

Developments in Storage and Monitoring for CCUS

Steve Whittaker

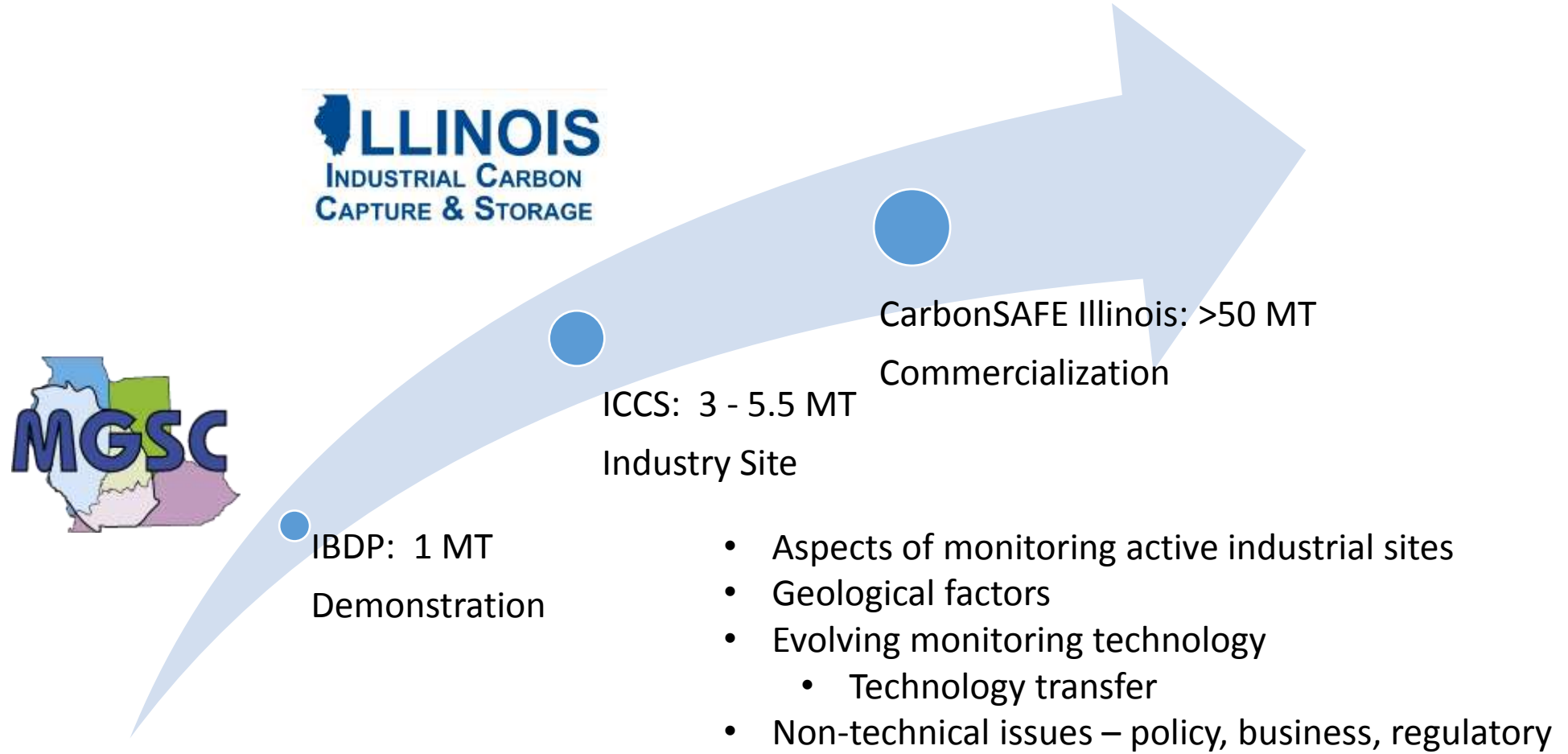
Director Energy Research & Development

Illinois State Geological Survey

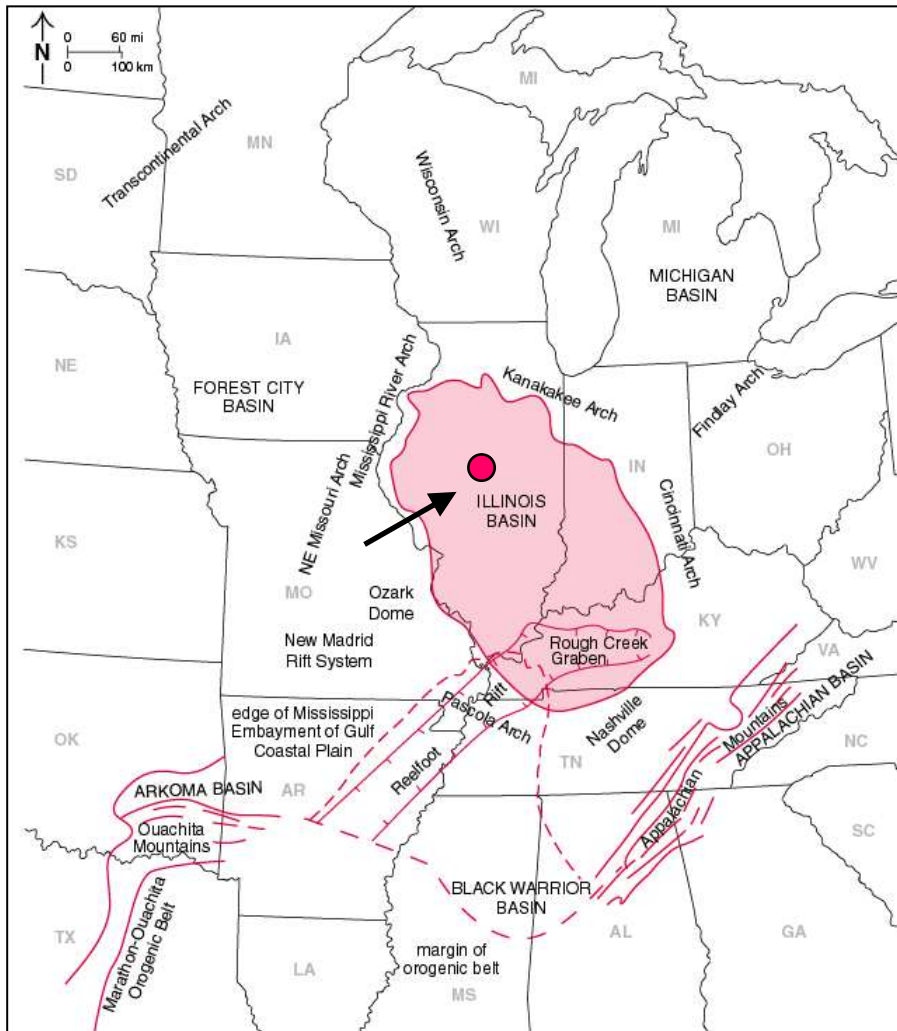
4th Beijing International Forum on Carbon Capture, Utilization and Storage Technology



CCUS Progression to Commercialization



STORAGE: Geology - Illinois Basin



4th Beijing International Forum CCUS

Mt Simon Storage Complex

- Sandstones about 2100m (7,000 ft) depth

Illinois Basin – Decatur Project

- Demonstration 1 MT CO₂

Illinois Industrial CCS Project

- Industrial 3.5 – 5 MT CO₂

CarbonSAFE Illinois

- Commercial >50 MT CO₂

Lower Cambrian Sandstones used for CCUS at other North American storage sites

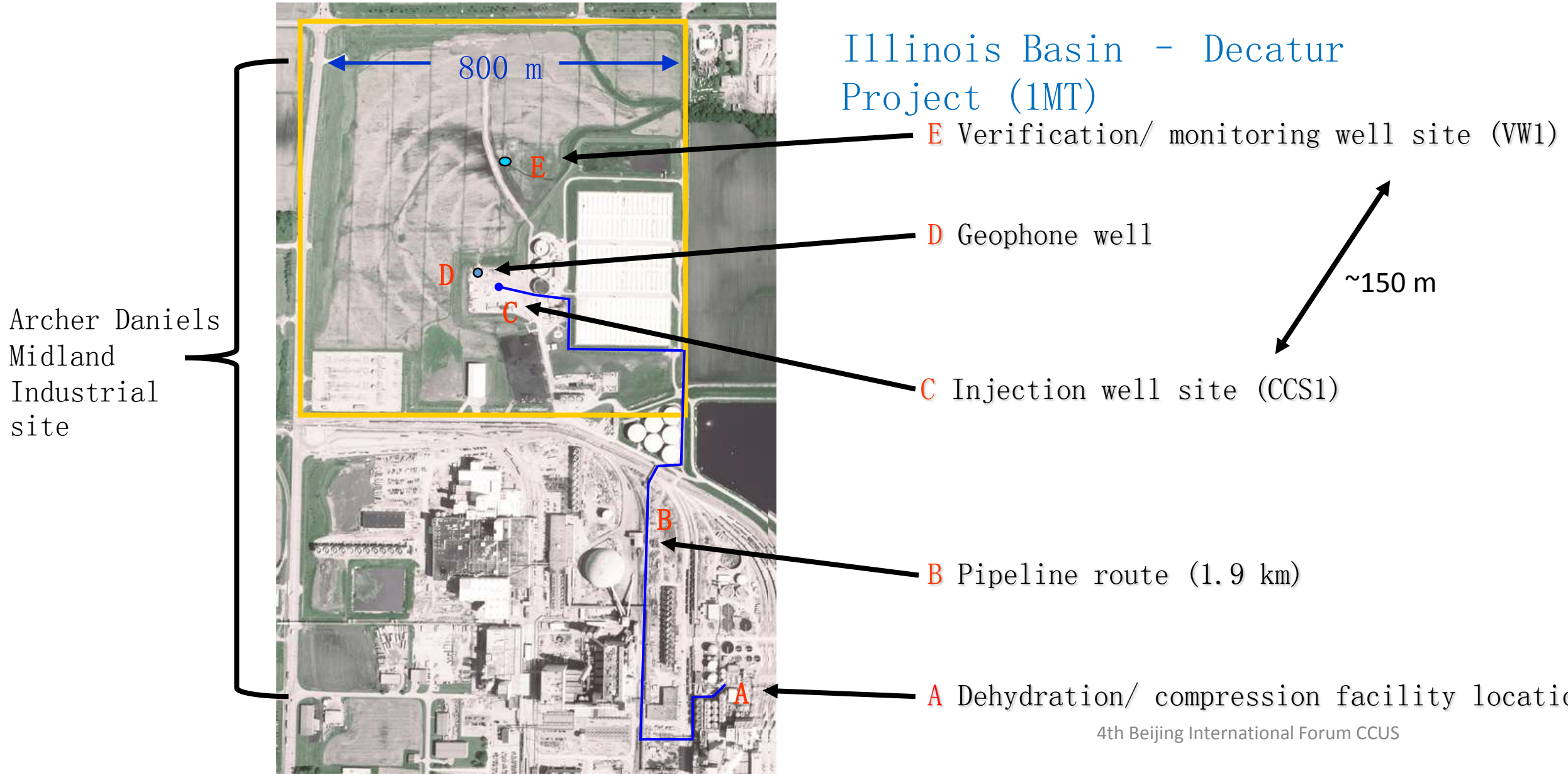
- QUEST – Alberta Canada
- AQUISTORE – Saskatchewan Canada
- Michigan USA

