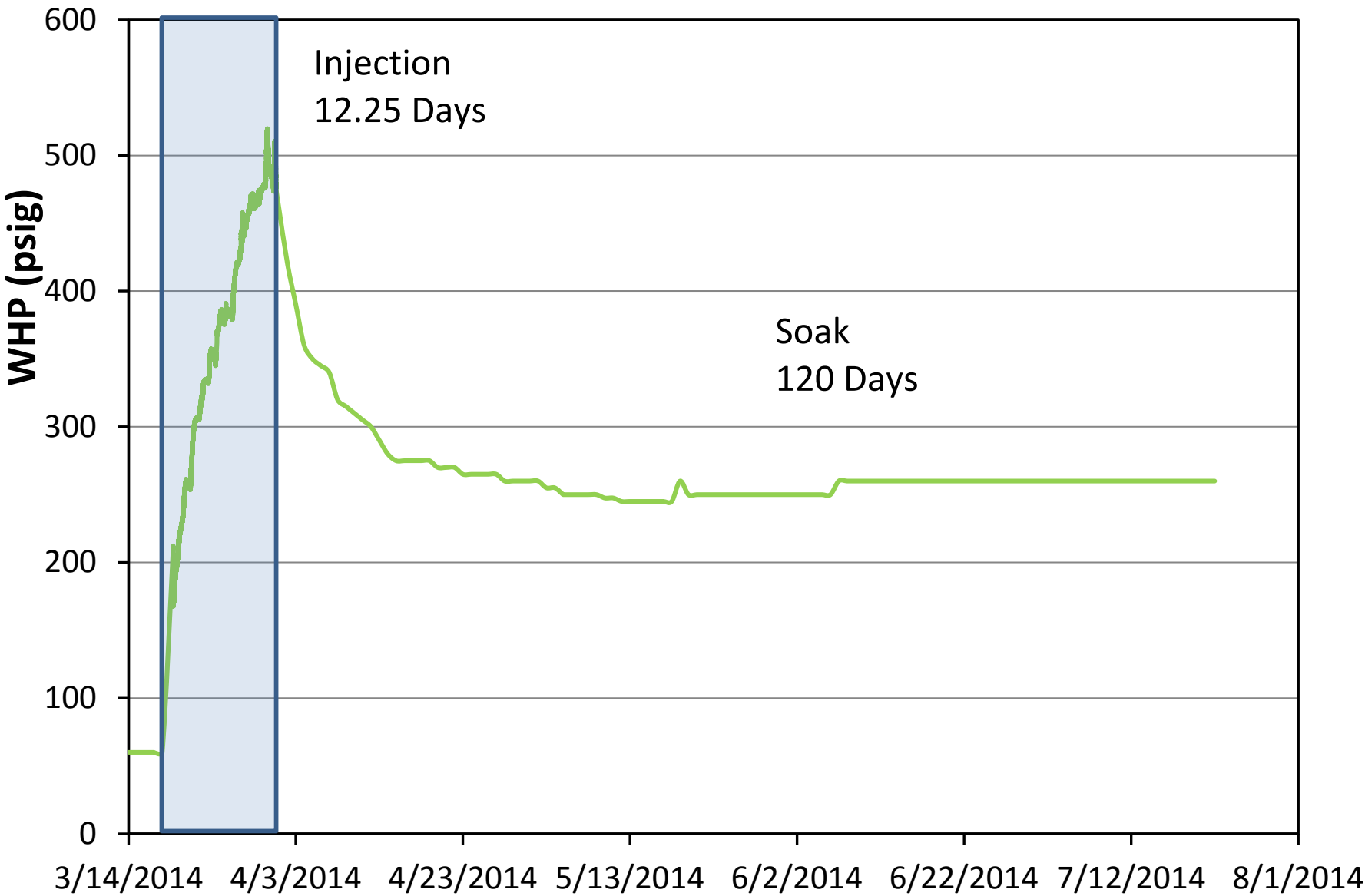
— PMCH Phase

— CO2 Injection

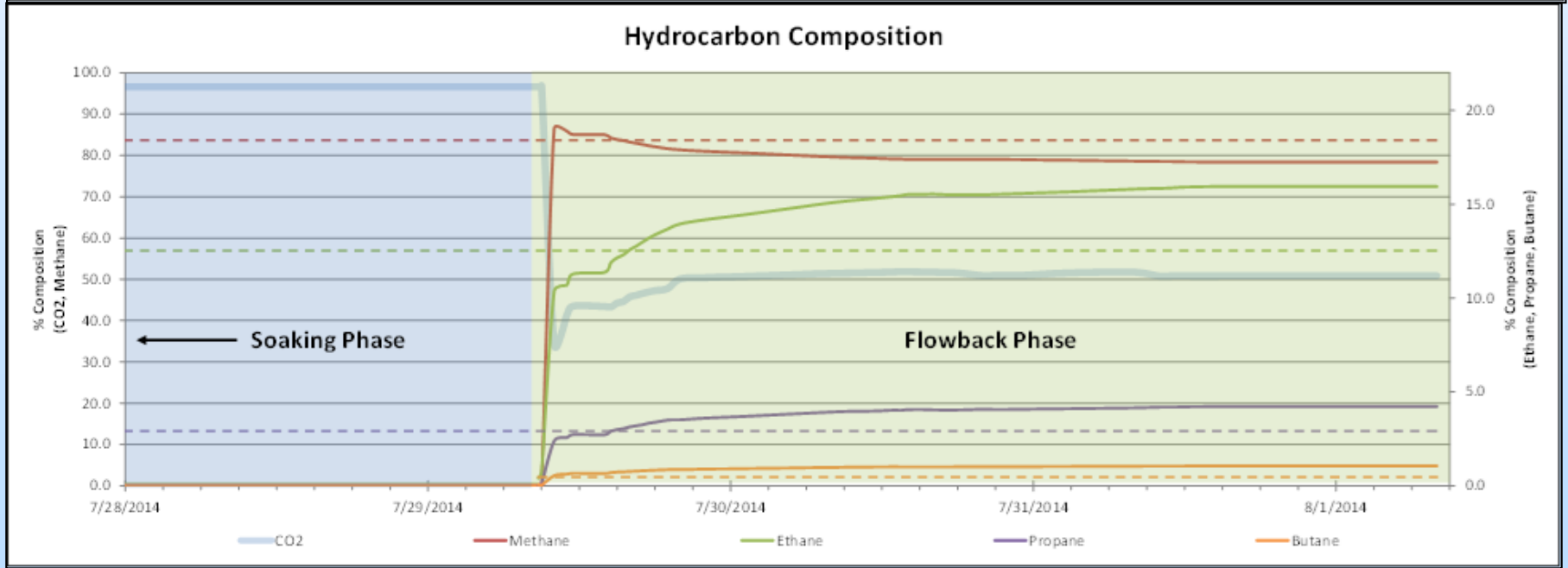
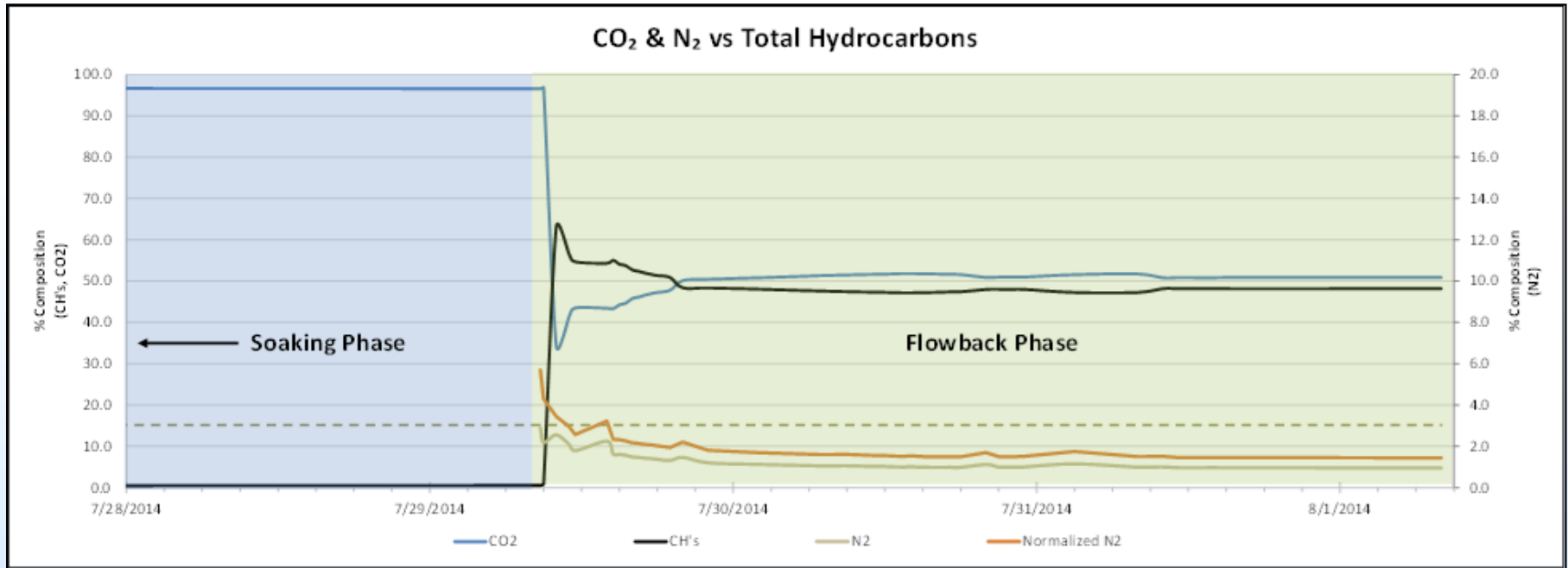
— CO2 + SF6 + PMCP Injection

— CO2 + PMCH Injection

Well Head Pressure (WHP)



Very Early Flowback Results



Shale Injection Overview

- 509 tons of CO₂ injected over 12.25 days
 - Average of 41 tons per day
 - Limited by temperature and heating capabilities
- 3 tracers injected at 2 separate times
 - 30-ton mark and 330-ton mark
- No breakthrough observed at off-set wells and no leakage observed to date
- Low pressure build-up on injection (gas injection)
- Temperature
- Pressure stabilized on 4-month soak
- Early flowback results show initial slug of hydrocarbons and N₂, followed by slug of CO₂, followed by 50/50 mix of HC and CO₂.
 - Higher percentage of heavy hydrocarbons in flowback
 - Currently producing at 200 Mcf/day, 60% HC and 52 psig
 - Up from 20 Mcf/day

One Successful and Safe Injection, One to Go!



Questions?

nino@vt.edu