



Midwest Geological
Sequestration Consortium

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

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University of Illinois - Illinois State Geological Survey

MGSC Annual Meeting - 19 September 2017 - Champaign, IL

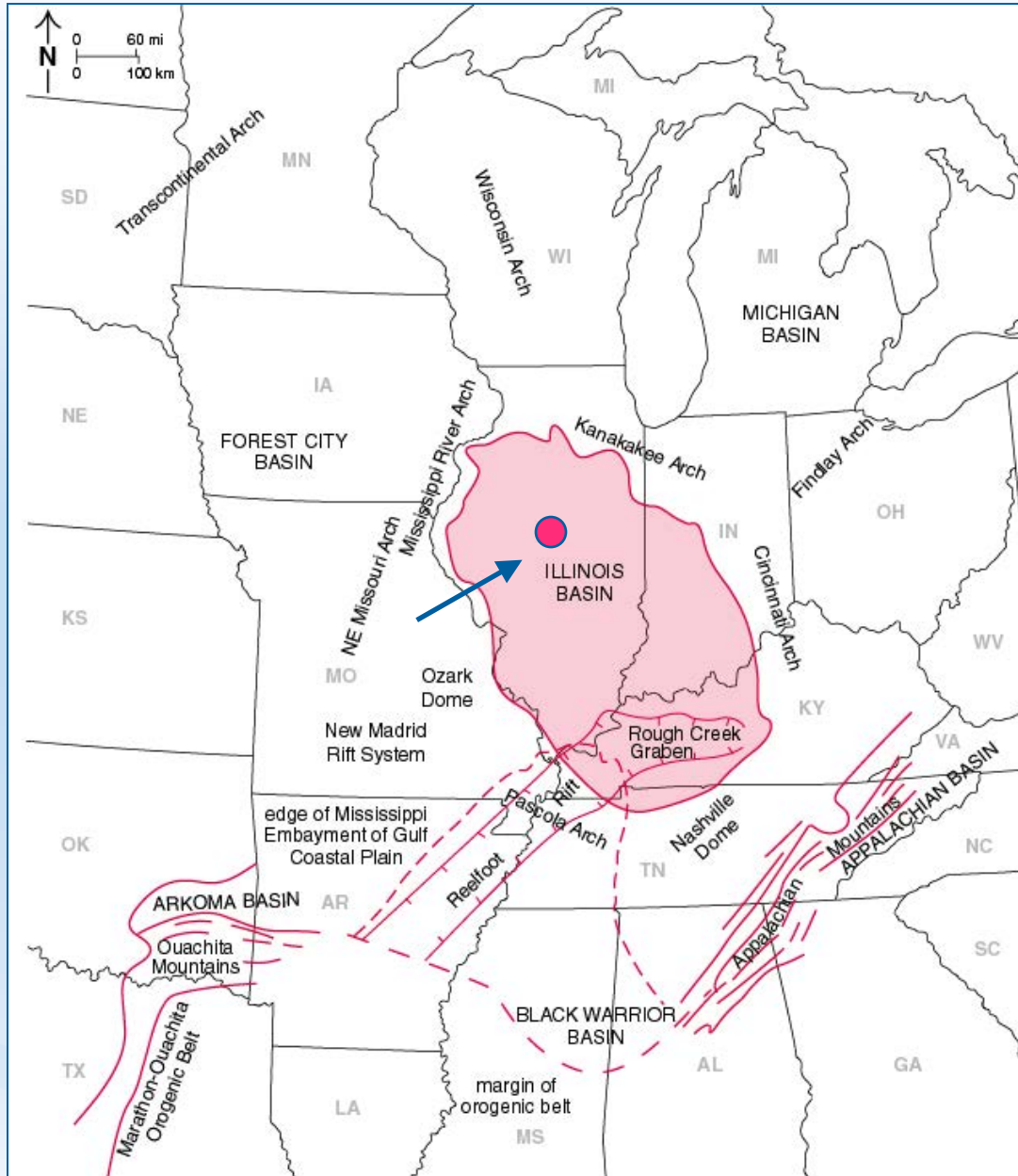


MGSC Path to Technology Innovation, Partnerships, and Collaboration

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



CCUS in the Illinois Basin

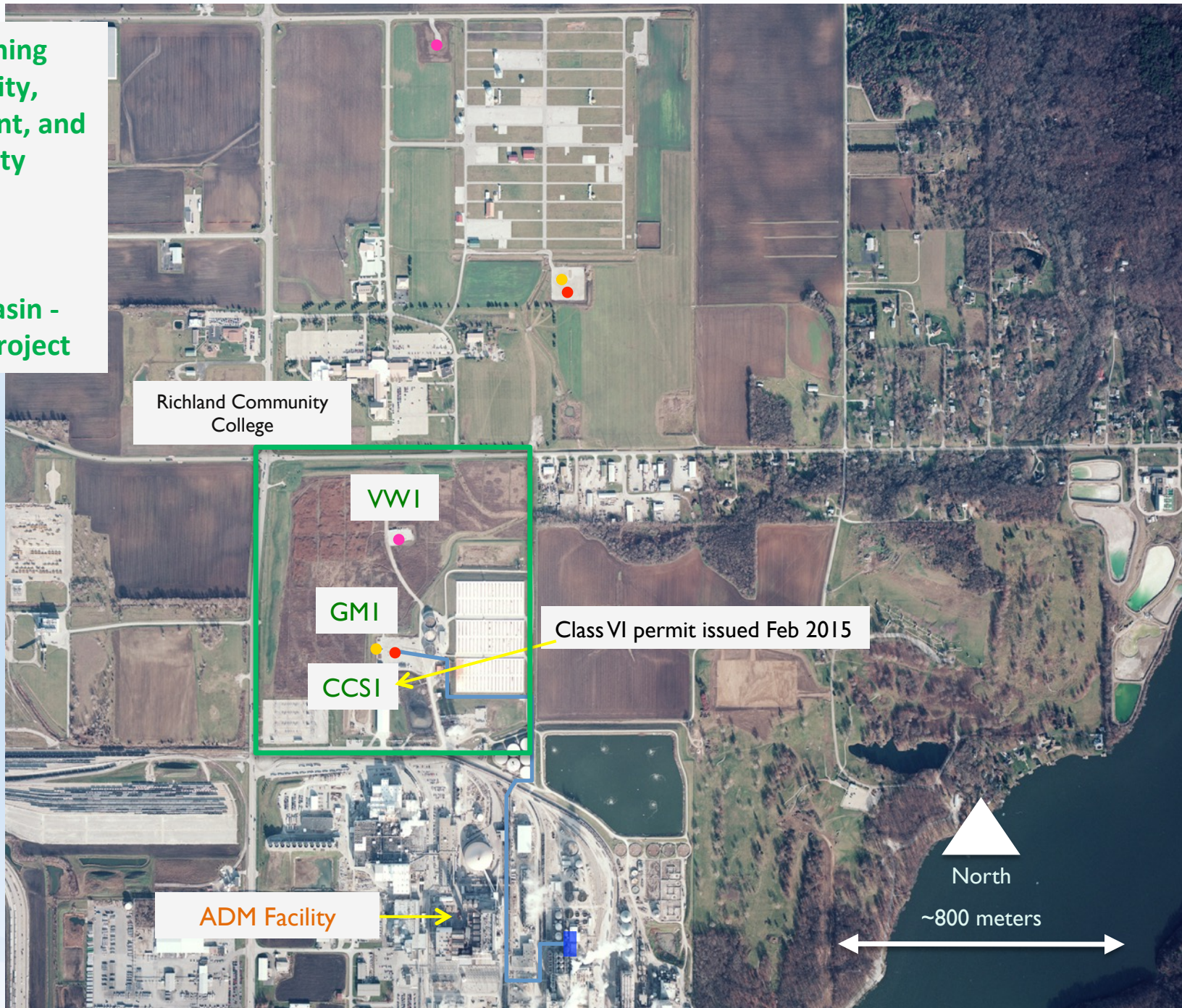


A collaboration of the Midwest Geological Sequestration Consortium, the Archer Daniels Midland Company (ADM), Schlumberger Carbon