



Midwest Geological
Sequestration Consortium

Carbon Storage from Biofuels: A Progressive Success Story in Technology Innovation, Partnerships, and Collaboration

Sallie E. Greenberg, Ph.D. and the MGSC Project Team
Illinois State Geological Survey
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
2 August 2017 – Pittsburgh, PA

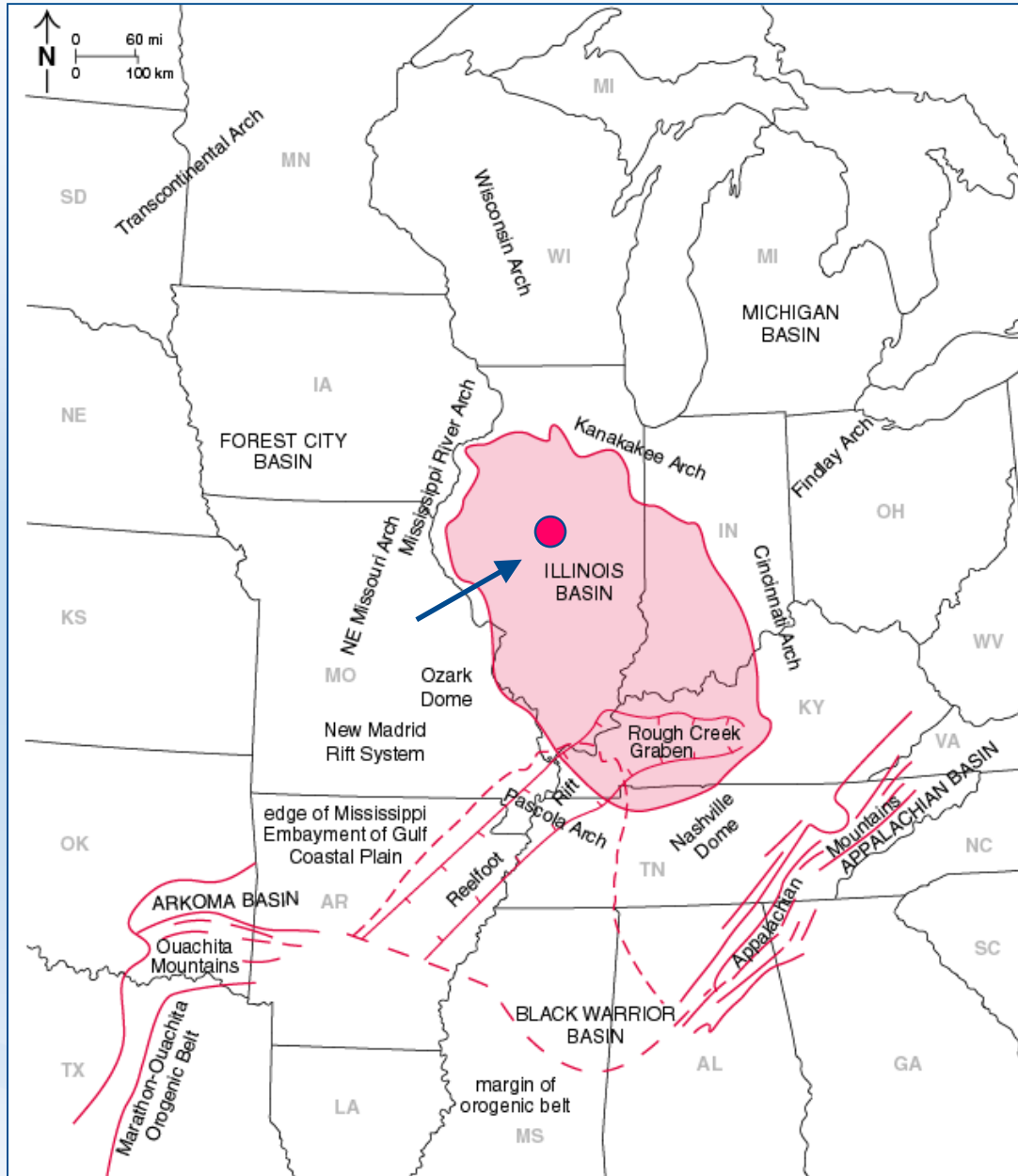


MGSC Path to Technology Innovation, Partnerships, and Collaboration

- Building CCUS Foundations
- Addressing Questions
- Meeting Challenges
- Deploying Industrial-scale CCUS
- Learning from Experience
- Taking the Next Steps



CCUS in the Illinois Basin



A collaboration of the Midwest Geological Sequestration Consortium, the Archer Daniels Midland Company (ADM), Schlumberger Carbon Services, and other subcontractors to inject 1 million metric tons of anthropogenic carbon dioxide at a depth of ~2,100 m to test **geological carbon sequestration in a saline reservoir** at a site in Decatur, IL

- Prove injectivity and capacity
- Demonstrate security of injection zone
- Contribution to best practices

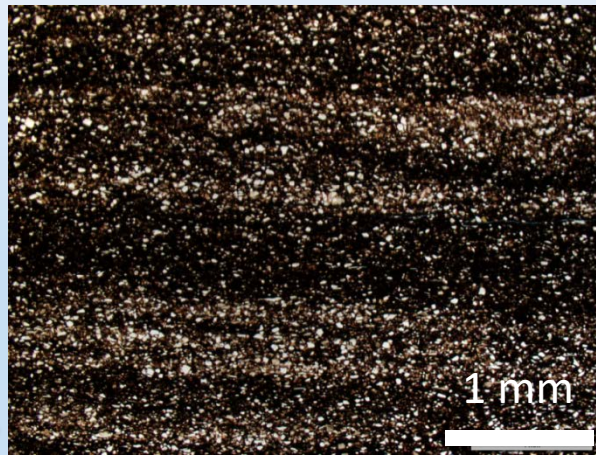
Establishing
Injectivity,
Containment, and
Capacity

Illinois Basin -
Decatur Project



Addressing Questions

Mudstone Baffle Between Injection Zones



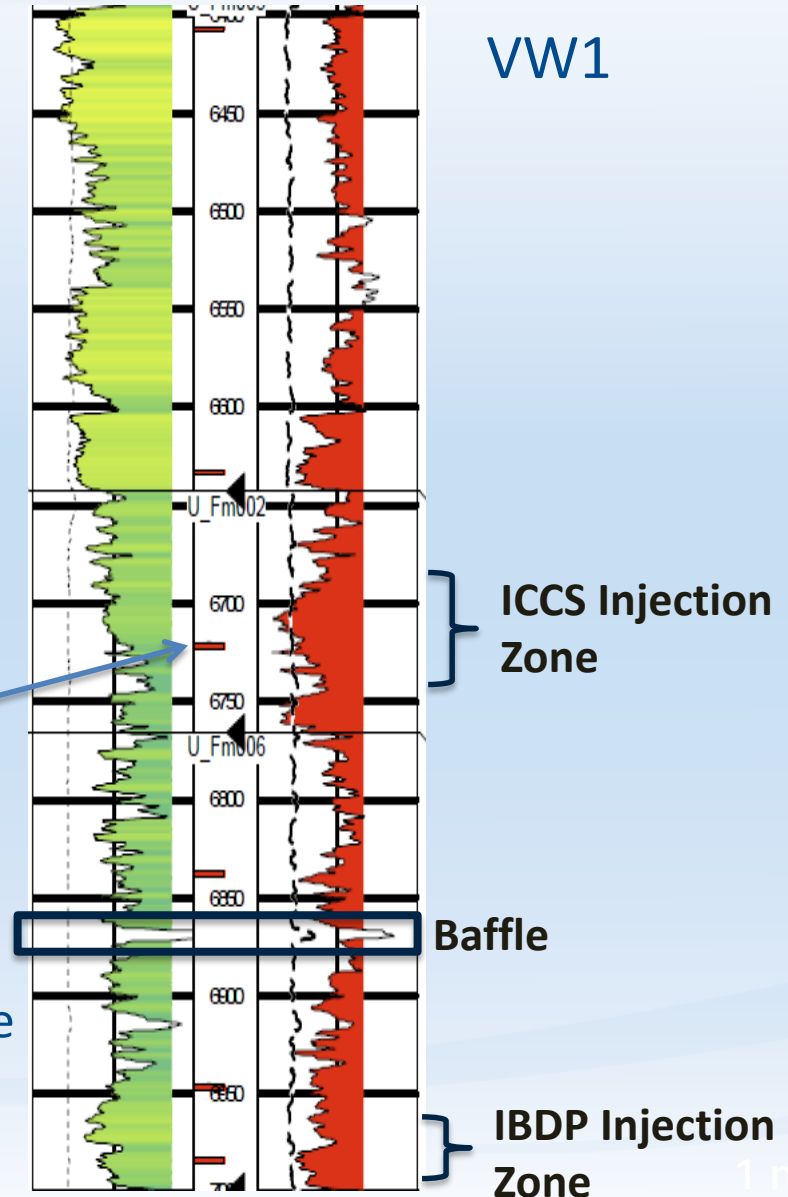
6,863-6,863.25 (2,092 m)