SYSTEM	GROUP	FORMATION	Storage Elements	
Ordovician	Maquoketa	Brainard	Secondary Seal	
		Ft. Atkinson		
		Scales		
	Galena	Kimmswick	Secondary Seal/Reservoir	
		Decorah		
	Plateville	Joachim	Potential target	
		St. Peter		
	Cambrian	Knox	Shakoppee	Secondary Seal/Reservoir
			New Richmond	
			Oneota	
Gunter				
Eminence				
St. Peter-Knox Storage Complex		Potosi	Potential target	
		Franconia	Primary Seal	
		Ironton-Galesville		
		Eau Claire		
		Mt. Simon		Target reservoir
Precambrian				

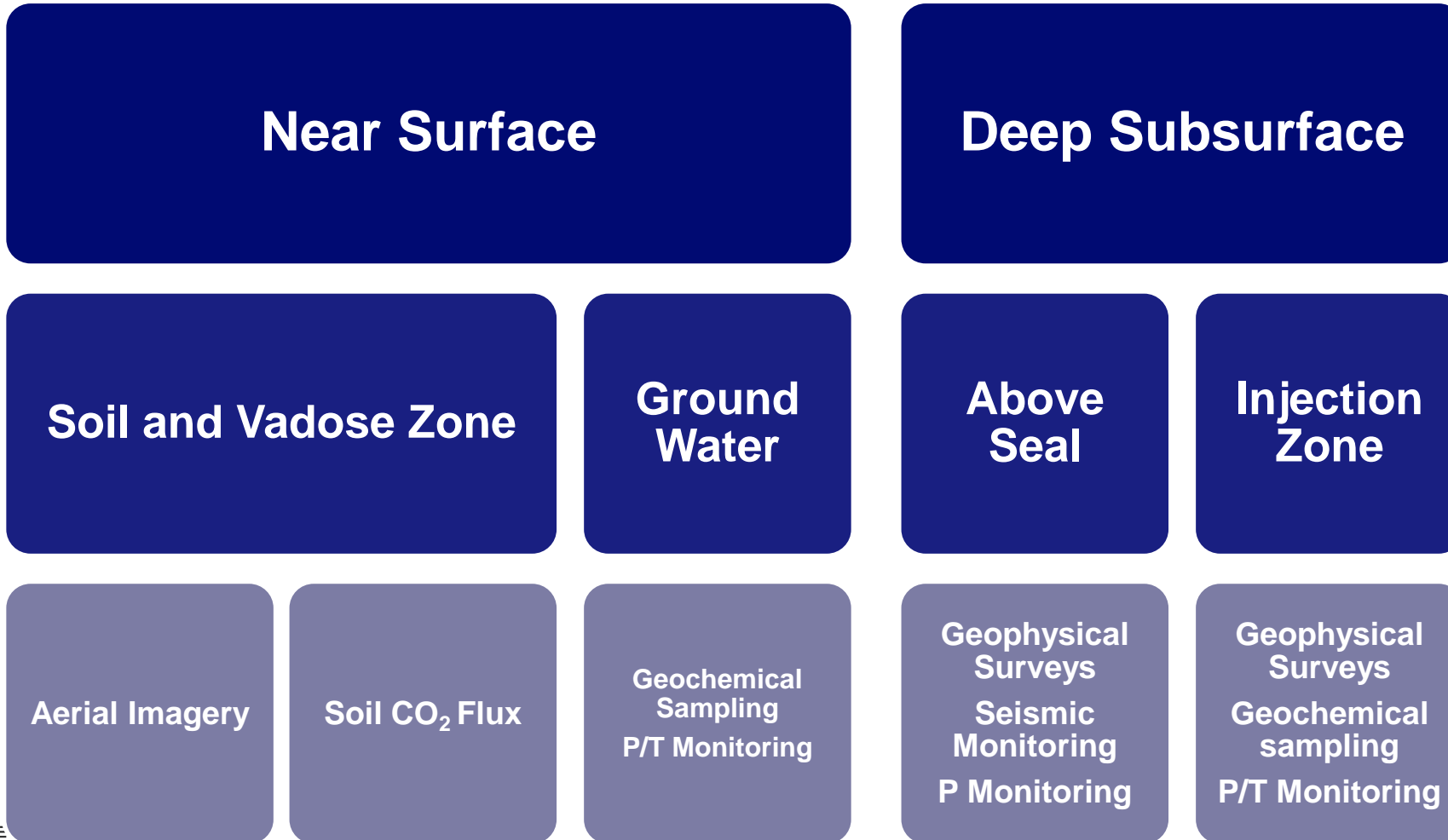
Mount Simon Storage Complex:

11 to 150 GT
(Efficiency = 0.4 to 5.5%)

Industrial Sites Impact Monitoring



Environmental Monitoring (MVA) *Risk Based Conceptual Framework*



MONITORING: Verification Well 1 - Westbay Completion

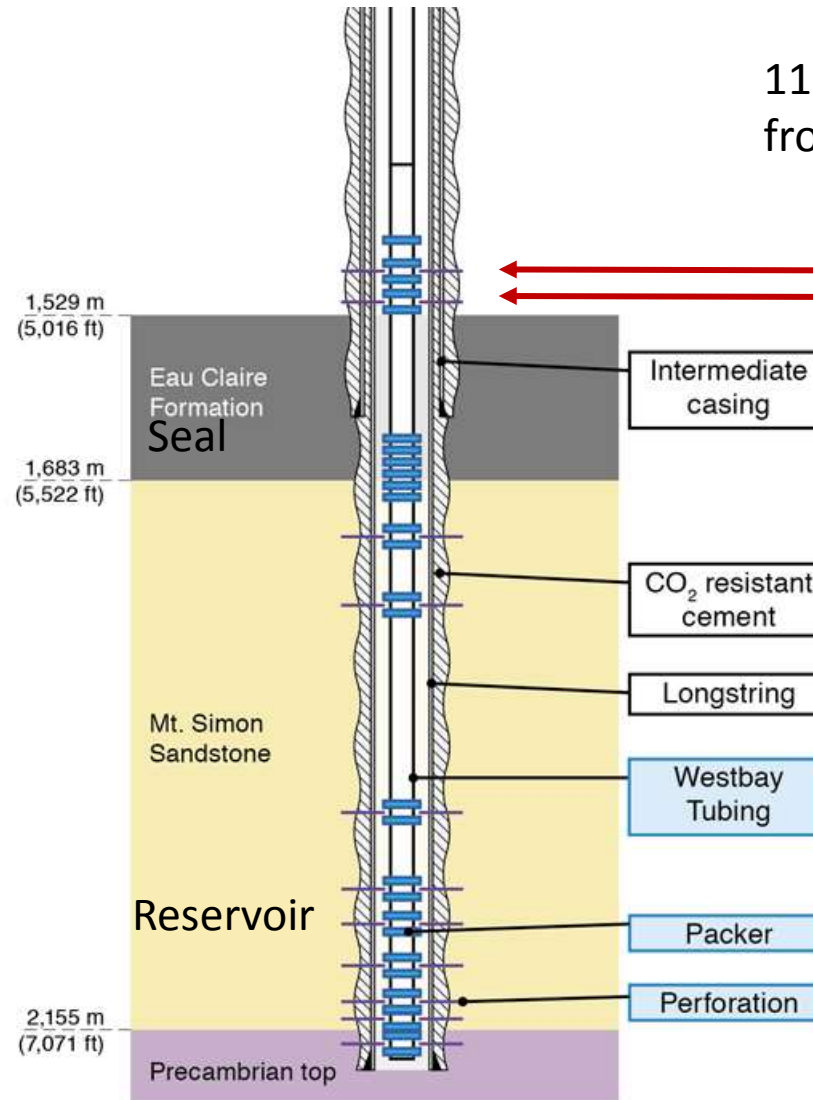
Deepest Westbay installation in the world 7126 ft (2172 m)