Services, and other subcontractors to inject 1 million metric tons of anthropogenic carbon dioxide at a depth of ~2,100 m to test **geological carbon sequestration in a saline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

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

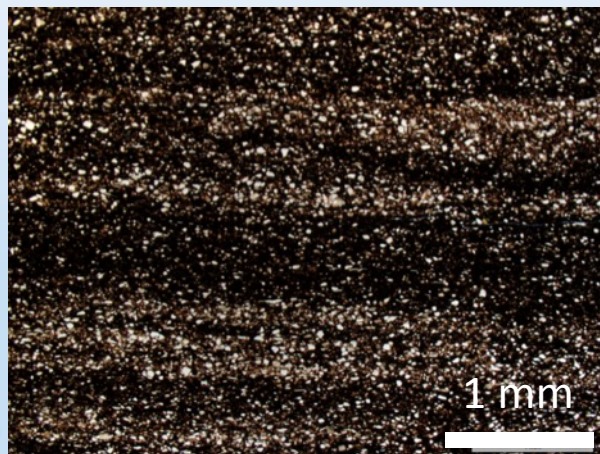
Establishing
Injectivity,
Containment, and
Capacity

Illinois Basin -
Decatur Project



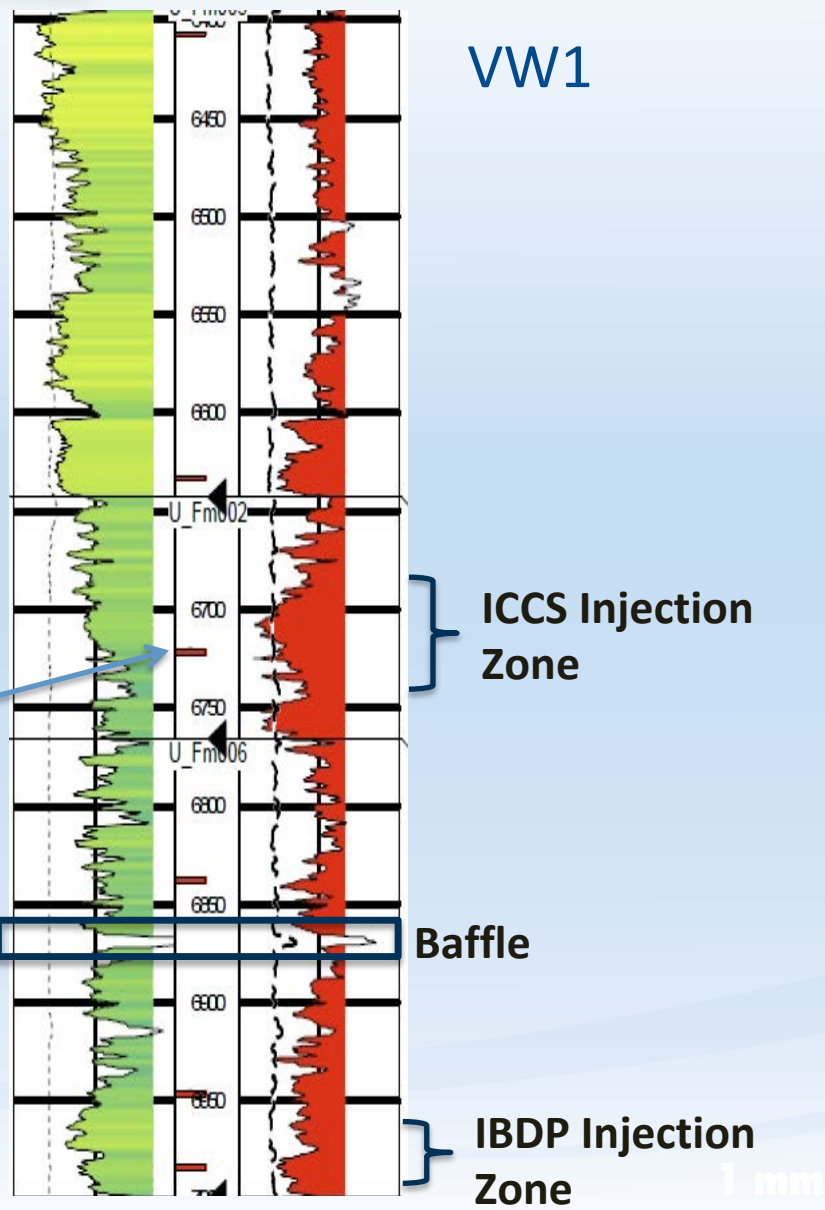
Addressing Questions

Mudstone Baffle Between Injection Zones

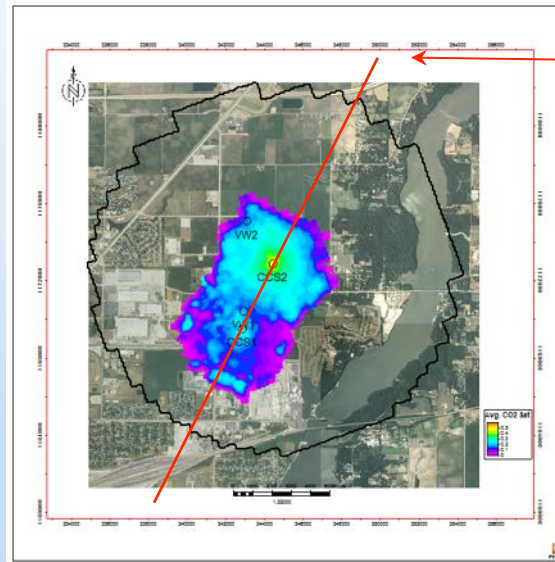


6,863-6,863.25 (2,092 m)
Porosity: 1.5%
 K_v : <0.01 mD
 K_h : 4.13 mD in siltstone laminae