Porosity: 1.5%

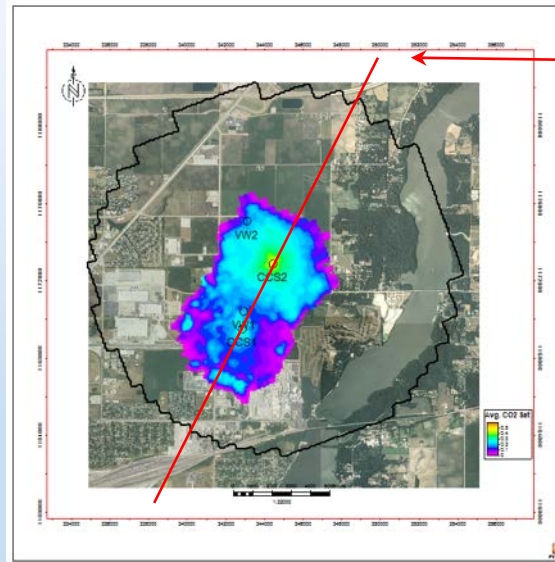
K_v : <0.01 mD

K_h : 4.13 mD in siltstone laminae

Zone 5

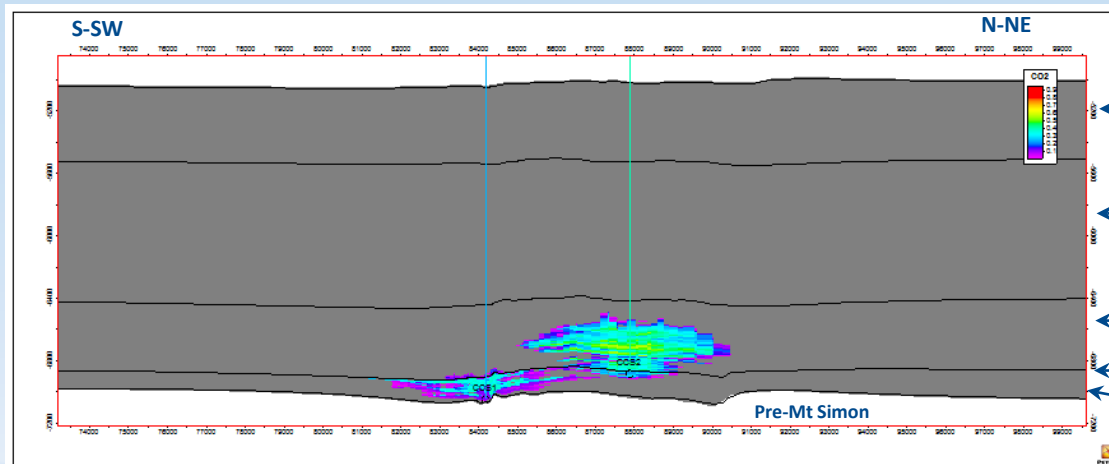


Extent of Plume & Saturation Cross Section January 1, 2020 (year 8, end of CCS2 injection)



Cross Section Orientation

— $DP_{if} \geq 86$ psi
 $SCO_2 \geq 1.0\%$



Eau Claire

Mt Simon C, D, E

Mt Simon A, B

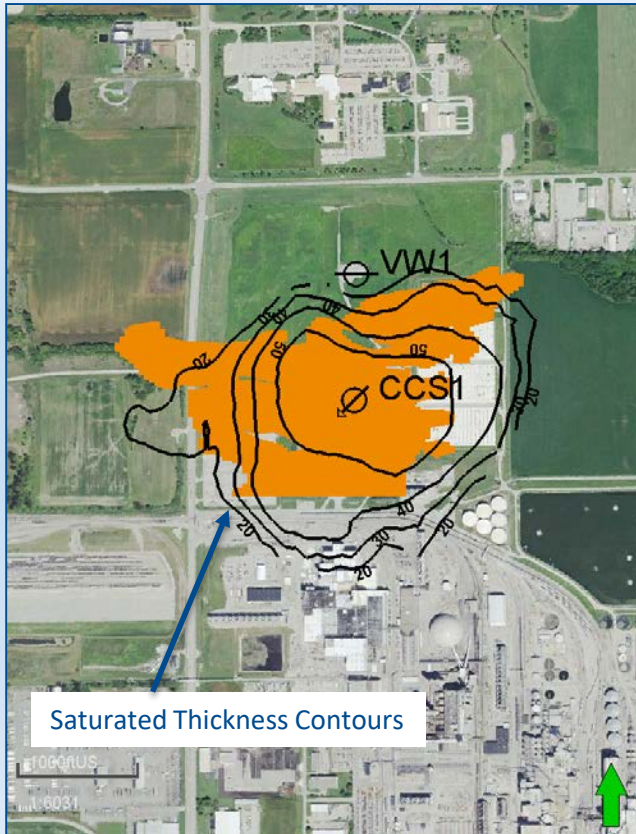
Mudstone

Lower Mt Simon A

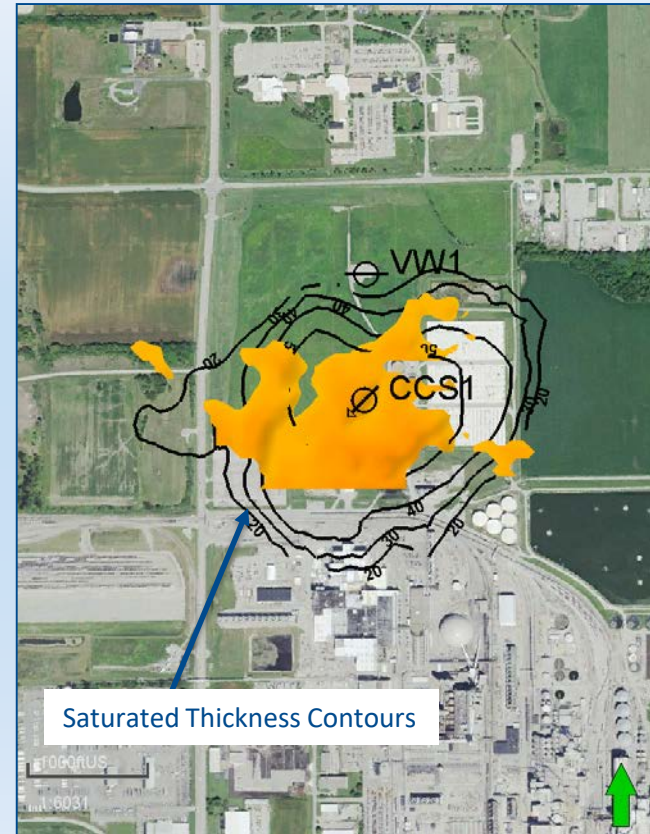
Pre-Mt Simon

Qualitative Time-Lapse Attributes: Inferring Seismic Detection Limit with Saturated Thickness