- Inflatable packer

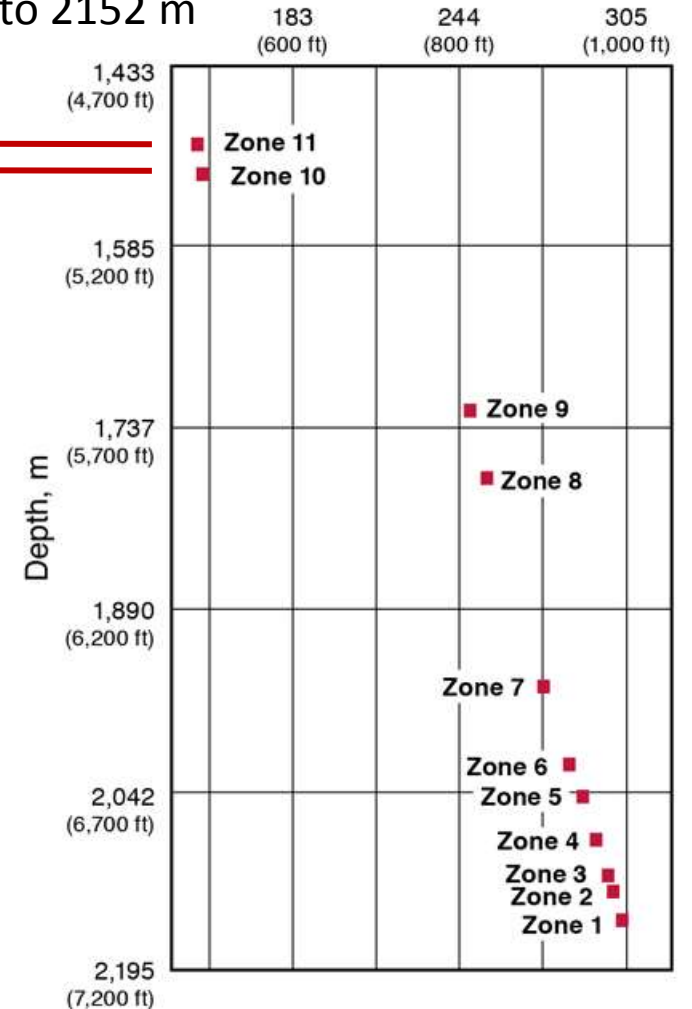
- Pressure and fluid sampling port

- Sliding Sleeve



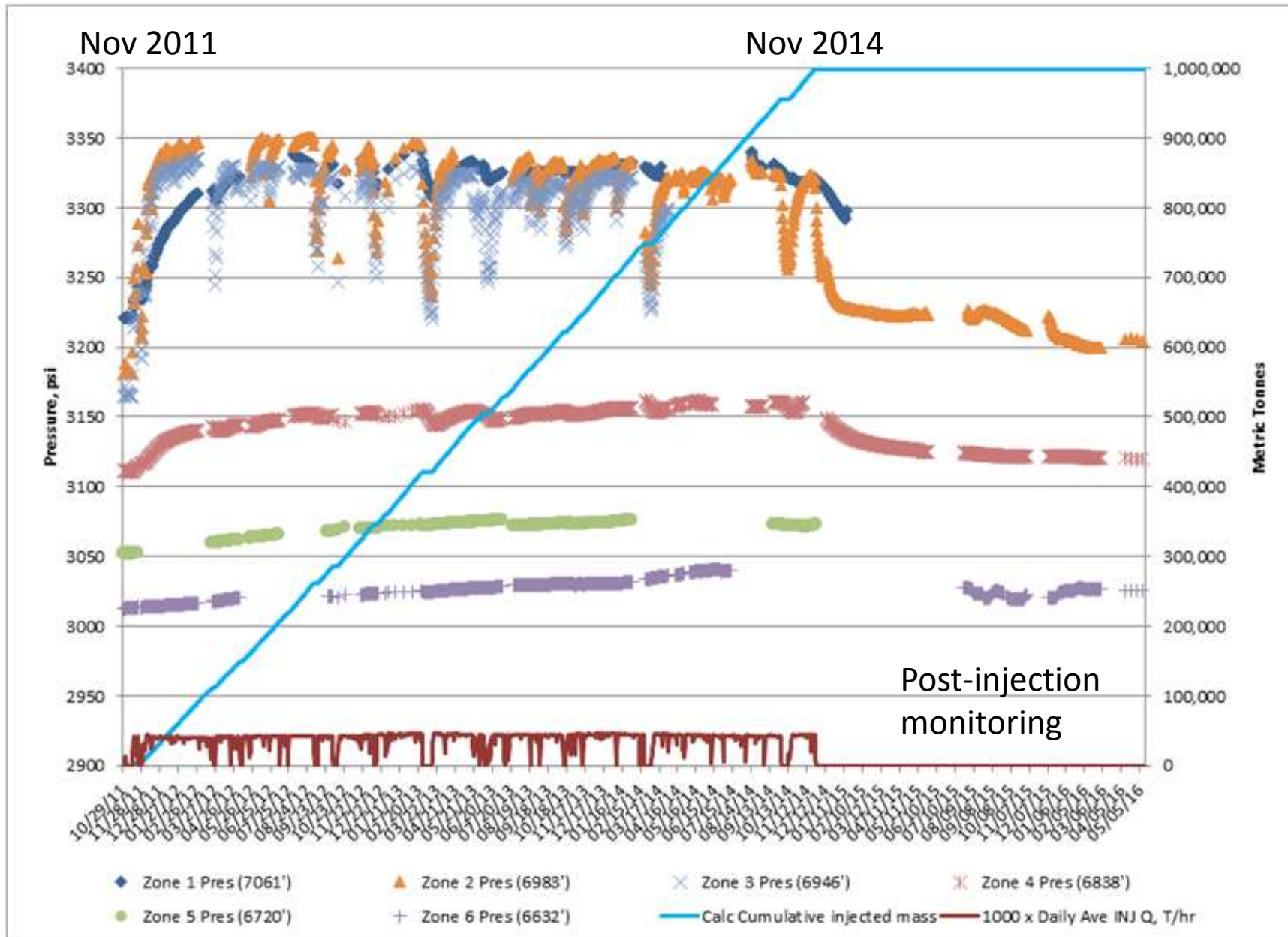
11 monitoring zones
from 1493 to 2152 m

Groundwater Elevation
(m msl, Freshwater Head)



Monitoring zones in injection zone and above seal

MONITORING: Pressure Response in Verification Well 1



IBDP = 1MT
injection
(999,215 tonnes)

MONITORING: Upgrading Technology Recompletion of VW1 Well

- Option 1 – Retain Westbay
- Option 2 – Schlumberger IntelliZone
- **Option 3 – Baker Hughes Intelligent System**
- Option 4 – Drill new 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 deformability, 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 (MP28 and MP36) and manufactured from plastic or stainless steel to fit various borehole dimensions and operational requirements. Hydraulically-actuated packers and/or backseals provide engineered seals between monitoring zones, preventing unwanted flow and cross-contamination. Valved ports 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

WESTBAY SYSTEM PROBES
A variety of probes are available for use with the Westbay System. Reliable, accurate, and 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
- document quality assurance

For more information, visit www.bakerhughes.com



Oil field technology transfer

REPacker™ Reactive Element Packers



Baker Hughes Intelligent System



HCM-Plus Hydraulic Sliding Sleeve

Baker Hughes intelligent well systems flow control valves



The Baker Hughes intelligent HCM™ Plus downhole valve provides remote and reliable isolation of a specific interval. It reduces costs and increases production efficiency by allowing production to continue from the wellbore to be allowed without intervention from the surface. This product is compatible with oil or water-based control fluids.

The hydraulically balanced piston exerts high shifting forces to overcome scale and debris, and it requires less 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 reliable control line gas tool 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 shut-in 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

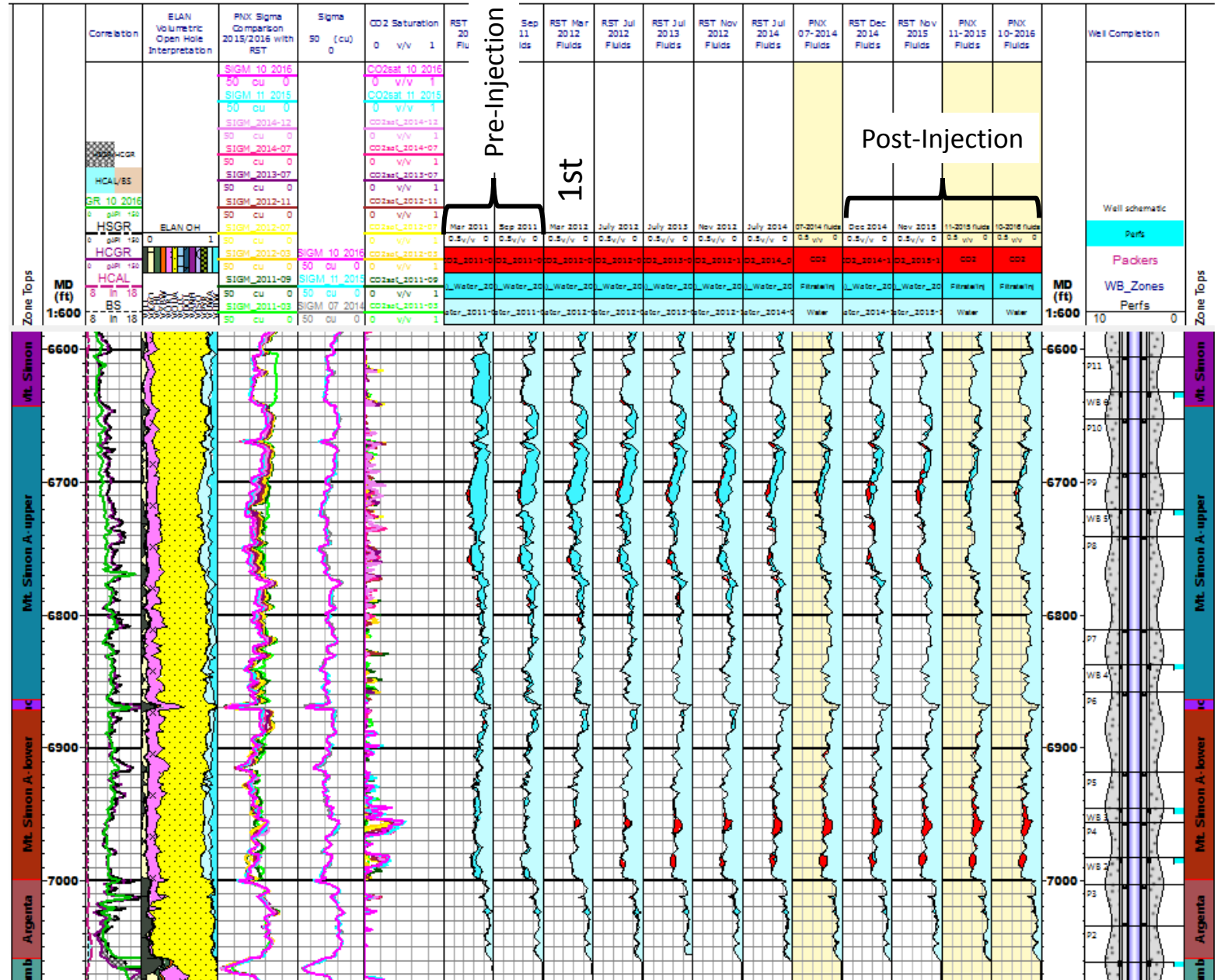
- Balanced piston design to open and close the valve at deep setting depths
- Simple surface procedures for valve isolation
- Non-Abutment sealing technology for high-performance sealing from tubing to annulus
- Testable control line gas tool fittings
- Control line bypass allows multiple valves, sensors, or chemical injection valves to be set as part of an intelligent well system
- Internal profiles allow placement of flow control devices
- Integral profile for receiving mechanical shifting
- Water or oil based control line fluid compatible