Zone 5

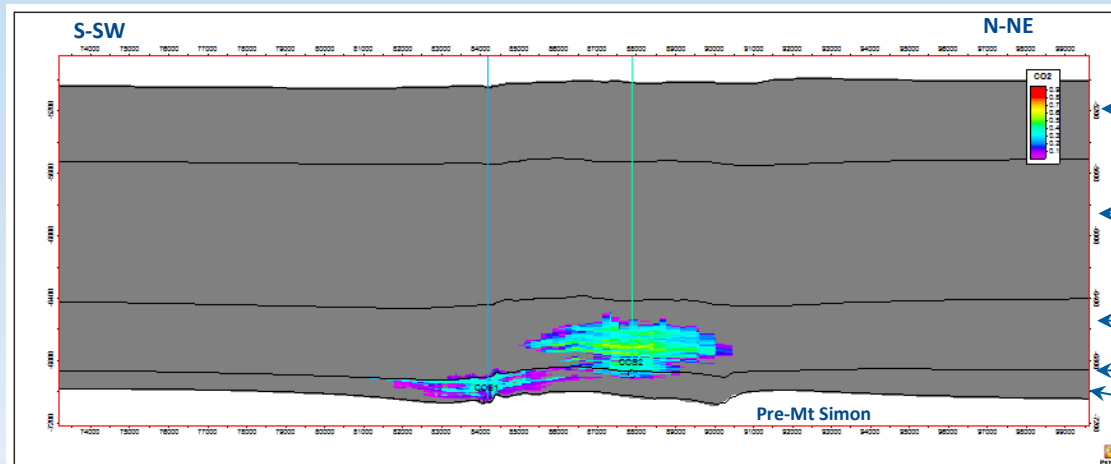


Extent of Plume & Saturation Cross Section January 1, 2020 (year 8, end of CCS2 injection)



Cross Section Orientation

— DP_{if} ≥ 86 psi
SCO₂ ≥ 1.0%



Eau Claire

Mt Simon C, D, E

Mt Simon A, B

Mudstone

Lower Mt Simon A

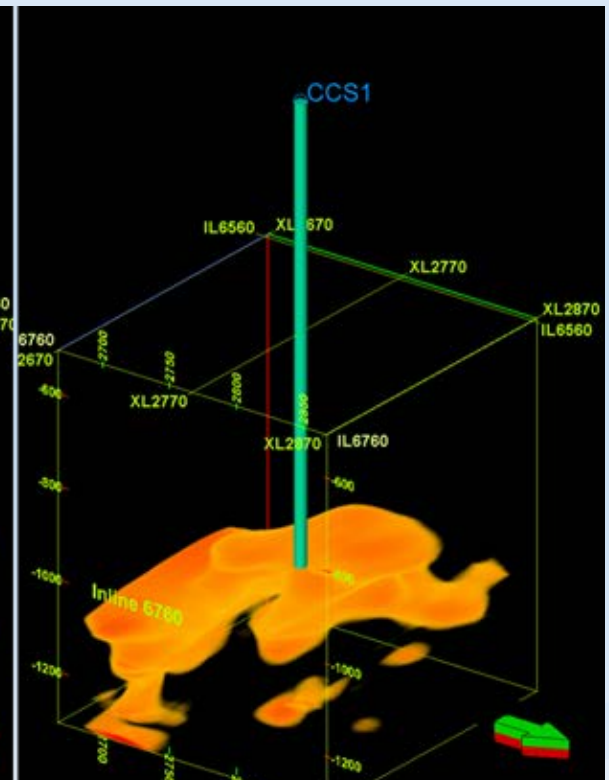
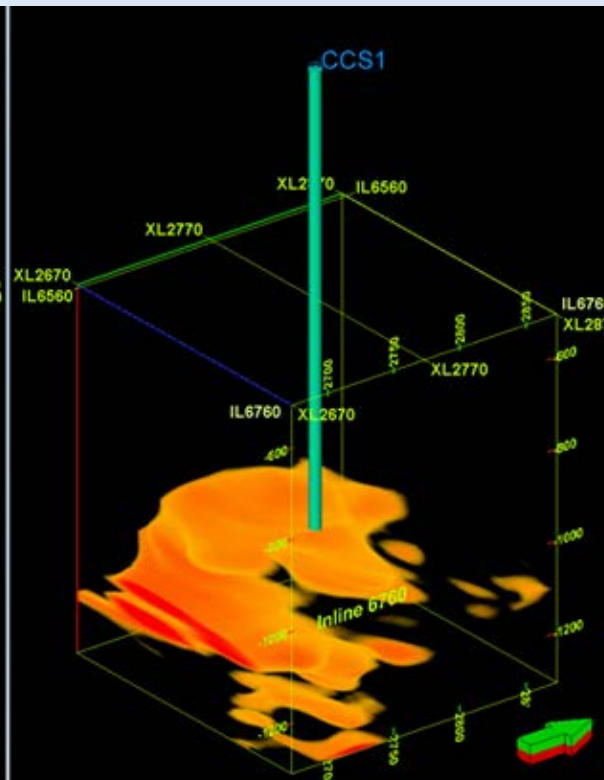
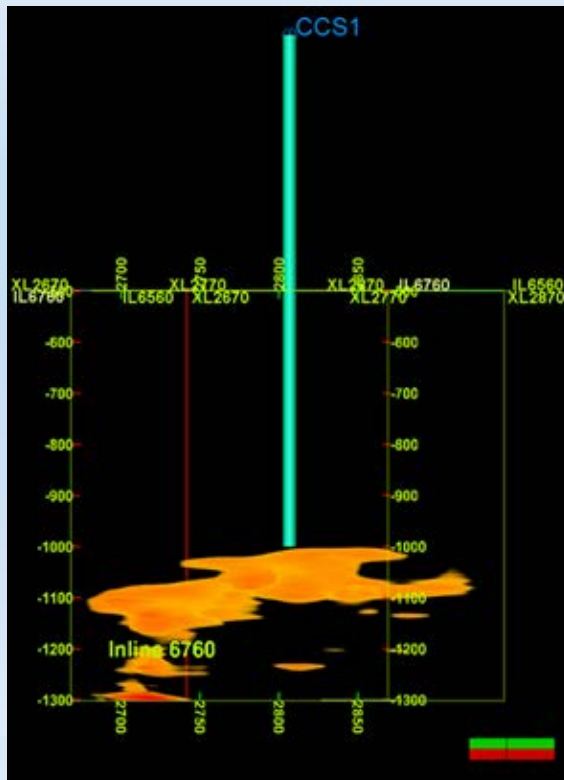
Pre-Mt Simon