NRM Attribute

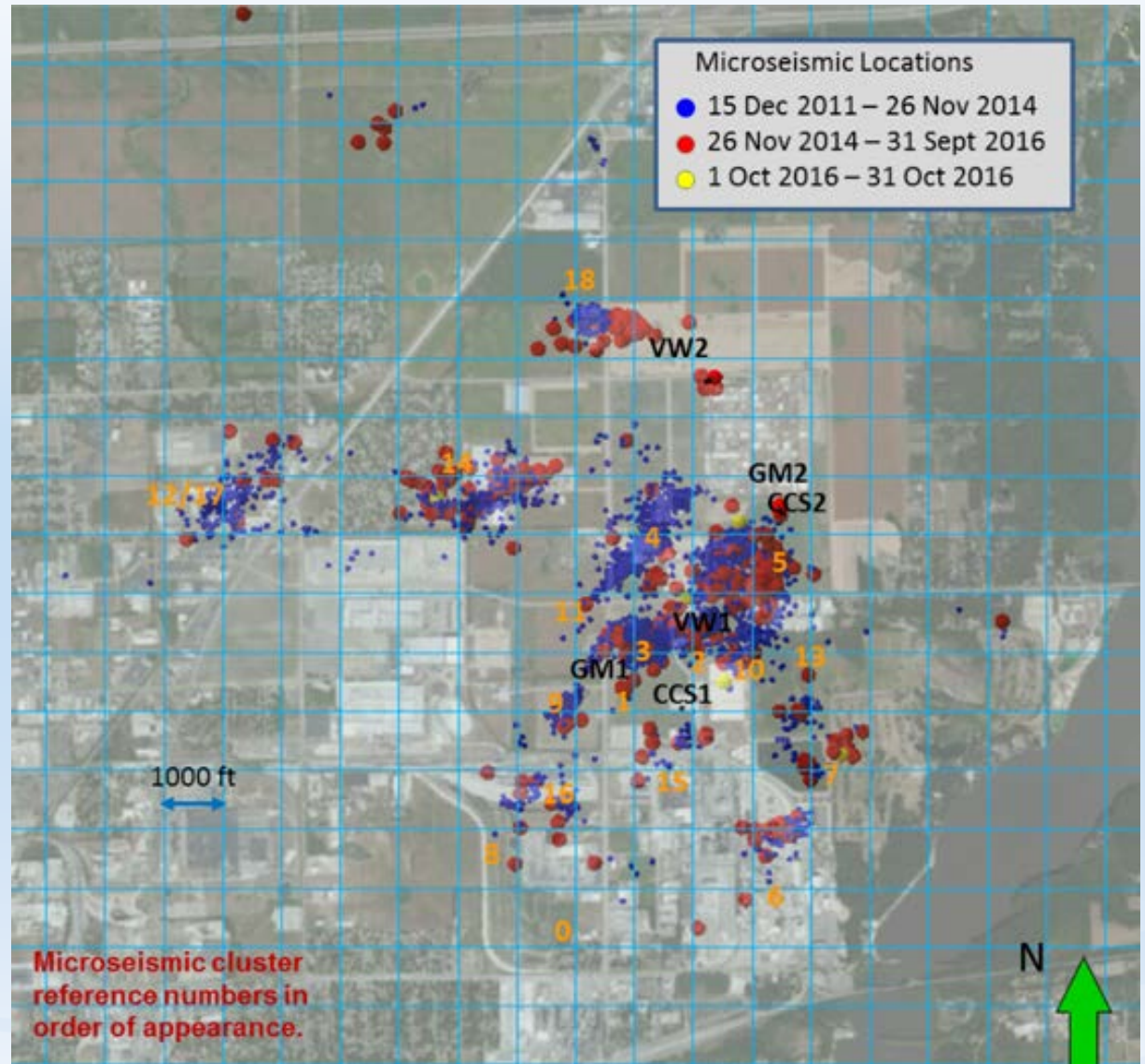


NRMS Attribute

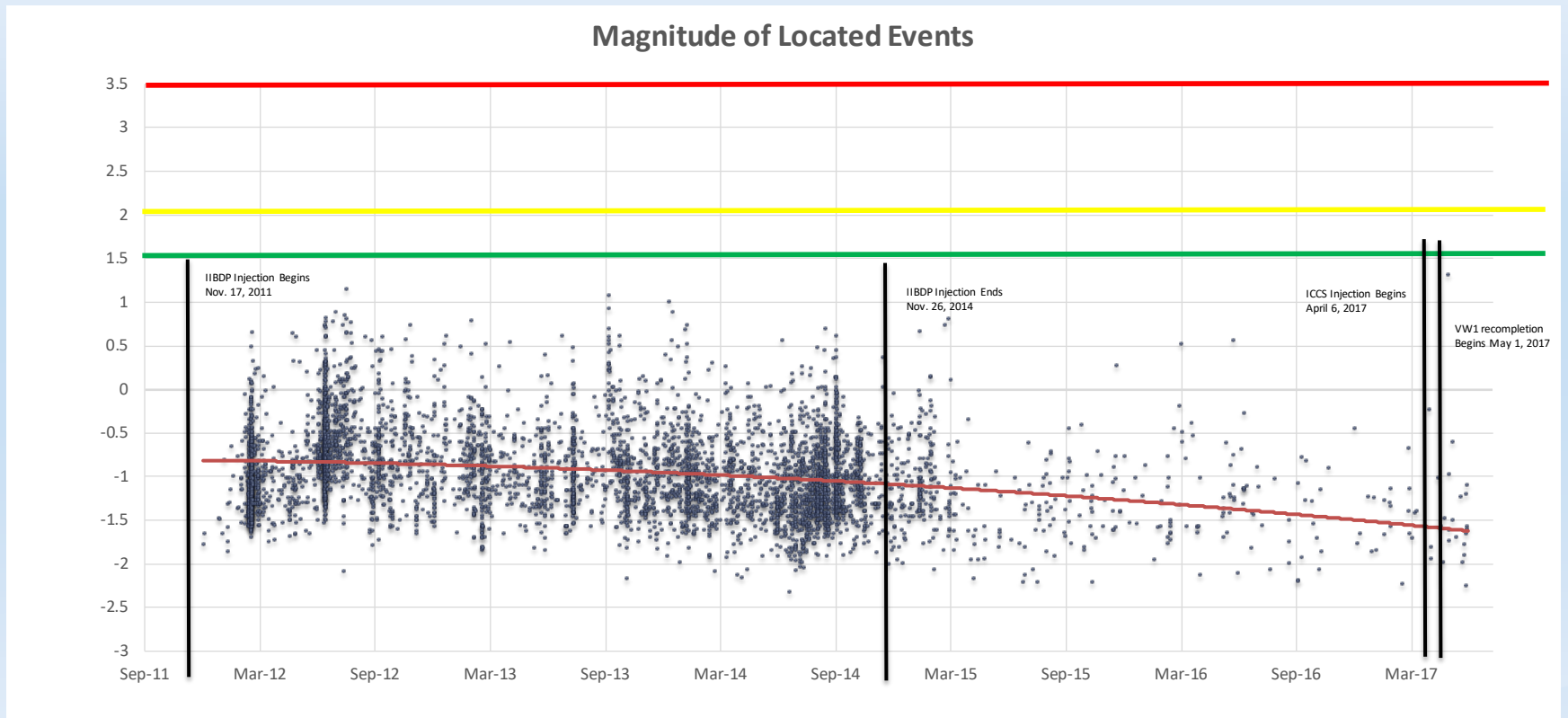


Microseismic Activity at the Illinois Basin – Decatur Project

- Observed Microseismicity associated with injection
- Location critical to understanding reservoir response
- Original correlation between cluster development and pressure front under examination
- ICCS created stoplight map to mitigate potential associated risks from felt events



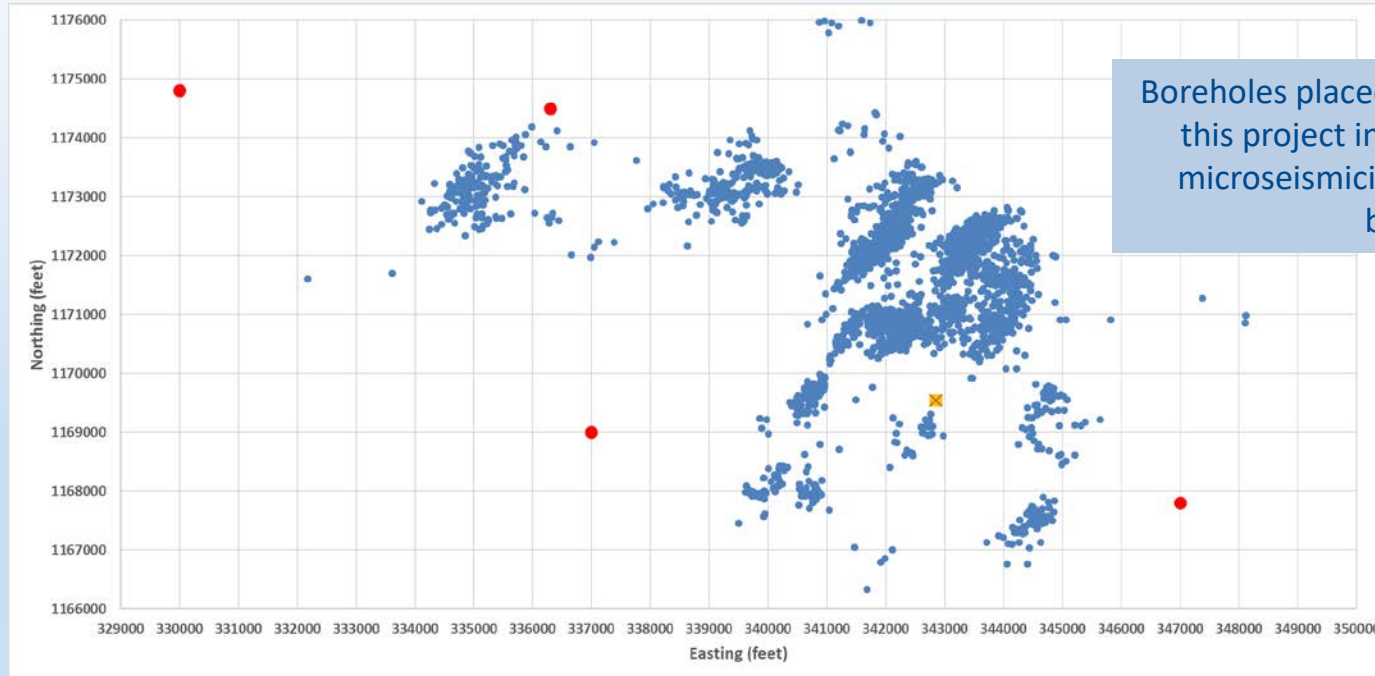
Microseismicity Time and Magnitude Related to Injection and Post-injection Activity



Collaboration between US (ISGS and BEG) and Norway (NORSAR and SINTEF)

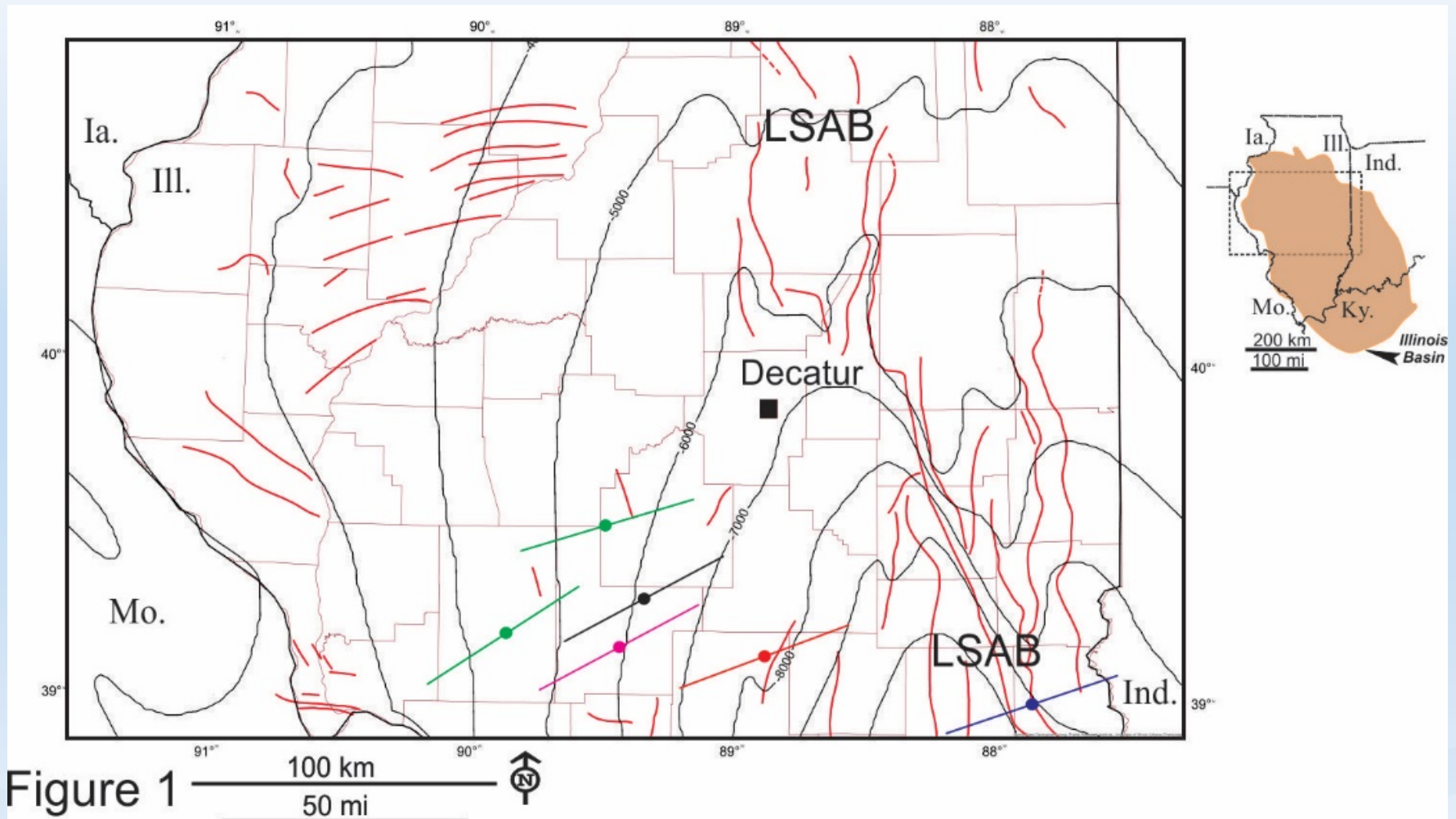
- Using surface and subsurface seismic recordings of microseismicity through time to detect CO₂ injection front in reservoir
- 3-D Compressive (V_p) and Shear wave (V_s) velocity model from surface seismograph stations down into basement rocks.
- Need to develop Glacial V_p (compressive wave) & V_s (shear wave) velocity model & add to existing 3-D velocity bedrock model which goes from a depth of 1,000 feet to the basement.
- For use with monitored seismic waves at surface stations to more accurately locate microseismic events at depth.