- Two Fluid Sampling
- Four Pressure Zones

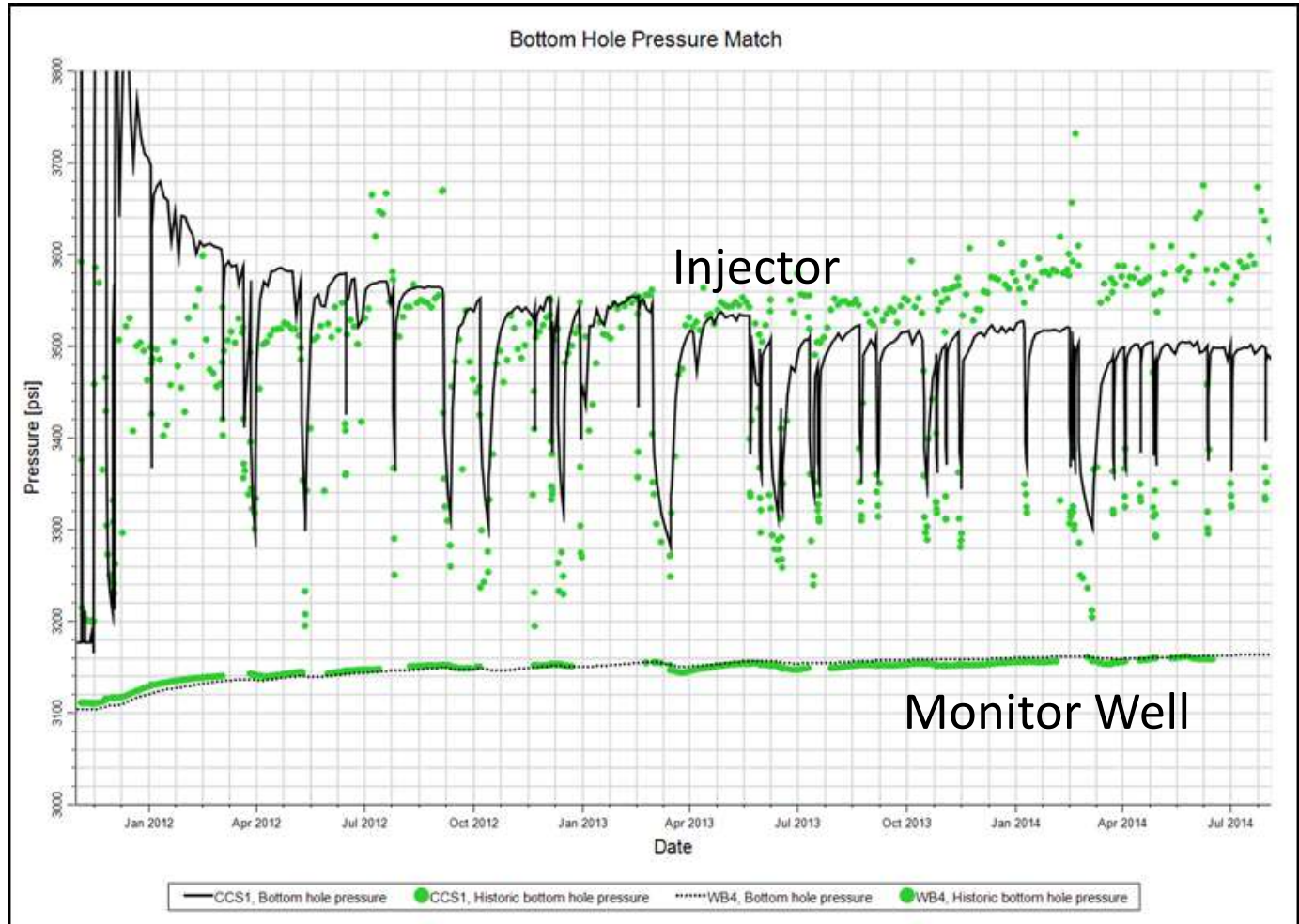
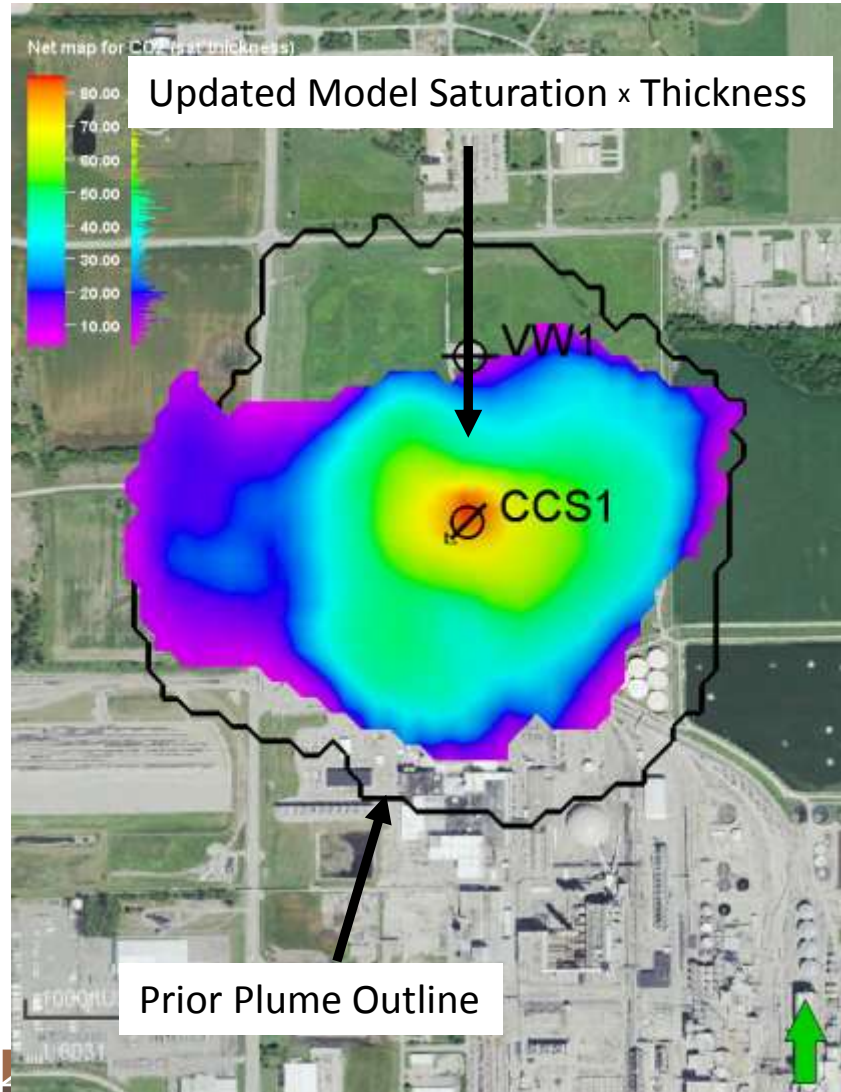
MONITORING: Repeat Pulsed Neutron Logging in VW1

RST Monitoring

- Baseline surveys
- CO₂ arrival before Mar 2012
- CO₂ saturation increasing though Nov 2015