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

Predictability

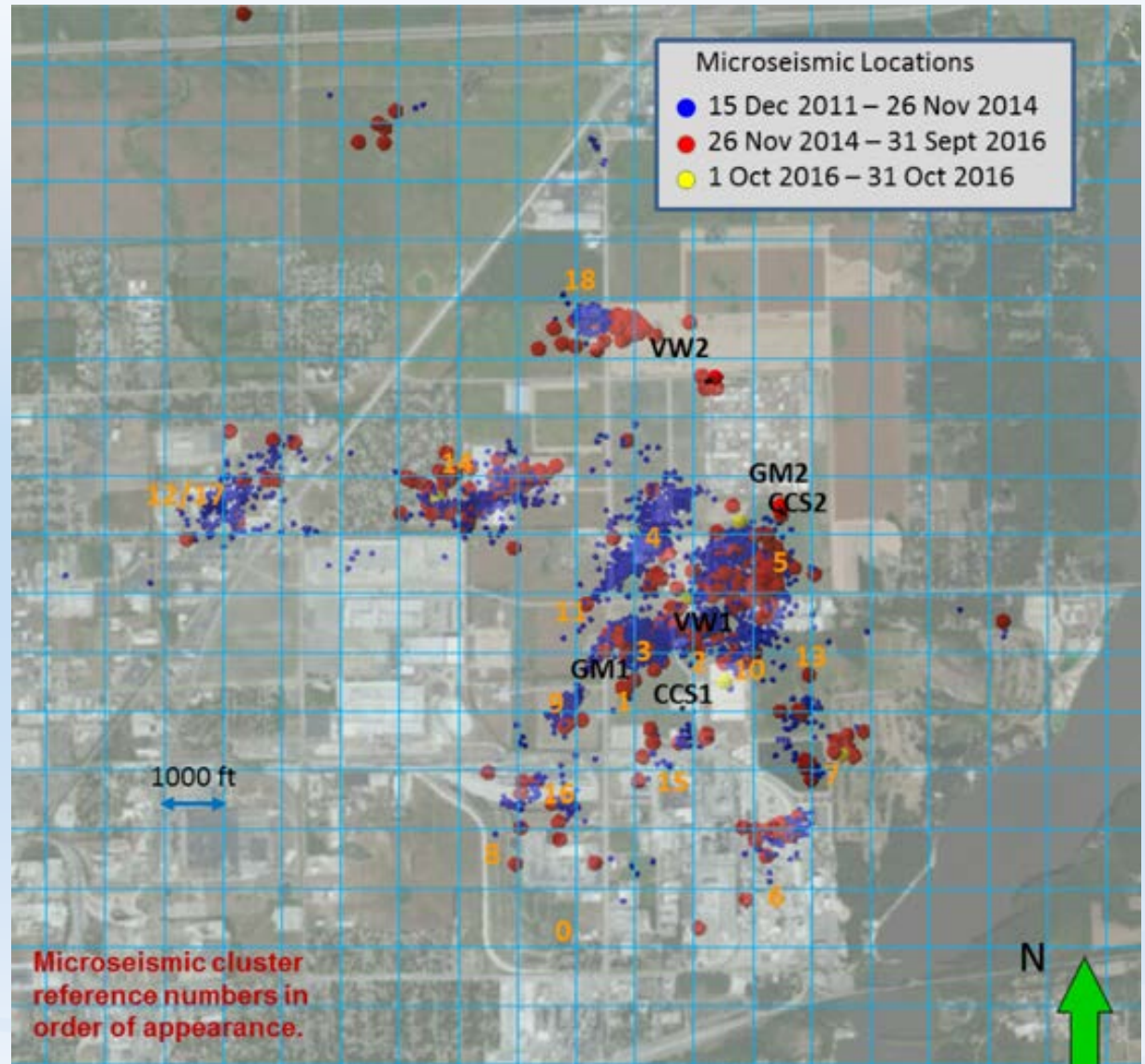
Normalized Root Mean Square

Non Rigid Matching

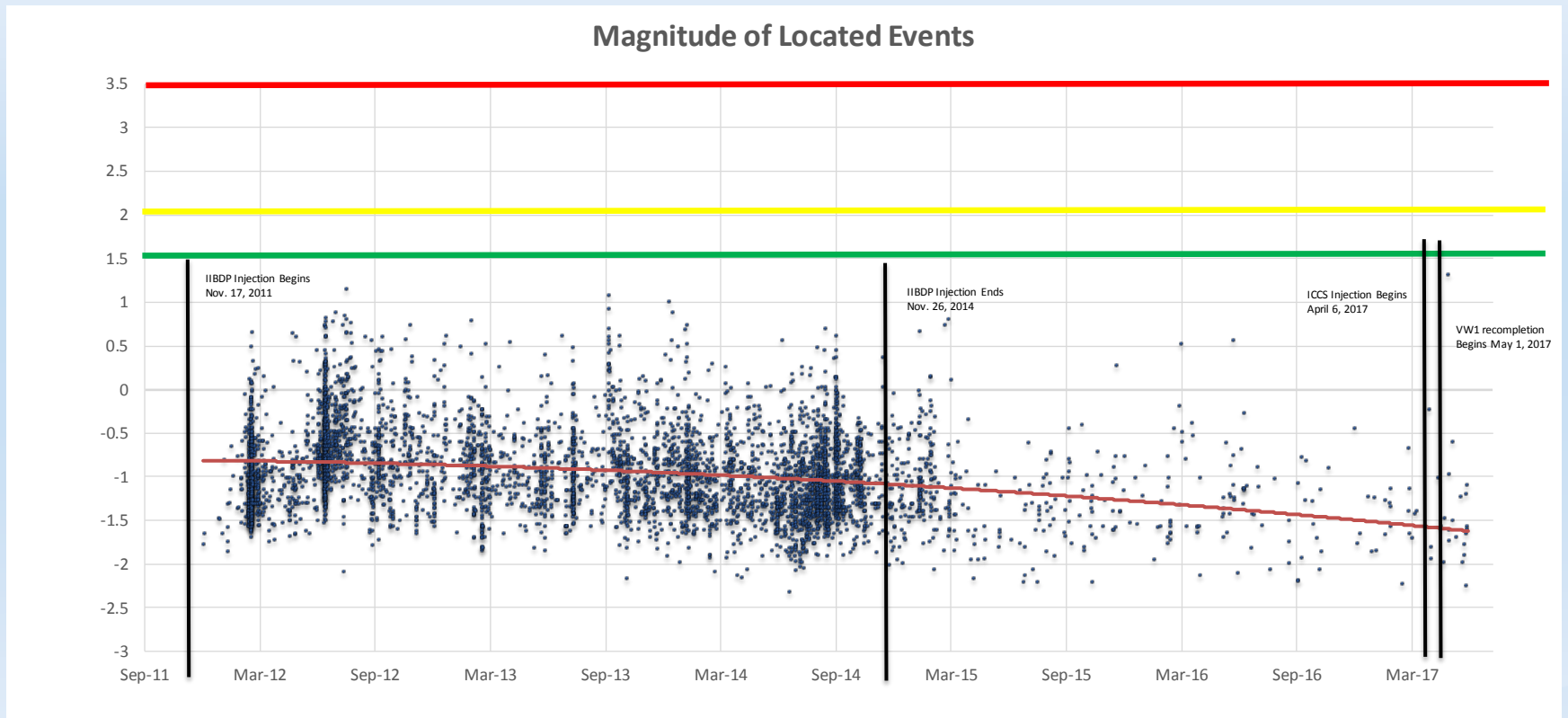