Characterize Glacial overburden for Compressive and Shear Wave Velocities by placing 4 boreholes near surface seismic stations.



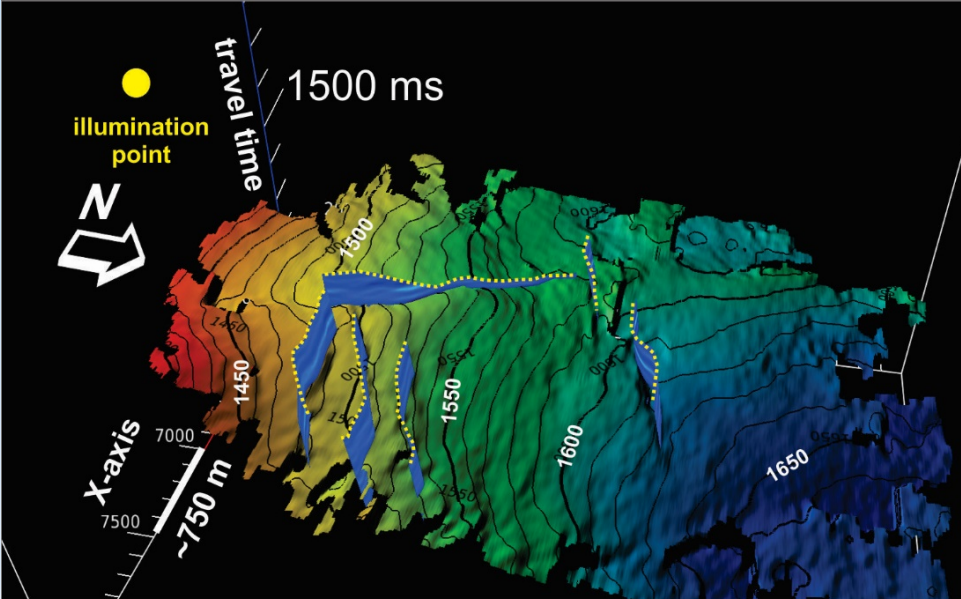
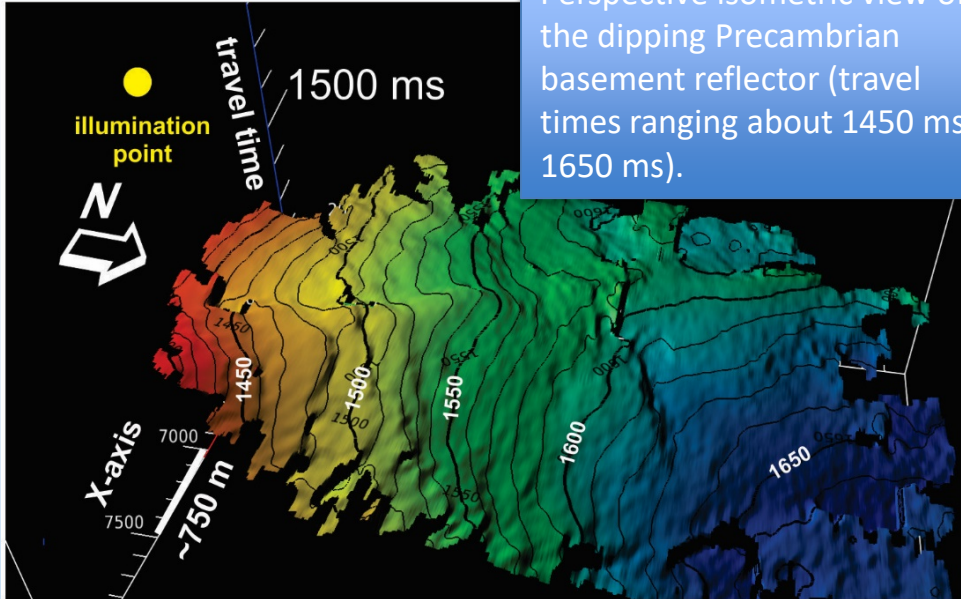
- 4 boreholes 5 to 10 feet into bedrock
- Continuously sampled and described
- Moisture content & density determinations in lab
- Boreholes geophysically logged
- 2 inch PVC casing installed
- Performing V_p & V_s measurements at 1 meter intervals

Visualizing Precambrian Basement Tectonics beneath IBDP



General location map for central Illinois Basin (USA) centered over IBDP study area, Decatur, Illinois.

Perspective isometric view of the dipping Precambrian basement reflector (travel times ranging about 1450 ms to 1650 ms).

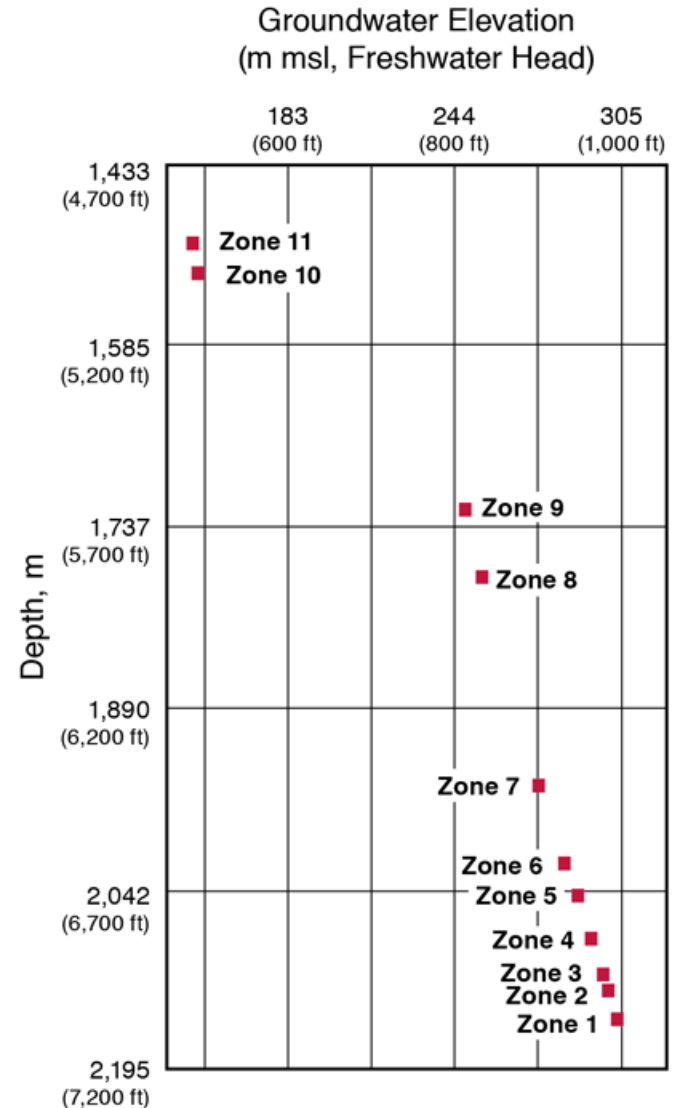
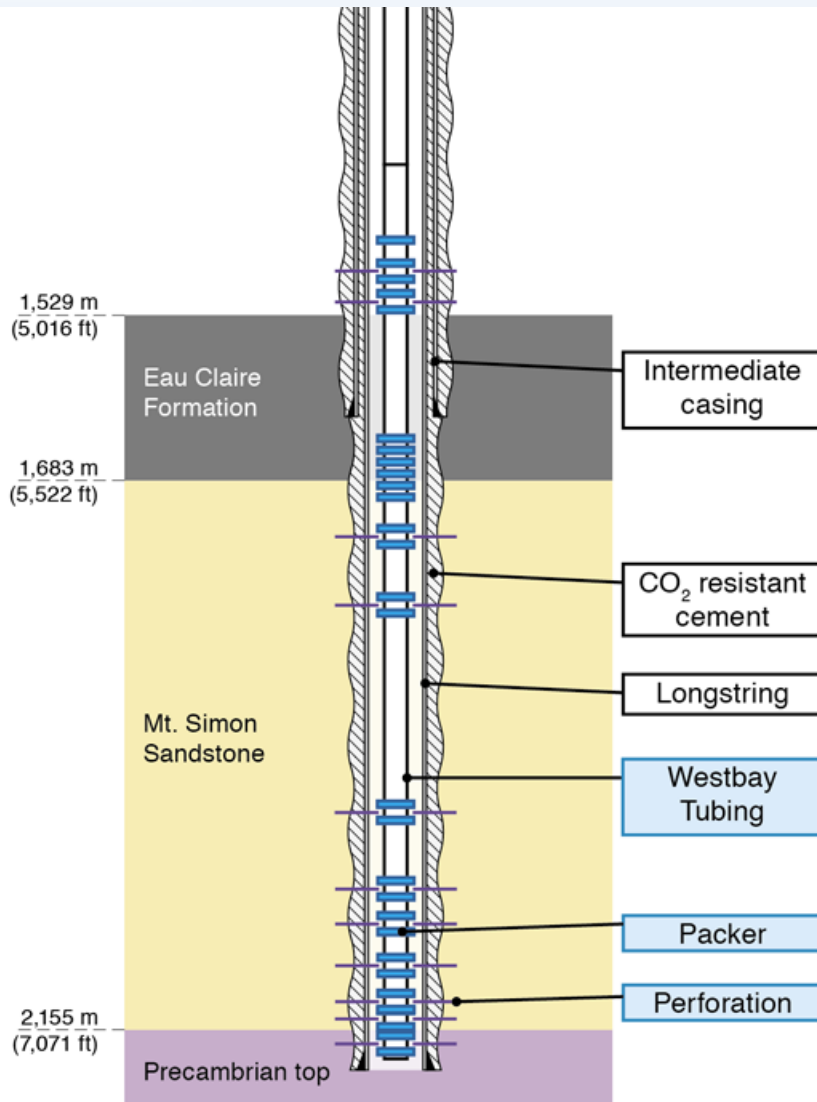


- Precambrian basement tectonics critical to constrain geology.
- 3D seismic visualization & attribute analysis used to detect and map fine-scale structure, including discontinuities difficult to recognize with conventional amplitude.
- McBride et al. propose development of Precambrian discontinuities could be related to fractured damage zone higher in basement, extending upward to Precambrian-Paleozoic contact.
- Injection-related microseismicity may be reactivating small faults and fractures within the upper part of this damage zone as governed by the contemporary stress field.