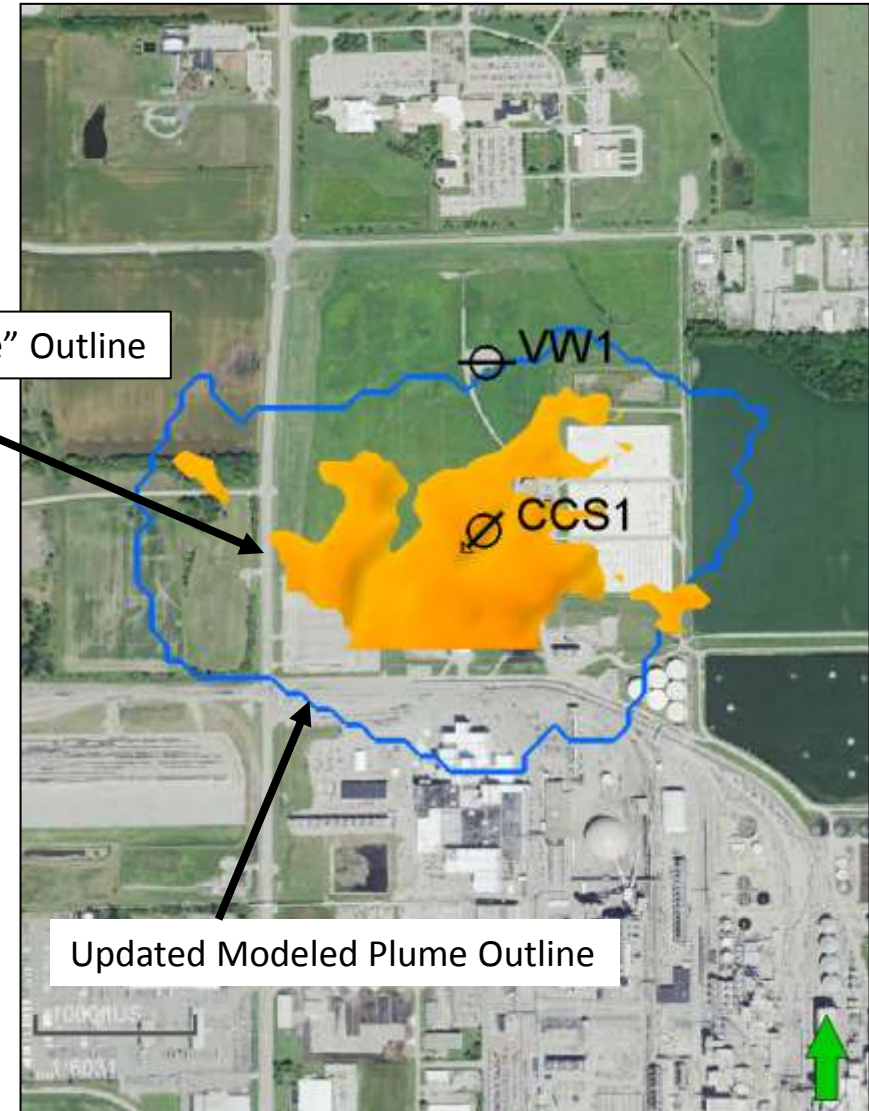
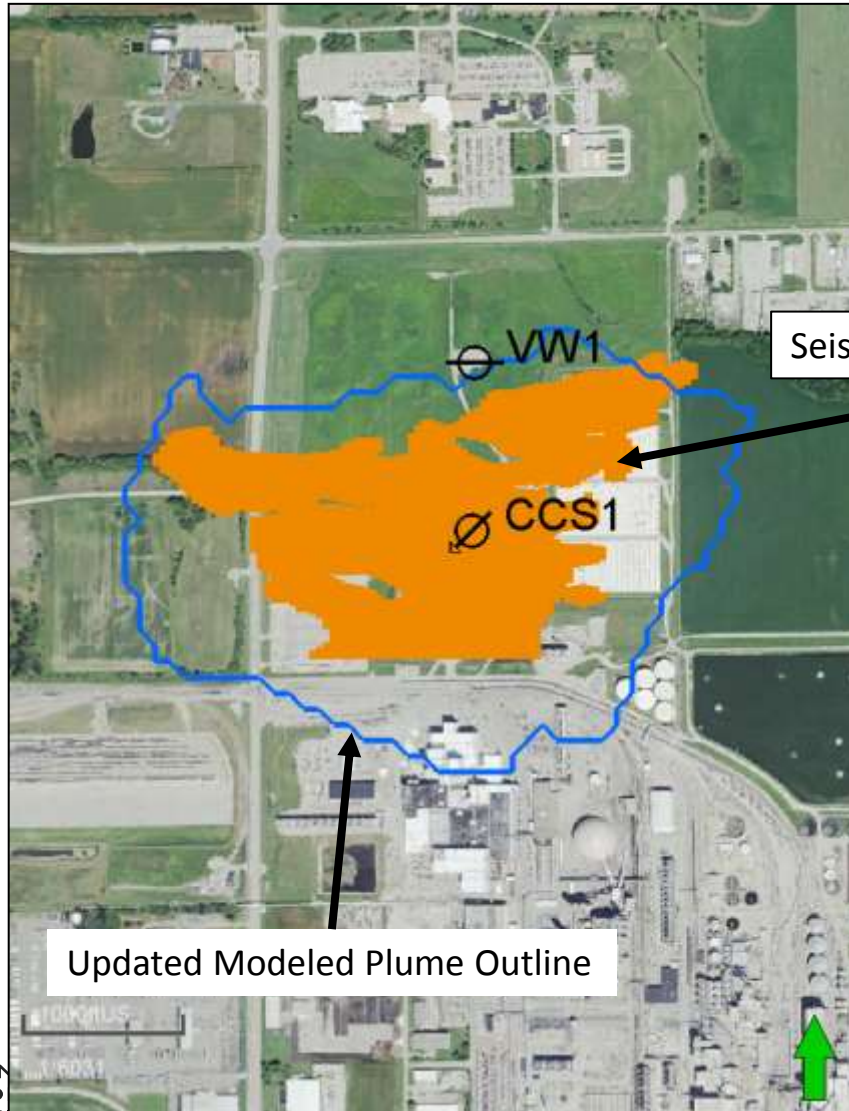
PERFORMANCE MONITORING: Improves Prediction



MONITORING: Time-lapse Seismic

NRM Attribute

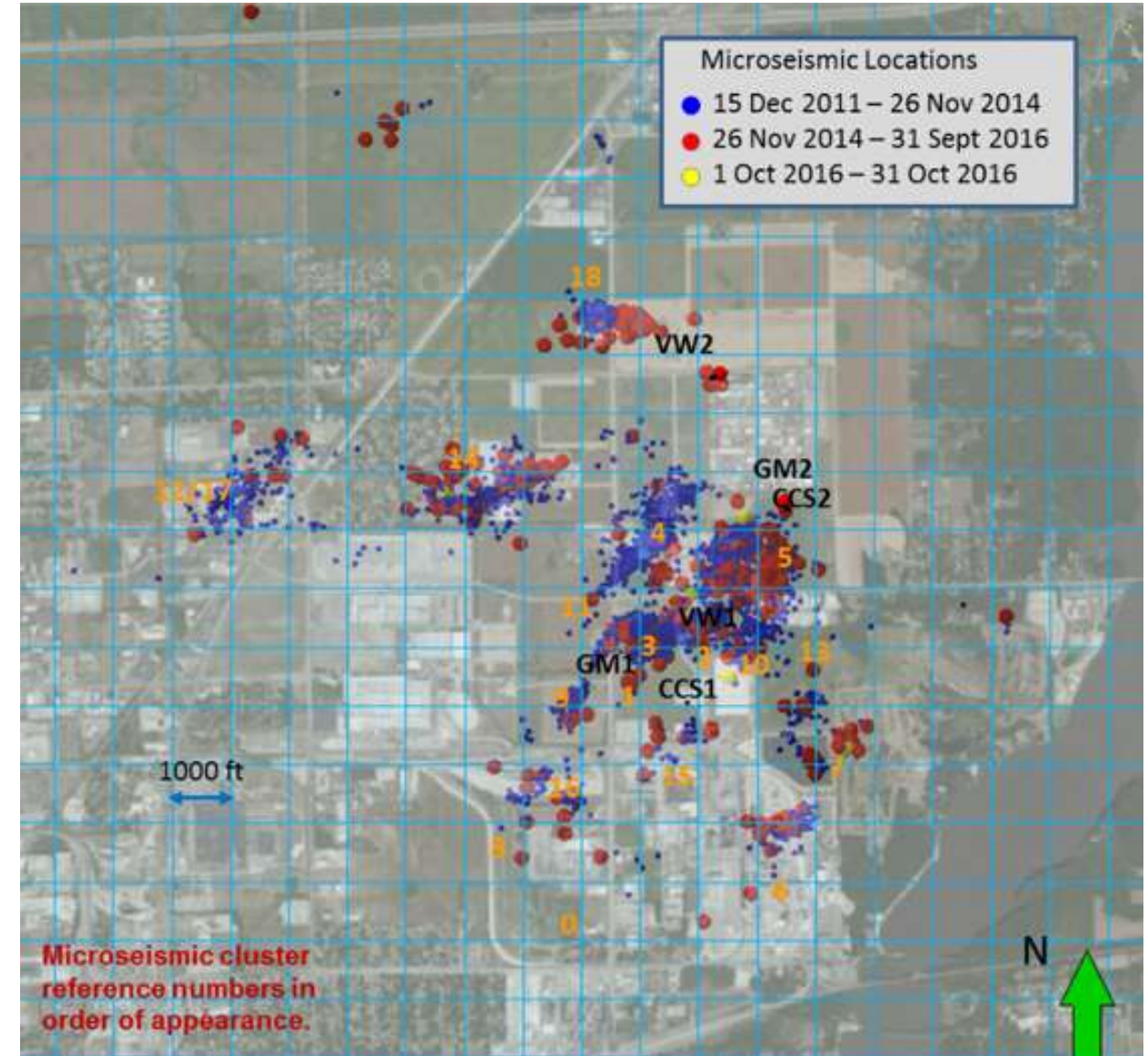
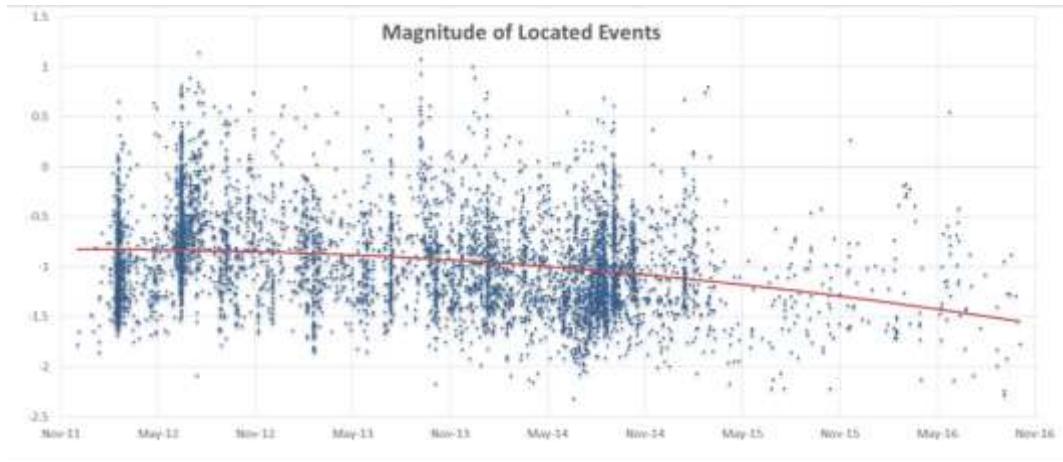
NRMS Attribute