Microseismic Activity at the Illinois Basin – Decatur Project

- 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

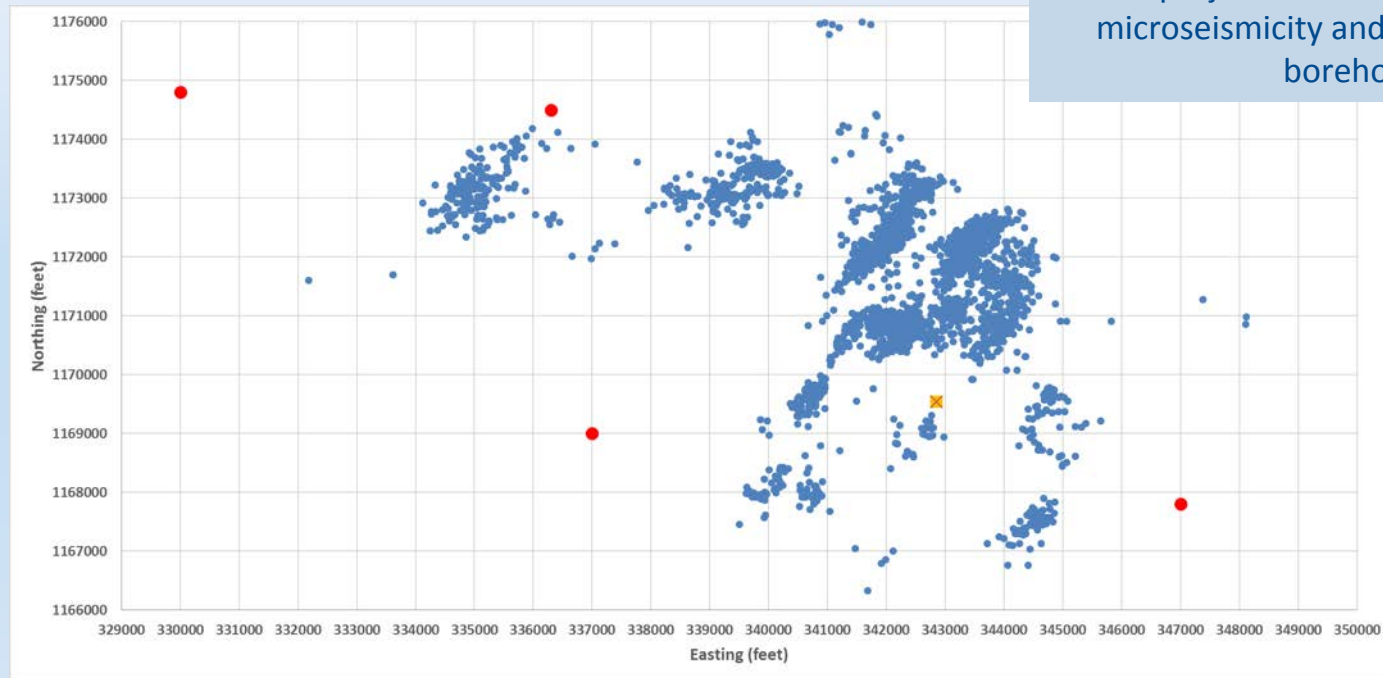


Microseismicity Time and Magnitude Related to Injection and Post-injection Activity