Figure 2A

Meeting Challenges

VWI Westbay Completion



Recompletion of VWI Monitoring Well

Westbay System

Flexible, industry-tested design offers Superior Performance

OVERVIEW
The Westbay System is a completely versatile, multilevel monitoring technology that allows testing of hydraulic conductivity, monitoring of fluid pressure and collection of fluid samples from multiple zones within a single borehole. Designed for reliability and deflexibility, the Westbay System can accommodate a wide variety of borehole conditions including diameter, depth, temperature and chemistry considerations.

Westbay System advantages:

- Obtain measurements and samples at any number of discrete locations along a single borehole.
- Collect samples without purging.
- Designed for long-term monitoring.
- Engineered to operate at great depths.
- Reduced drilling and installation costs, with minimal site disturbance.
- Removable probes allow for convenient calibration and servicing.
- Built-in defensible QA/QC procedures.

WELL COMPLETIONS
Westbay Systems are engineered with a unique, customizable casing system. The casing system is available in two sizes (MP20 and MP30) and manufactured from plastic or stainless steel to fit various borehole dimensions and operational requirements. Hydraulically-inflated packers and/or backfill provide engineered seals between monitoring zones, preventing crossflow and cross-contamination. Valved parts in the zones provide access for monitoring, sampling and hydraulic testing.

PACKERS

- Engineered seal in a range of borehole sizes.
- No dedicated inflation lines.
- Controlled hydraulic inflation with record of pressure and volume.
- Quality control tests to confirm performance at any time after installation.

MEASUREMENT POINT

- For fluid pressure measurements, fluid sampling and low-k testing.

PUMPING POINT

- For purging, hydraulic conductivity testing, and quality control testing.

WESTBAY SYSTEM PROBES
A variety of probes are available for use with the Westbay System. Reliable, accurate, portable wireline-operated probes can be lowered into the casing system and used to:

- Measure groundwater pressure.
- Test hydraulic parameters.
- Collect samples in-situ.
- Perform system specific tests.

SAMPLING PROBES
Westbay Systems offer the unique ability to collect discrete fluid samples at formation pressure. For sample collection the probe and sample container are lowered to the desired depth, where the sample is collected into the container. The probe and container are then retrieved to the surface for further analysis.

Westbay System sampling allows you to:

- Collect samples with minimal disturbance and without repeated purging.
- Maintain samples at formation pressure.
- Monitor pressure during sampling.
- Discourage quality assurance.

For more information, visit www.bakerhughes.com



Advancing Reservoir Performance

REPACKER™ Reactive Element Packers

HCM-Plus Hydraulic Sliding Sleeve
Baker Hughes intelligent well systems flow control valves

The Baker Hughes Inforce HCM™-Plus downhole valve provides remote and reliable isolation of a specific interval. It reduces costs and minimizes production downtime by allowing production or injection from the wellbore to be altered without intervention from the surface. This product is compatible with oil- or water-base control fluids.

The hydraulically balanced piston yields high shifting forces to overcome scale and debris, and it requires two control lines per HCM-Plus valve. A third port is included on the valve as part of the closed line circuit. This port reduces the number of lines required to operate a multizone system.

Hydraulic pressure applied from the surface shifts the HCM-Plus valve to the open or close position. If a hydraulic operation cannot be performed, the HCM-Plus valve has an integral shifting profile for mechanical operation.

The Baker Hughes testable control line jam nut fittings are some of the most widely used hydraulic connectors available in the market.

Applications

- Multiple zone production or injection wells requiring remote operations to isolate a specific zone when choking is not required.

Benefits

- Intervention not required to open or close the valve.
- Cost-effective, remote valve operation.
- Reliable, simple design with proven technology and built-in flexibility.

Features

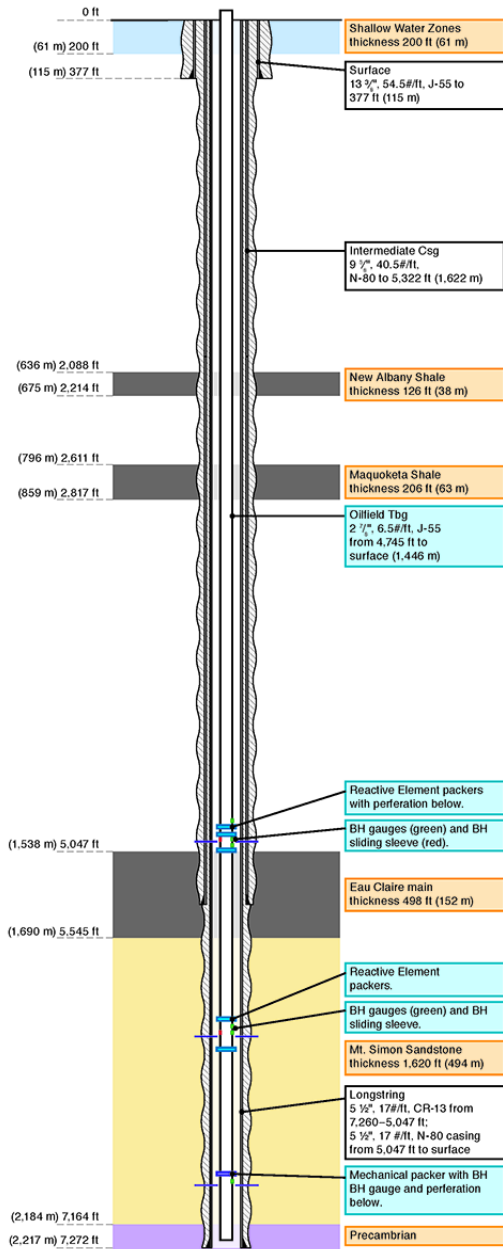
- Balanced piston design to open and close the valve at deep setting depths.
- Simple surface procedures for valve actuation.
- Non-elastomeric sealing technology isolated during flowing operations for high-performance sealing from tubing to annulus.
- Testable control line jam nut fittings.
- Control line bypass allows multiple valves, sensors, or chemical injection valves to be run as part of an intelligent well system.
- Internal profiles allow placement of flow control devices.
- Integral profile for secondary mechanical shifting.
- Water- or oil-base control line fluid compatible.

- Option 1 – Retain Westbay
- Option 2 – Schlumberger IntelliZone
- Option 3 – Baker Hughes Intelligent
- Option 4 – Drill new well