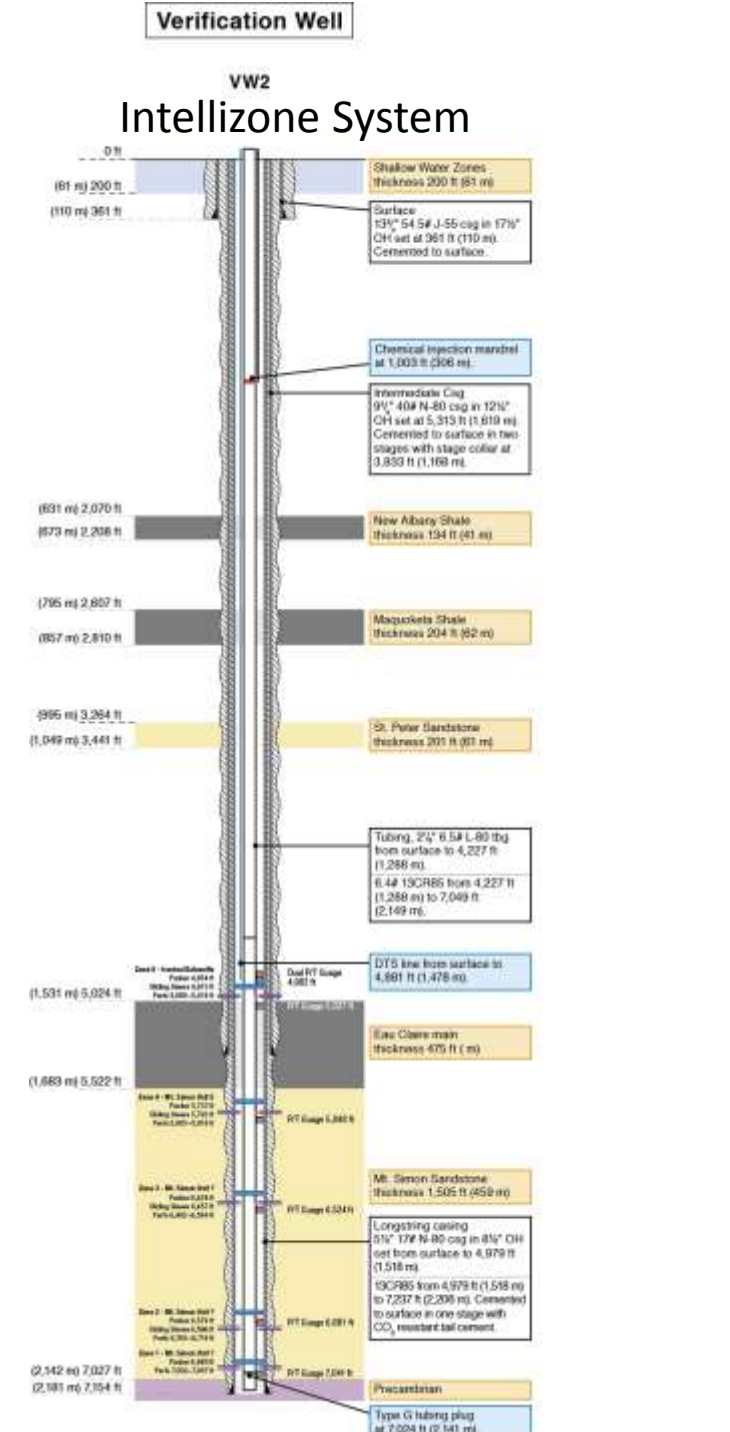
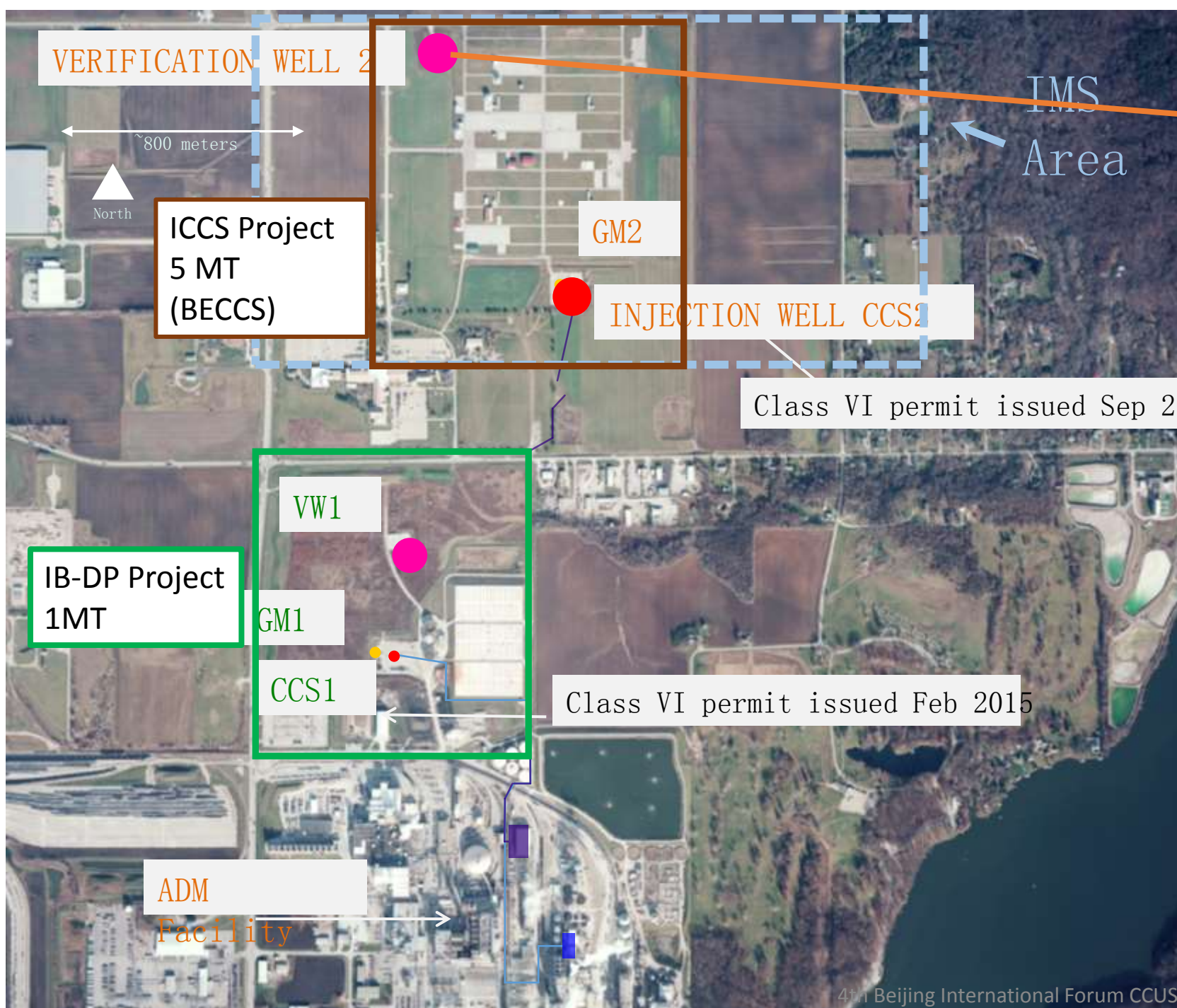