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

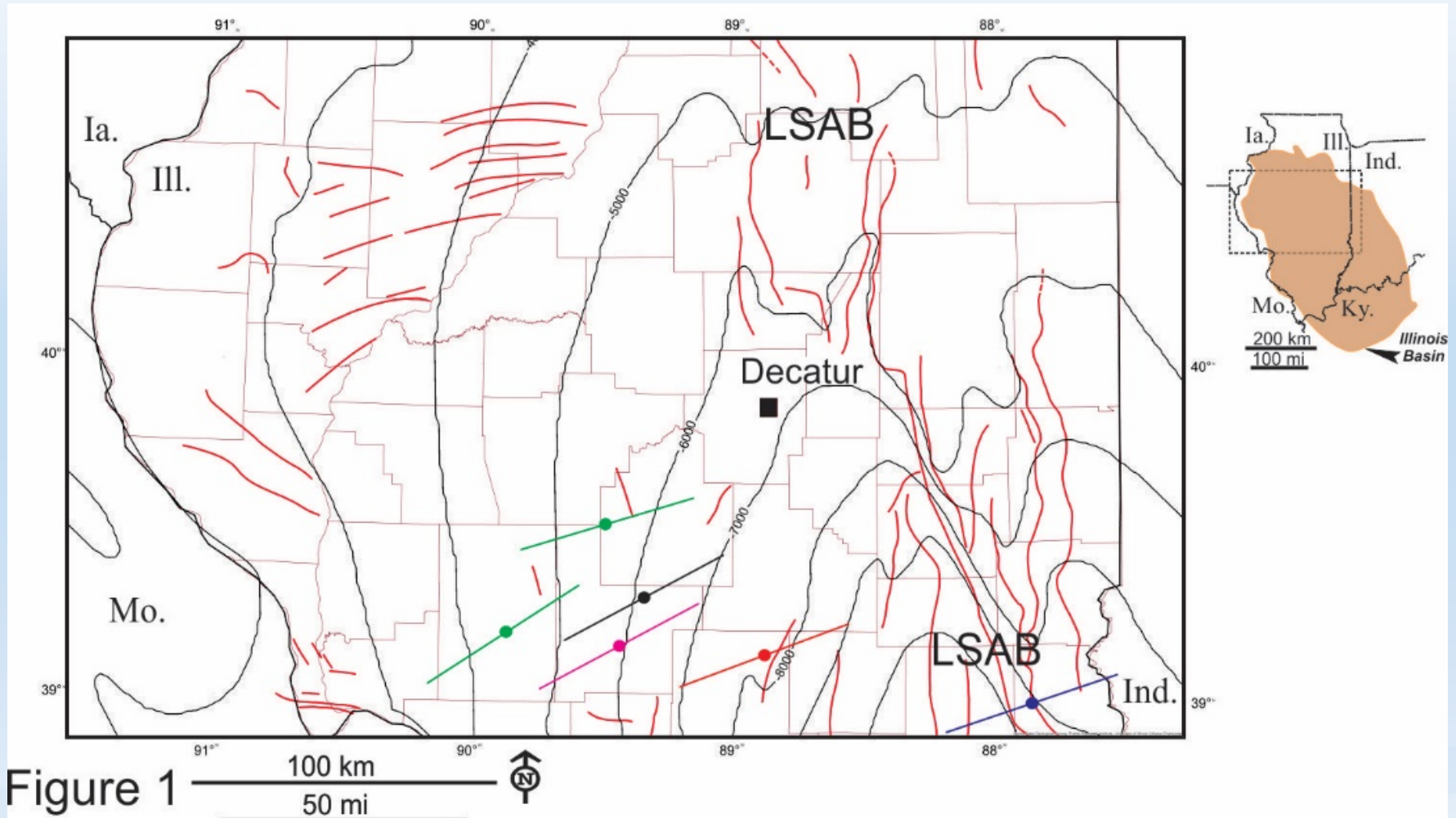
Collaboration between US and Norway: Combining passive and active seismic monitoring



Boreholes placed in glacial materials for this project in relation to recorded microseismicity and CCS1 injection borehole

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

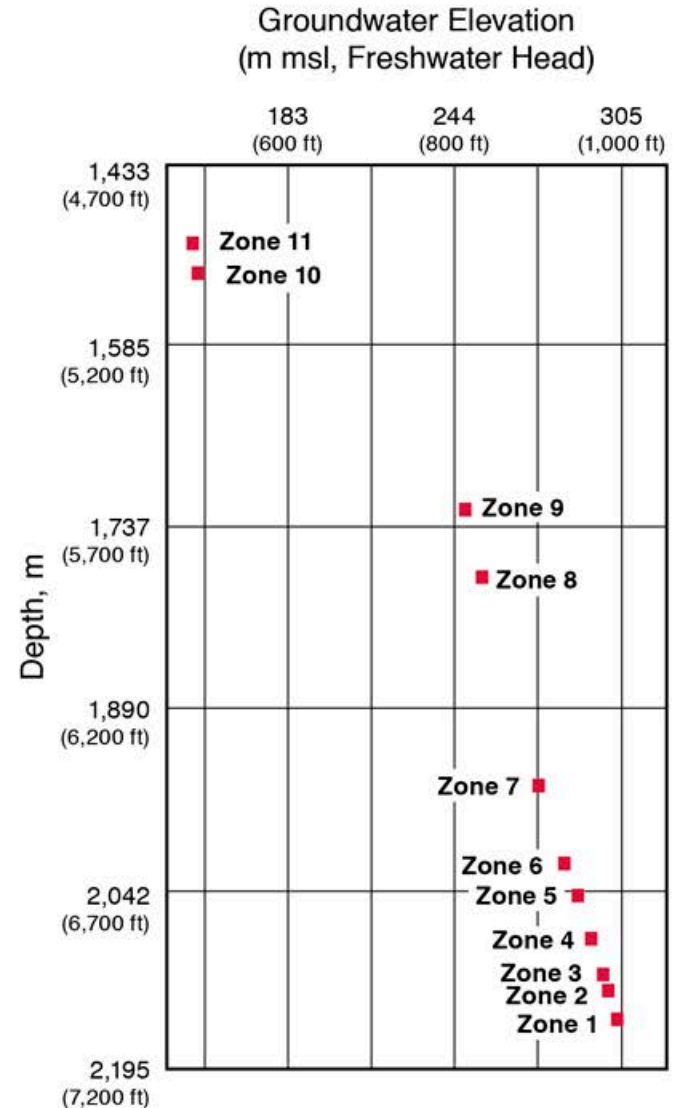
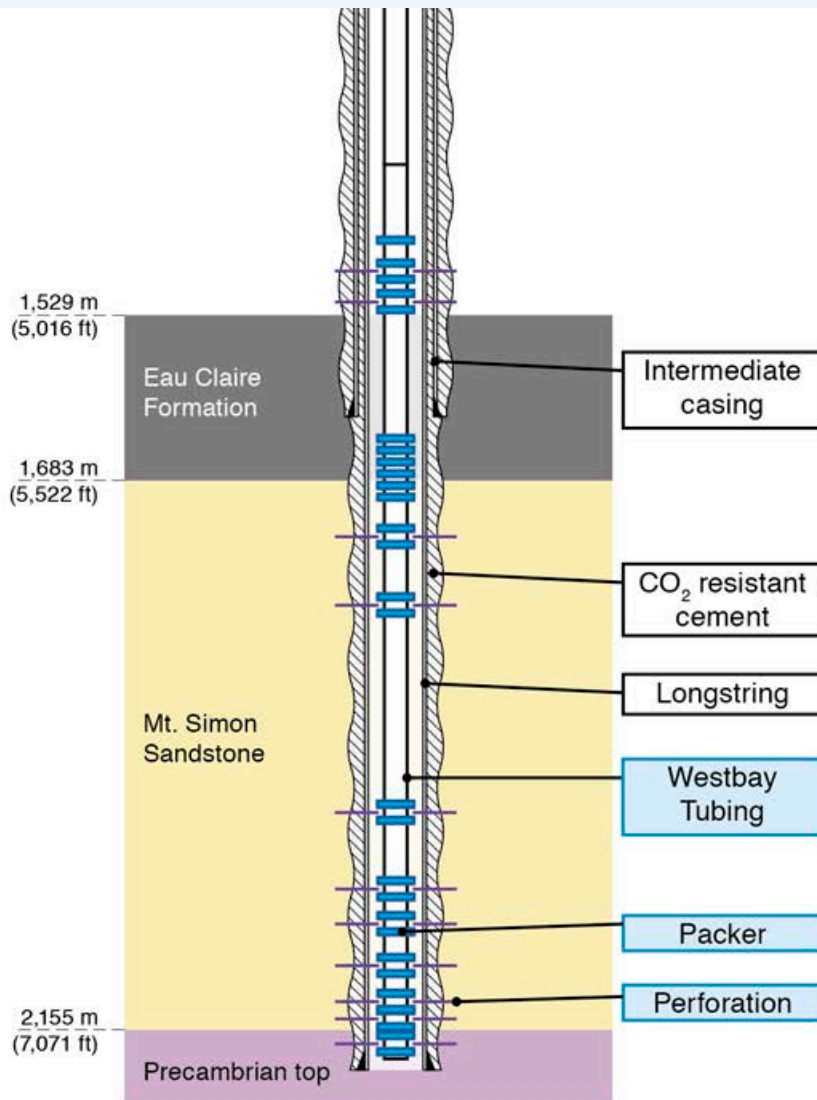
Visualizing Precambrian Basement Tectonics beneath IBDP