Two Fluid Sampling and Four Pressure Zones

In-Zone Monitor Well

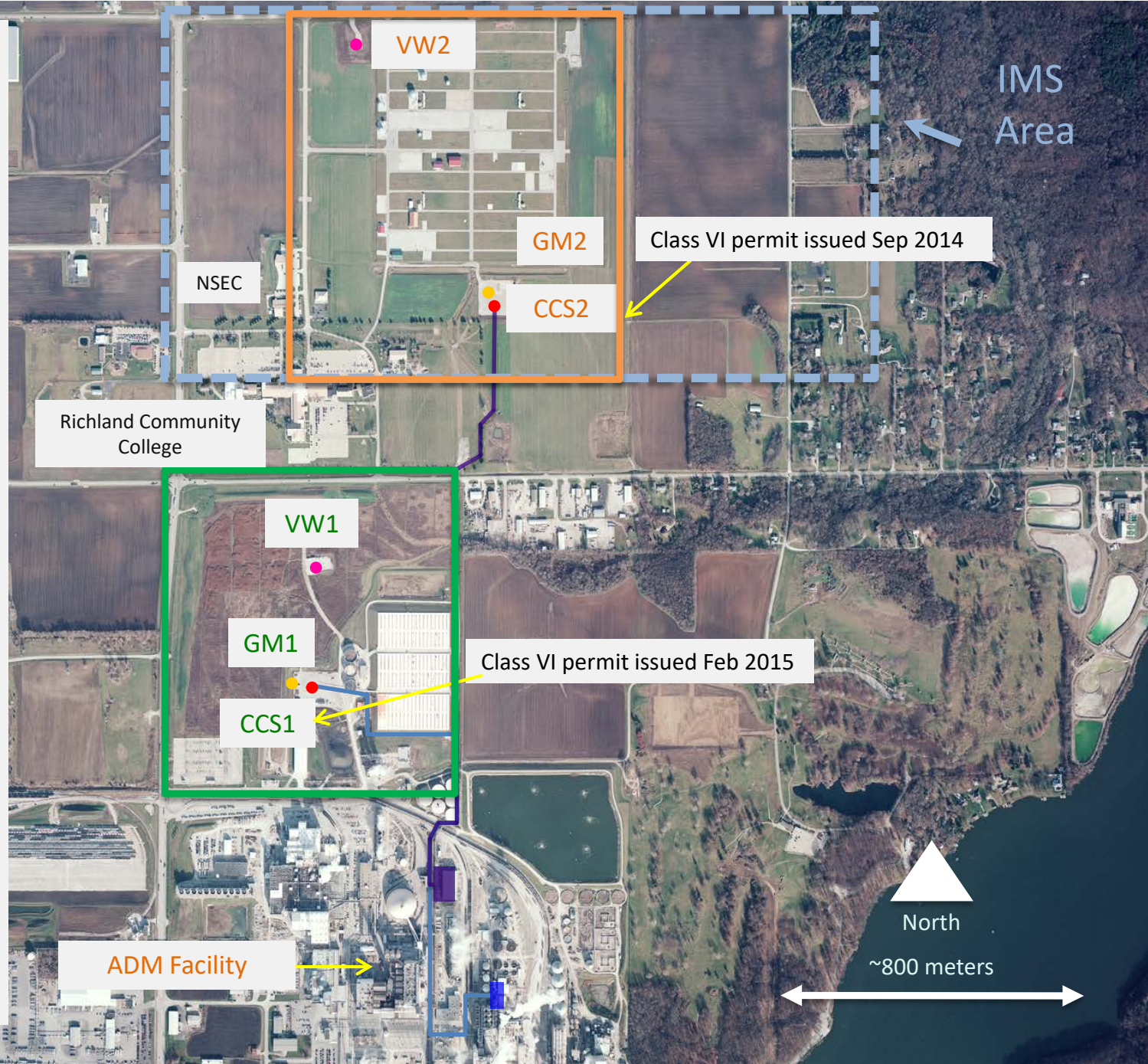
VW1



Deploying Industrial-scale CCUS

**Multiple Projects
Build Framework
for CCUS Research
and
Commercialization**

**Illinois Basin -
Decatur Project
Illinois Industrial
Sources CCS
Intelligent
Monitoring
Systems
BEST - Brine
Extraction**



Current CCUS Projects in Decatur, IL USA



Illinois Basin – Decatur Project

- Large-scale demonstration
- Volume: 1 million tonnes
- Injection period: 3 years
- Injection rate: 1,000 tonnes/d
- Compression capacity: 1,100 tonnes/day

Contribution:

- Geologic and Social Site Characterization
- Reservoir Modeling and Risk Assessment
- MVA Development and Engineering Design
- Stakeholder Engagement

Status:

- Post-injection monitoring ends April 2020

Illinois Industrial CCS Project



- Industrial-scale demonstration
- Volume: up to 5 million tonnes
- Injection period: 3 years (or longer)
- Injection rate: 3,000 tons/d
- Compression capacity: 2,200 tonnes/day

Contribution:

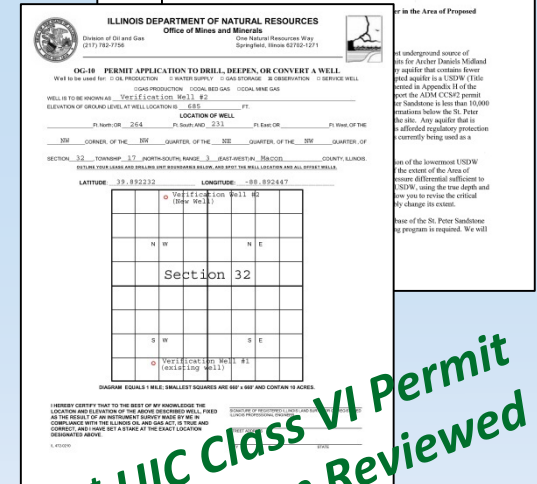
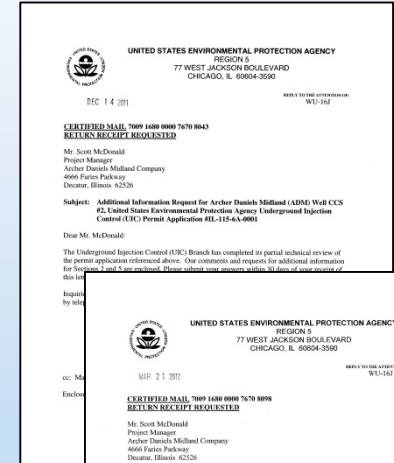
- Commercial-scale up surface and subsurface
- Multi-plume modeling
- Class VI permitting
- Regulatory MVA
- Education programs

Status:

- Injection Began April 7, 2017

Permitting of wells for two projects linked

- Permitting has been rate-limiting step for both projects
- Permits for IBDP Post-injection Site Care and ICCS injection + Post-injection tied together
- Project expansion due to delay in injection start
- Example:
 - ICCS application submitted: 25 Jul 2011
 - Draft permit issued: 4 Apr 2014
 - Public hearing conducted: 21 May 2014
 - Public comment period ended: 31 May 2014
 - Final permit issued: 28 Dec 2014
 - Permission to inject: 7 Apr 2017 (825,000 tonnes)



1st UIC Class VI Permit
Application Reviewed
by the USEPA

IBDP Environmental Monitoring Framework

Near Surface

Deep Subsurface

Atmos.

**Soil and
vadose
zone**

**Shallow
ground
water**

**Above
seal**

**Injection
zone**

**Eddy
covariance**

**Meteorological
conditions**

Ambient CO₂

**Tunable diode
laser for CO₂**

**CIR aerial
imagery**

InSAR and GPS

Soil gases

Soil CO₂ flux

**Tunable diode
laser for CO₂**

**Geophysical
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**Geochemical
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P/T monitoring

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P/T monitoring

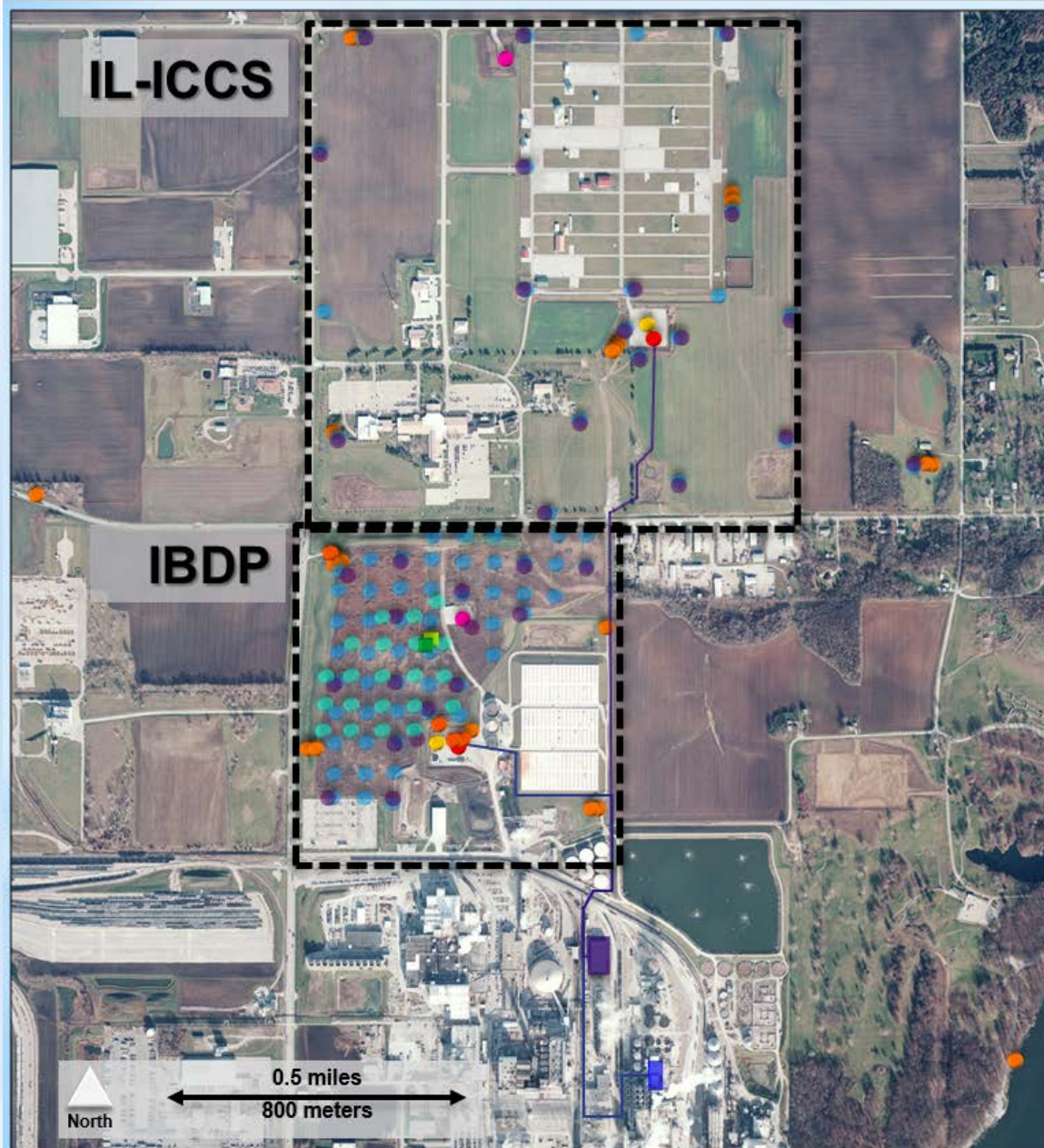
**Geophysical
surveys**

**Geochemical
sampling**

P/T monitoring

Monitoring Summary

- Injection wells (2)
- Verification wells (2)
- Geophysical wells (2)
- Compliance wells (4)
- Research wells (24)
- Soil gas points (35)
- Soil flux points (145)
- Eddy covariance station (1)
- Continuous GPS station (1)
- InSAR artificial reflectors (21)



IBDP and IL-ICCS Installations

- IBDP: Comprehensive research- and risk-based program
- IL-ICCS: targeted, regulatory focused program based on IBDP
 - Note: decrease in installation density
- Monitoring perspectives:
 - Programs should be risk based
 - Overall project de-risking may require a blend of
 - Research Goals
 - Regulatory Requirements
 - Commercial Drivers
 - Technique Scalability needs to be considered