Seismic attribute "plume" Outline

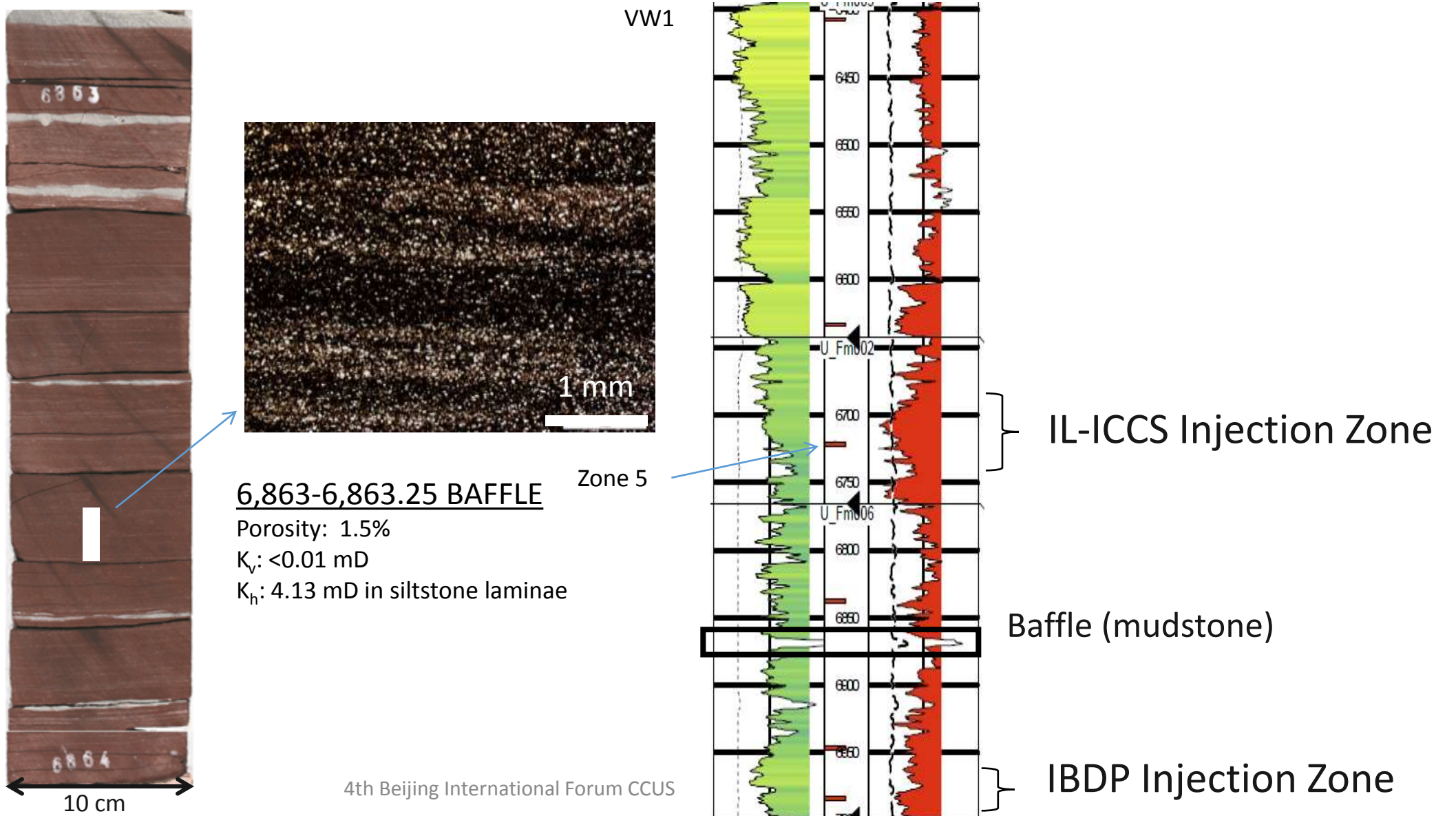
MONITORING: Microseismic Activity

- Location critical to understanding reservoir response
- Study of relation of clusters to:
 - *pressure front* and
 - *basement characteristics*