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

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 variable, 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 (MP30 and MP60) 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 PORT

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

PUMPING PORT

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

Completion methods include:

- packers in open borehole
- packers through temporary casing
- packers in a cased well
- direct backfill

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 permeability
- 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
- document 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

© 2015 Baker Hughes Intellectual Property



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

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:

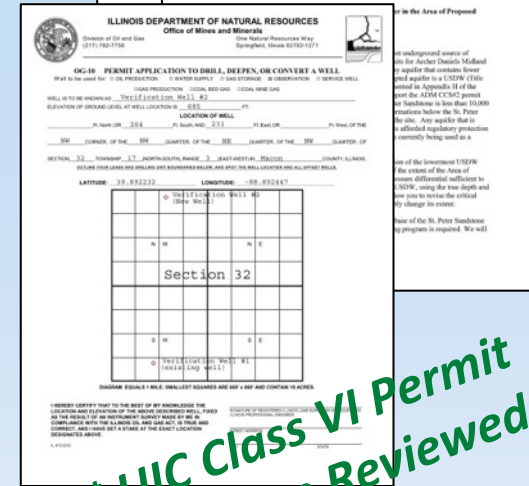
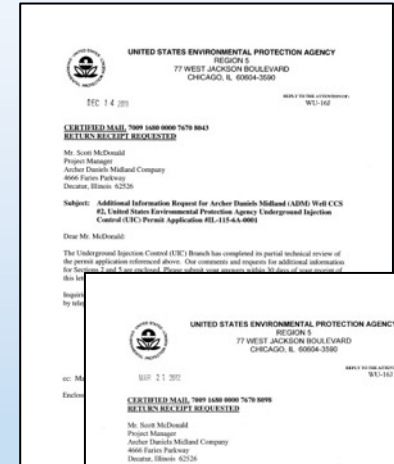
- Commercial-scale up surface and subsurface
- Multi-plume modeling
- Class VI permitting
- Regulatory MVA
- Education programs

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
surveys**

**Geochemical
sampling**

P/T monitoring

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Environmental Monitoring Framework

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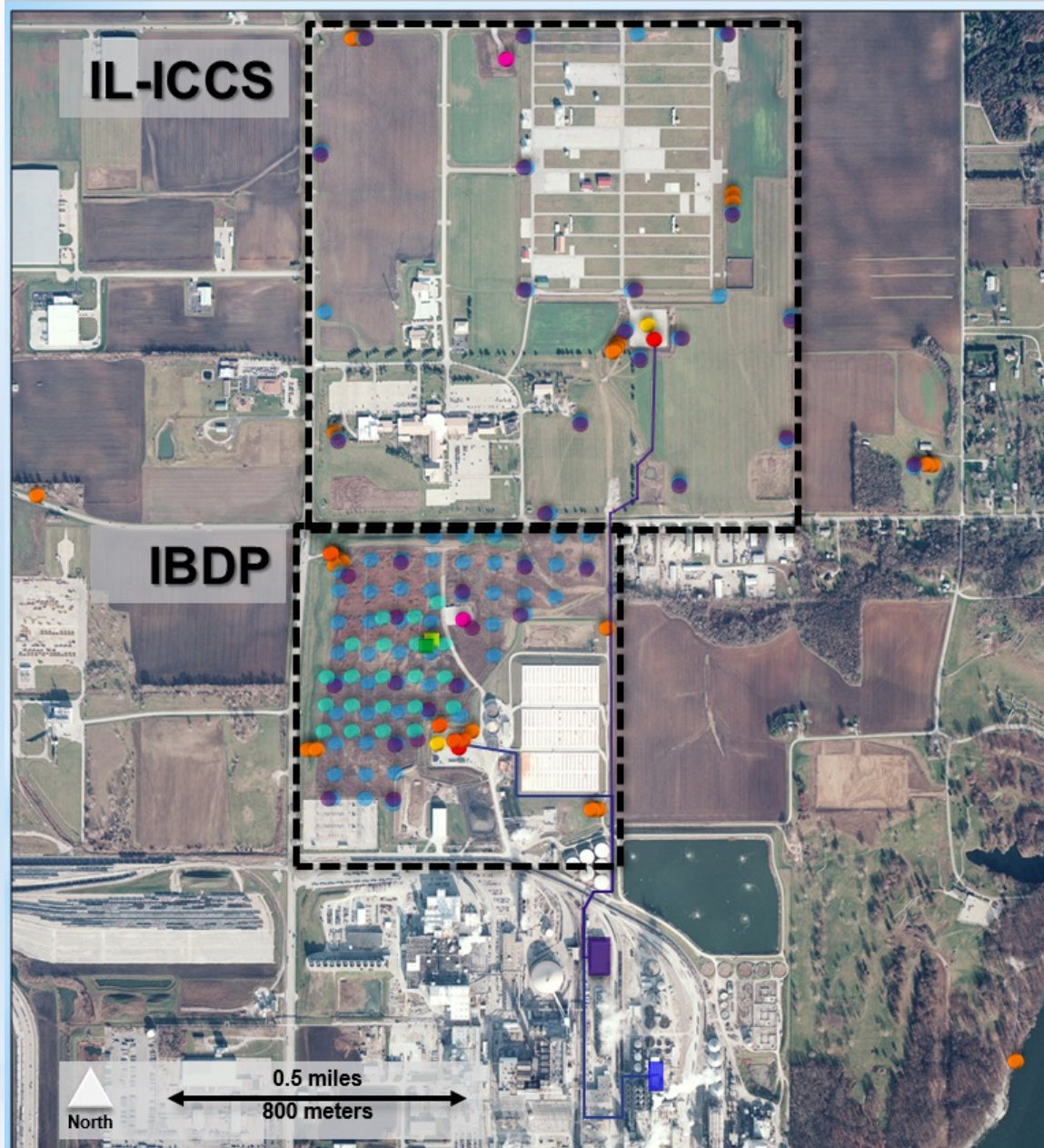
Geophysical
surveys