Illinois Industrial Sources CCS

- Operational Injection April 7, 2017
- Step rate increase of CO₂ to full injection
- Pressure in nearby wells
- ~213,000 tonnes injected to-date
- Limited to no microseismic activity
- 92 tonnes/hr
- 2,208 tonnes/day

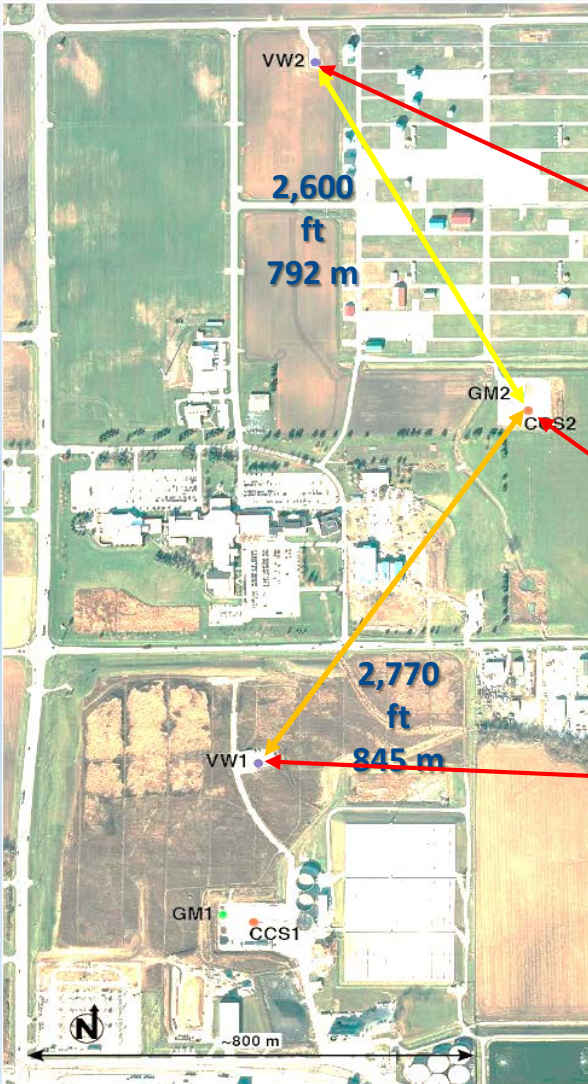




VW2 Pressure readings

ICCS Injection Well

VW1 Pressure readings



First Pressure Increases

30 April 2017 Readings

VW2 Pressure readings

Zone 3* @ 6524 ft +79 hours
 Zone 4 @ 6681 ft **+79.25**
 Zone 5 @ 7041 ft +202

Pressures & % Formation Increase

1.20 psi	0.040%
50.50 psi	1.666%
2.10 psi	0.065%

ICCS Injection Well (CCS2)

Started 7 Apr 2017 ~05:35 am
 Perforations 6630 – 6825 ft

VW1 Pressure readings

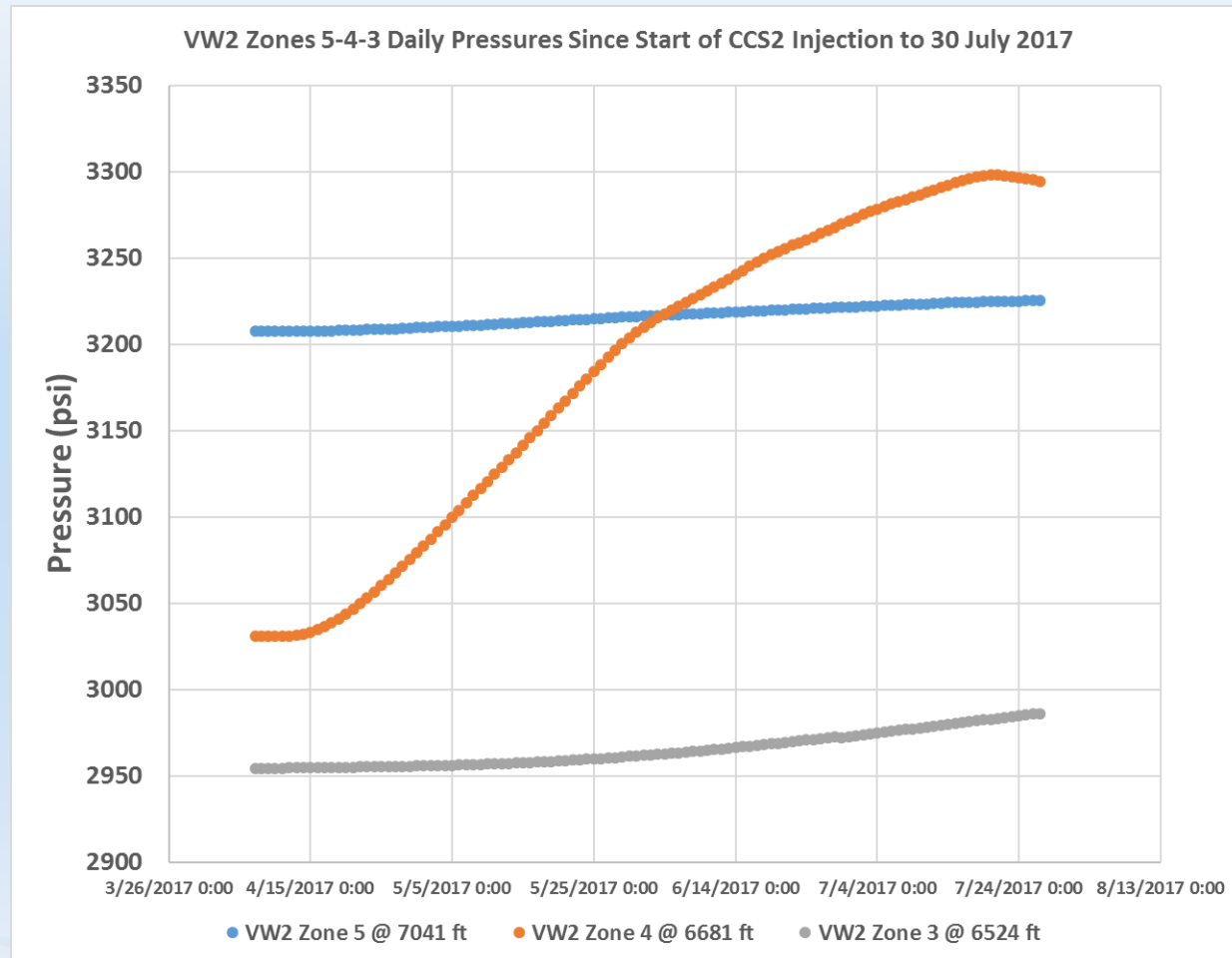
P6 @ 6632 ft +122.5 hours
 P4 @ 6838 ft **+56.5**

13.41 psi	0.444%
16.46 psi	0.528%

* WellWatcher data designation for Zone #

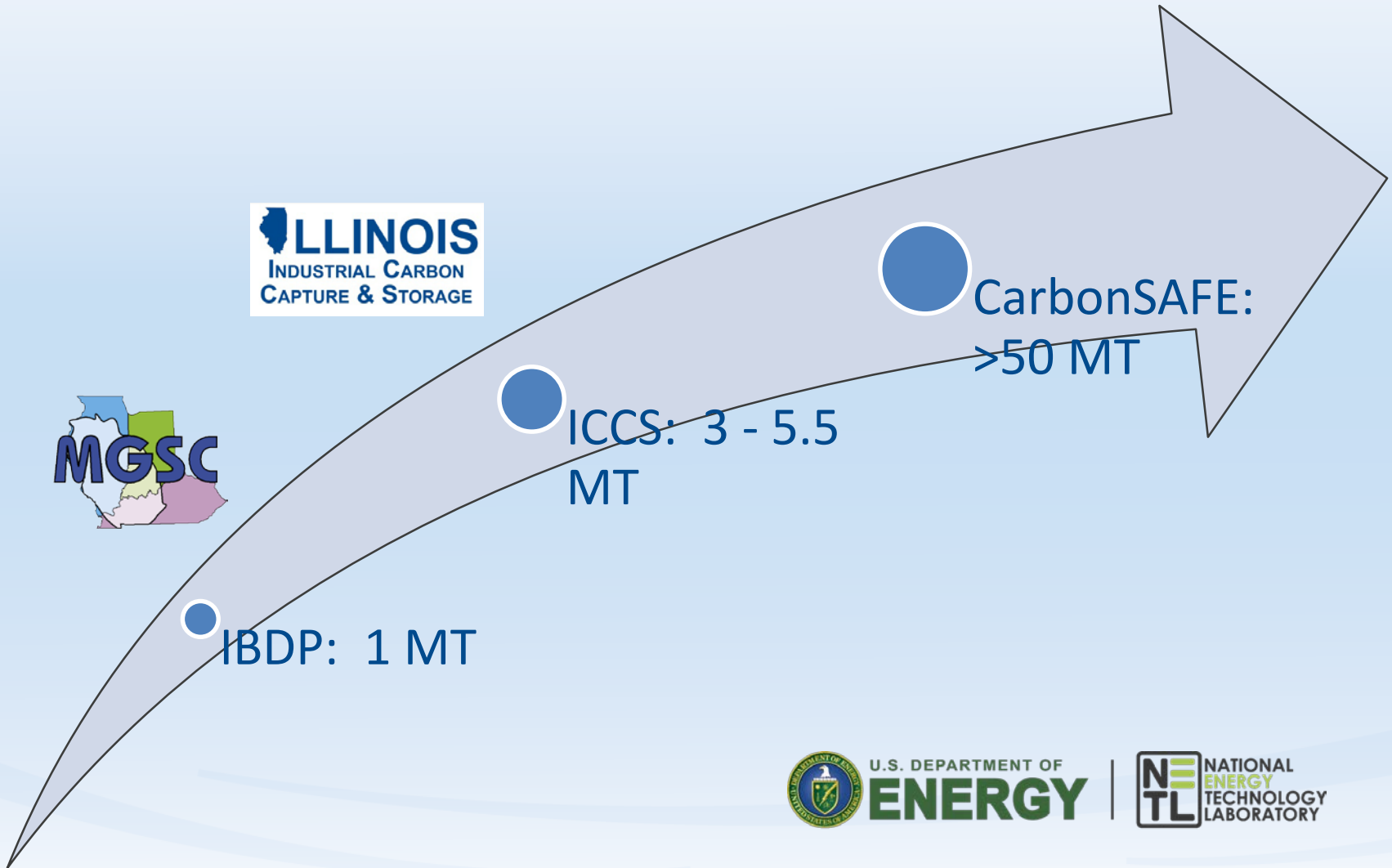
Zone 4

Delta P = 267 psi (1.84 MPa) - 69% of Fracture Pressure



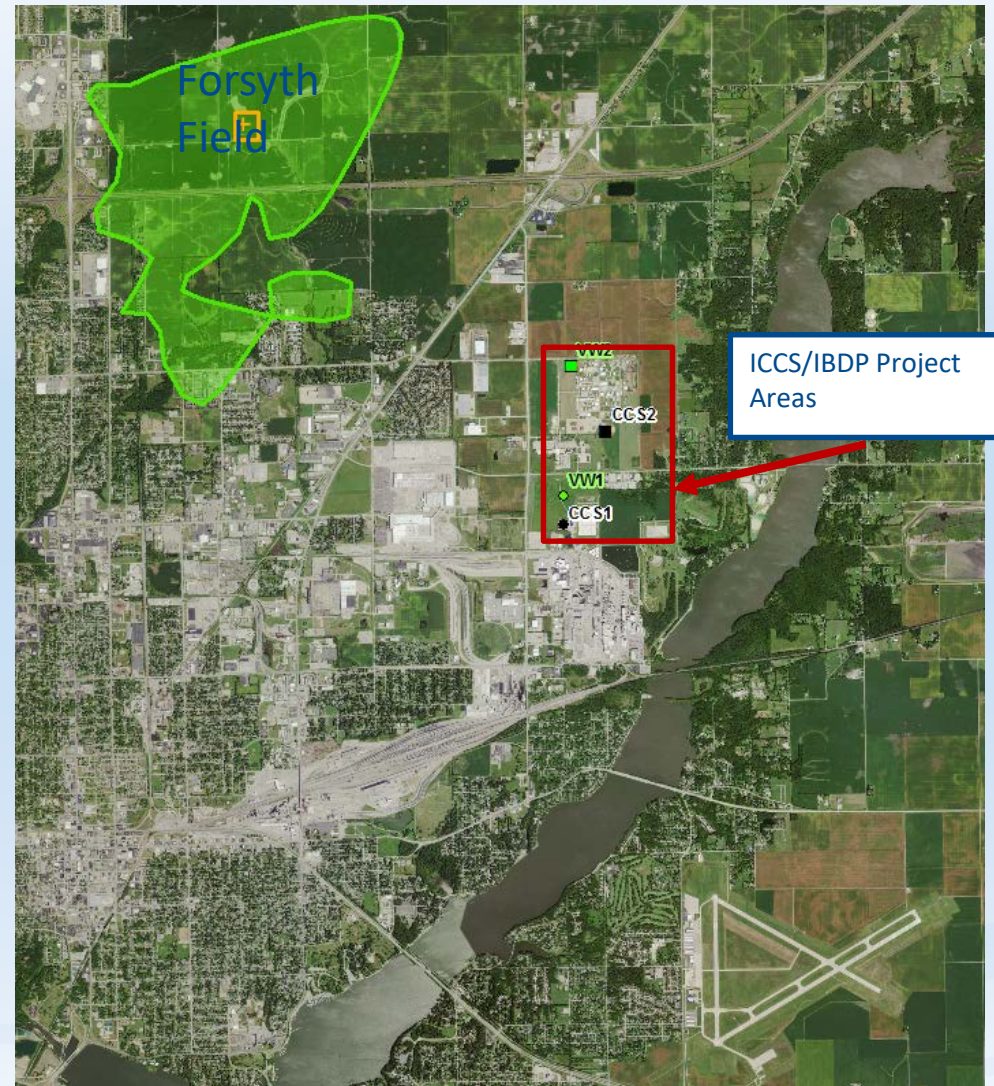
Learning from Experience

Illinois Basin Industrial CCS Progression



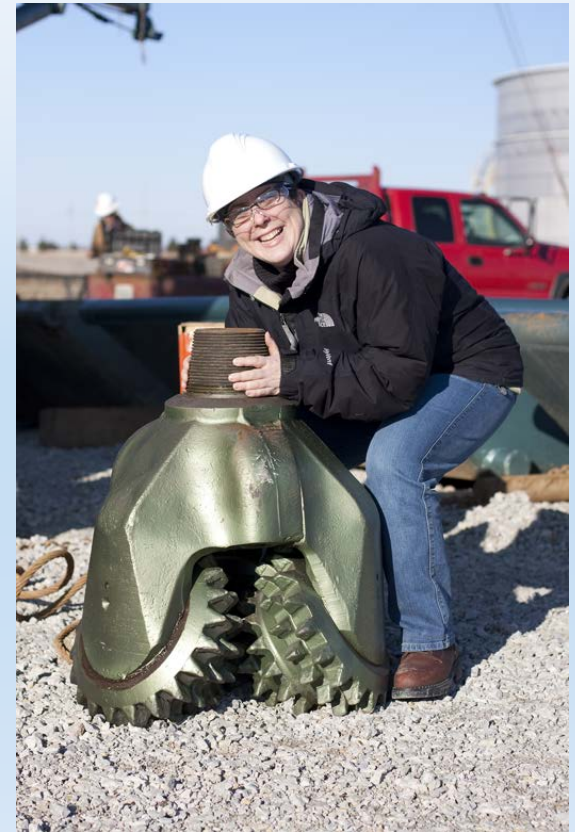
CarbonSAFE Illinois – East Basin and Macon County

- Pre-feasibility East Basin
- Feasibility Decatur
- 50 million tonne Storage Complex
- Address gap in development knowledge around large-scale carbon storage
- Validate technologies to ensure 99% storage
- Improve storage capacity estimates ($\pm 30\%$) for industry investment decisions
- Validate NRAP Toolkits for storage permanence and storage efficiency
- Contribute to best practice manuals to inform future commercialization efforts



IBDP by the numbers:

- A million tonnes stored from **biofuels** and...
- More than **5,000 meters** of drilled wells
- More than **245 meters** of collected core
- Near-surface groundwater monitoring efforts have resulted in more than **50,000 analyses**
- For basin-scale modeling, we will use **1,020,000 CPU-hours** of XSEDE supercomputing resources.
- More than **750 visitors from 29 countries** have been to IBDP
- More than **100 people at least 10 organizations** have worked together to make this project a success



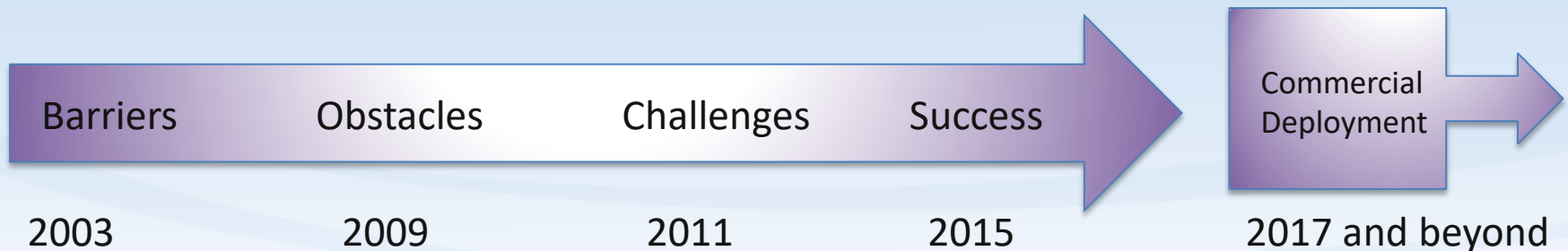
XSEDE is an NSF-sponsored supercomputer network

Major IBDP Accomplishments

- Integration of all components necessary to conduct successful large-scale storage demonstration at an active industrial site
- Conversion of Illinois EPA Class I permit to US EPA Class VI permit while maintaining operational integrity of project
- Stakeholder engagement strategy that built trusted relationships enabling active research and commercial-scale demonstration project
- Met and exceeded technical and non-technical challenges
- Extensive site characterization, modeling, and project assessment leading to injection, monitoring, and increased understanding of microseismic reservoir response
- Extensive regional, national, and international partnerships and collaboration

What We've Learned:

- Carbon capture and storage from biofuel sources in deep saline reservoirs can be conducted safely
- Research and scale-up demonstration projects can lead directly to industrial-scale or commercial-scale projects
- The Mt. Simon Sandstone is a viable and important deep saline storage resource for the US
- Establishment of an MVA baseline is critical to characterize site and reduce project risk, but needs to be revisited on a regular basis
- Permitting can be time intensive and should not be underestimated as a potential project risk
- Economy of scale learnings essential to commercial CCS deployment



MGSC and IBDP Future Steps

- Compliance phase of post-injection monitoring – April 2020 (tied to start of ADM Industrial CCS Sources project)
- Compliance-related science activities
- Full integration and completion of dynamic model for use on additional regional projects
- Basin-scale modeling conducted with heterogeneous reservoir characteristics
- Microseismic research review
- Knowledge sharing and capacity building
- Publication of IBDP technical papers
- Publication of IBDP project experience and learnings book

Acknowledgements



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- The Industrial Carbon Capture and Storage project is administered by the U.S. Department of Energy's Office of Fossil Energy and managed by the National Energy Technology Laboratory (award number DE-FE-0001547) and cost share agreements with ADM, ISGS, SLB, & RCC.
- The Intelligent Monitoring System Project is administered by the U.S. Department of Energy's Office of Fossil Energy and managed by the National Energy Technology Laboratory (award number DE-FE-0026517) and by cost share agreements with the ADM, LBNL, Silixa, SLB, ISGS, & RCC.





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