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
- 500,000 tonnes injected as of 12/27/18
- Eligible for 45Q
- Limited microseismic activity



Learning from Experience

Illinois Basin Industrial CCS Progression



IBDP: 1 MT

ICCS: 3 - 5.5
MT

CarbonSAFE:
>50 MT



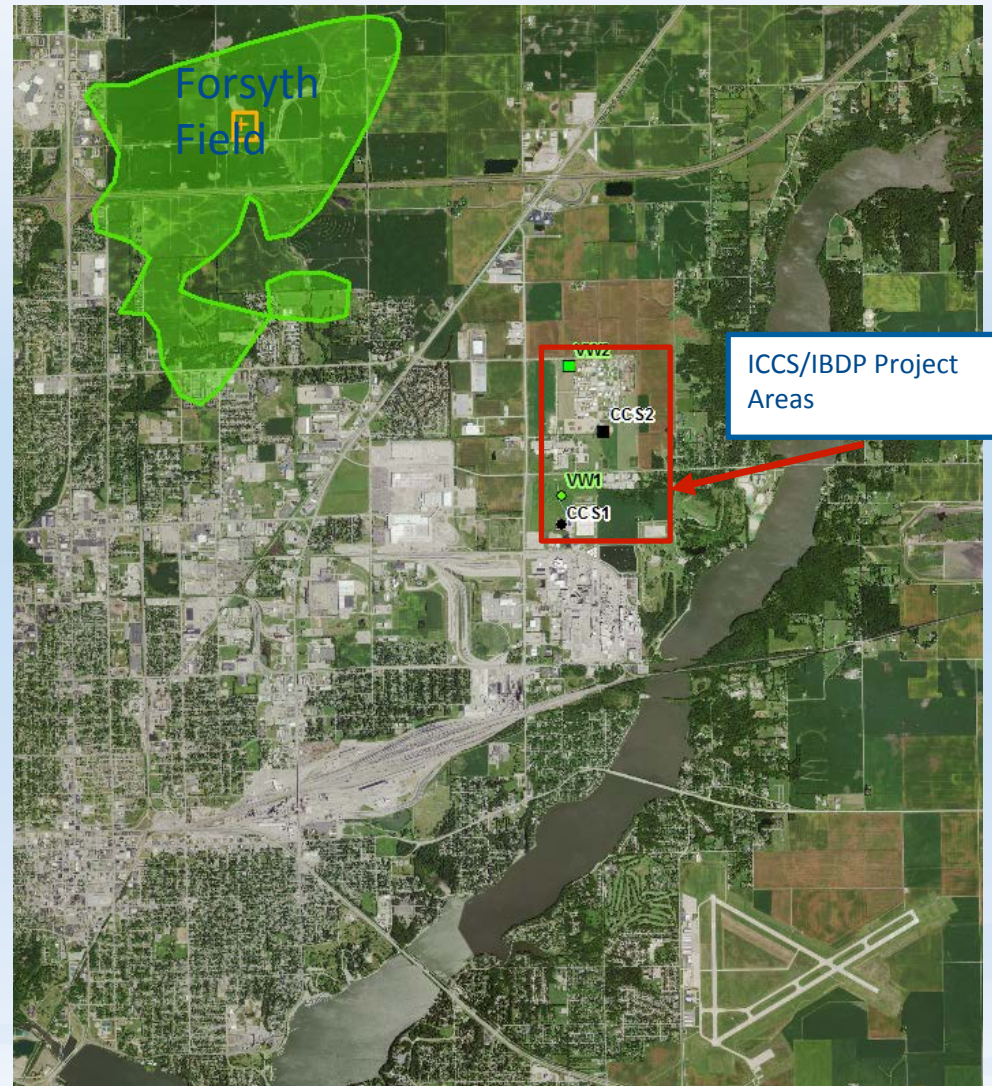
U.S. DEPARTMENT OF
ENERGY



NATIONAL
ENERGY
TECHNOLOGY
LABORATORY

CarbonSAFE Illinois – East Basin and Macon County

- Pre-feasibility East Basin
- Feasibility Decatur
- 50 million tonne Storage Complex
- Address gap in development knowledge for large-scale carbon 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:

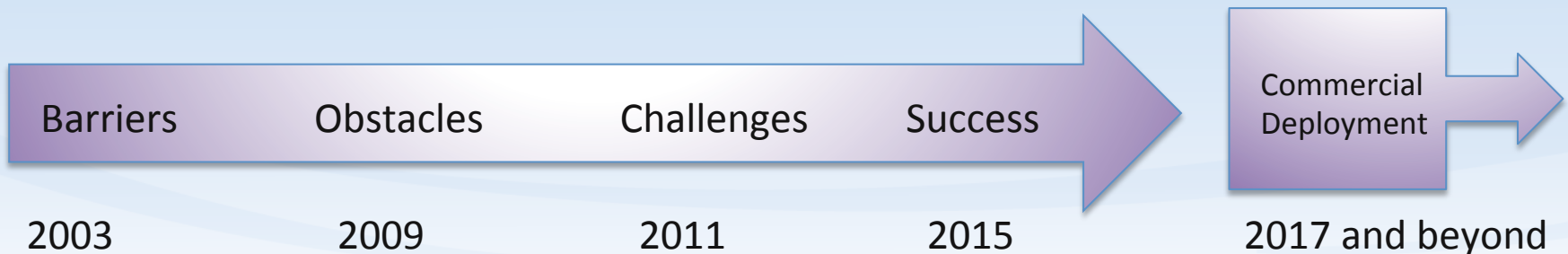
- A million tonnes stored from **biofuels** and...
- More than **5,000 meters** of drilled wells
- More than **245 meters** of collected core
- Near-surface groundwater monitoring efforts have resulted in more than **50,000 analyses**
- For basin-scale modeling, we will use **1,020,000 CPU-hours** of XSEDE supercomputing resources.
- More than **900 visitors from 30 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

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



The Future



MGSC and IBDP Future Steps

- Compliance phase of post-injection monitoring – April 2020 (tied to start of ADM Industrial CCS Sources project)
- Completion of 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 response
- Knowledge sharing and capacity building
- Publication of IBDP technical papers
- Publication of IBDP project experience and learnings book

Acknowledgements



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- The MGSC is a collaboration led by the geological surveys of Illinois, Indiana, and Kentucky
- 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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