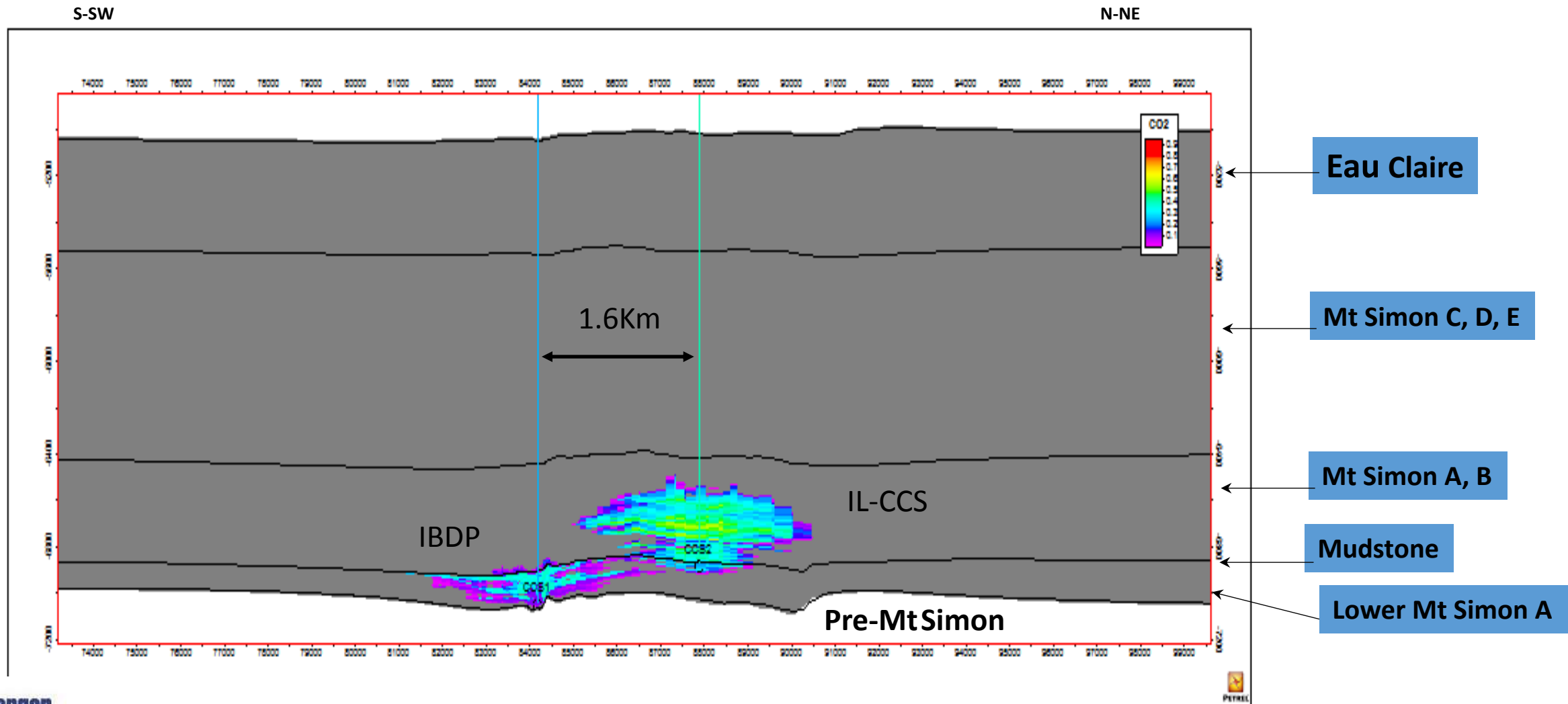




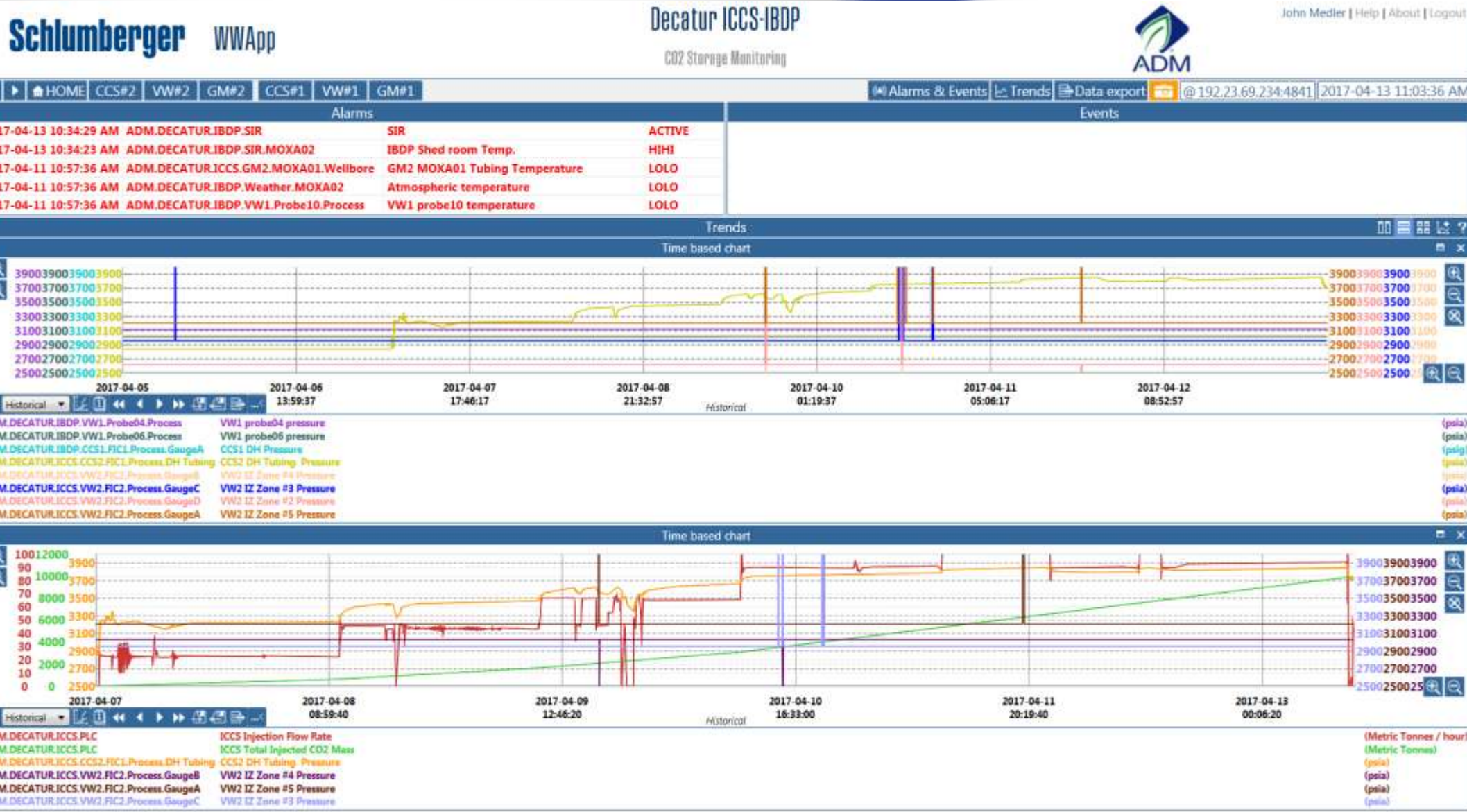
STORAGE: RESERVOIR CHARACTERIZATION



Simulated Plume Interaction After injection complete



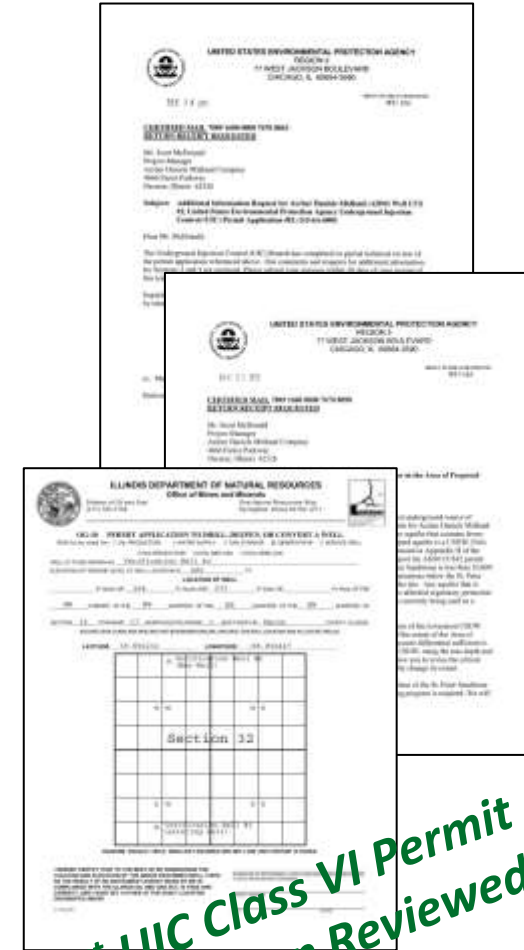
Illinois Industrial CCS – injection startup April 7



- Step rate increase of CO₂ to full injection

Permitting can be a Critical Factor for Project Advancement

- Permitting has been a rate-limiting step for both projects
- Permits for IBDP Post-injection Site Care and ICCS injection + Post-injection tied together
- 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**



1st UIC Class VI Permit Application Reviewed by the USEPA

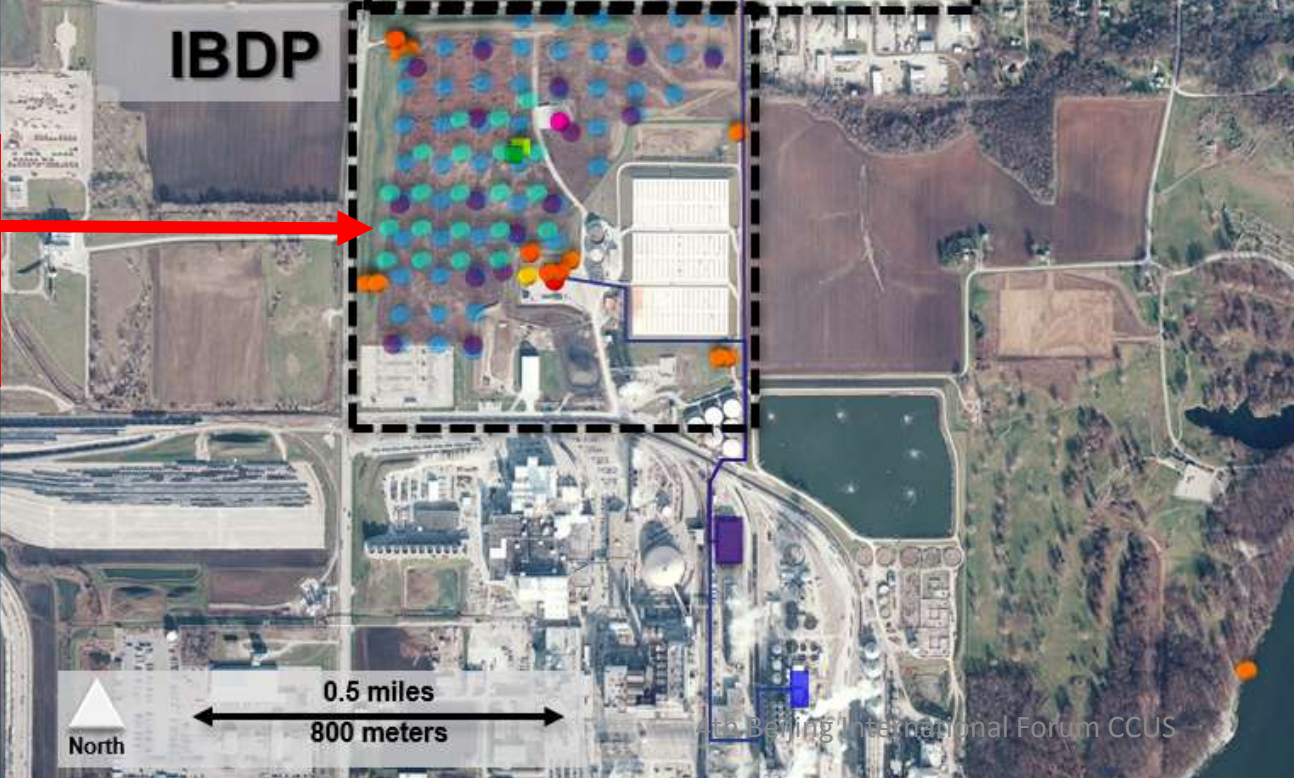
Monitoring Summary

- 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)

Industrial scale
Risk based



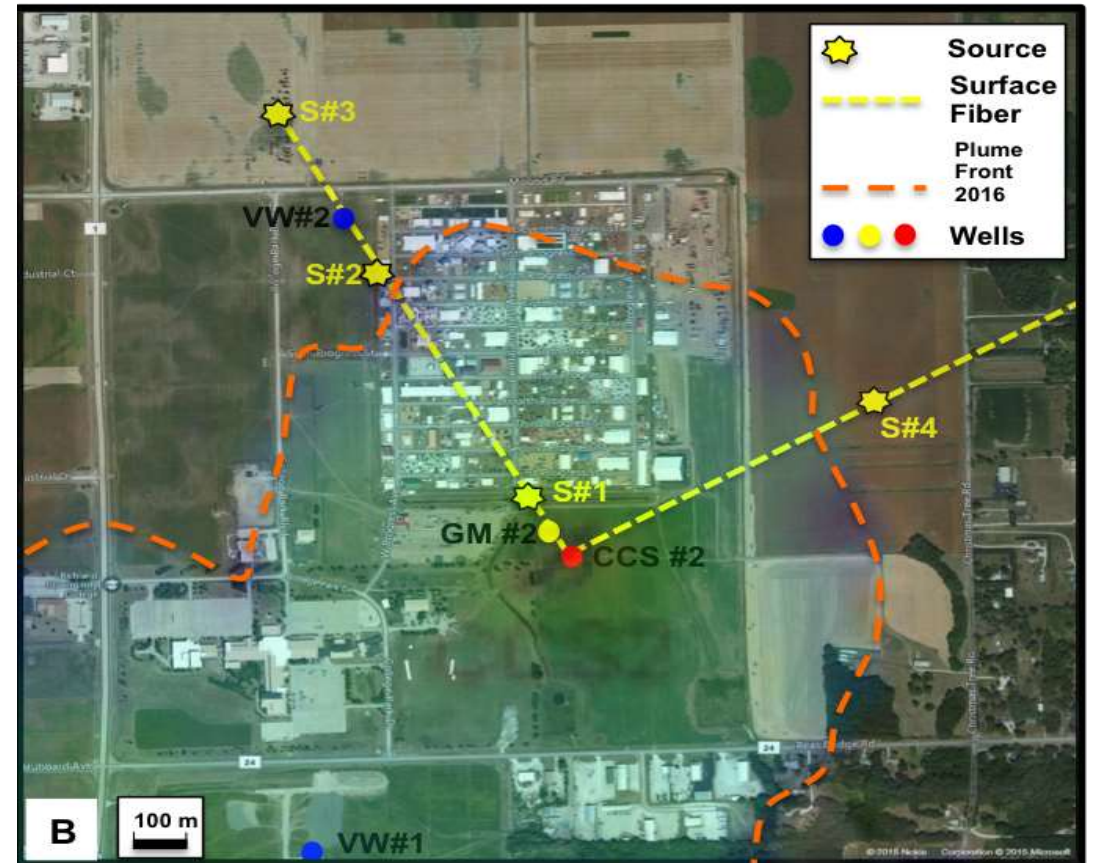
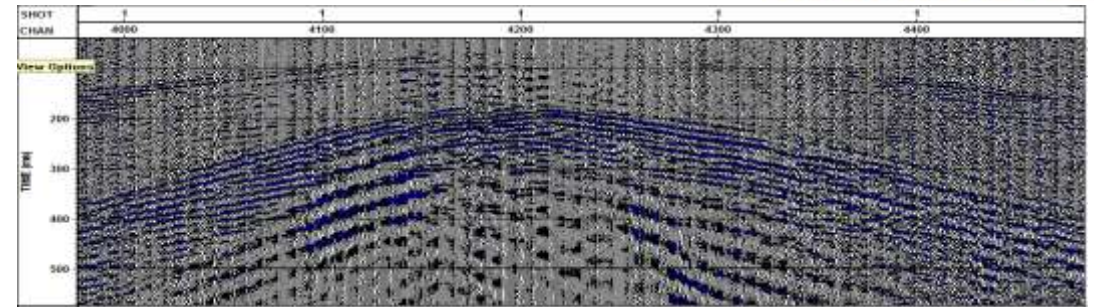
Demonstration scale
Risk and research based



Intelligent Monitoring Systems (IMS)

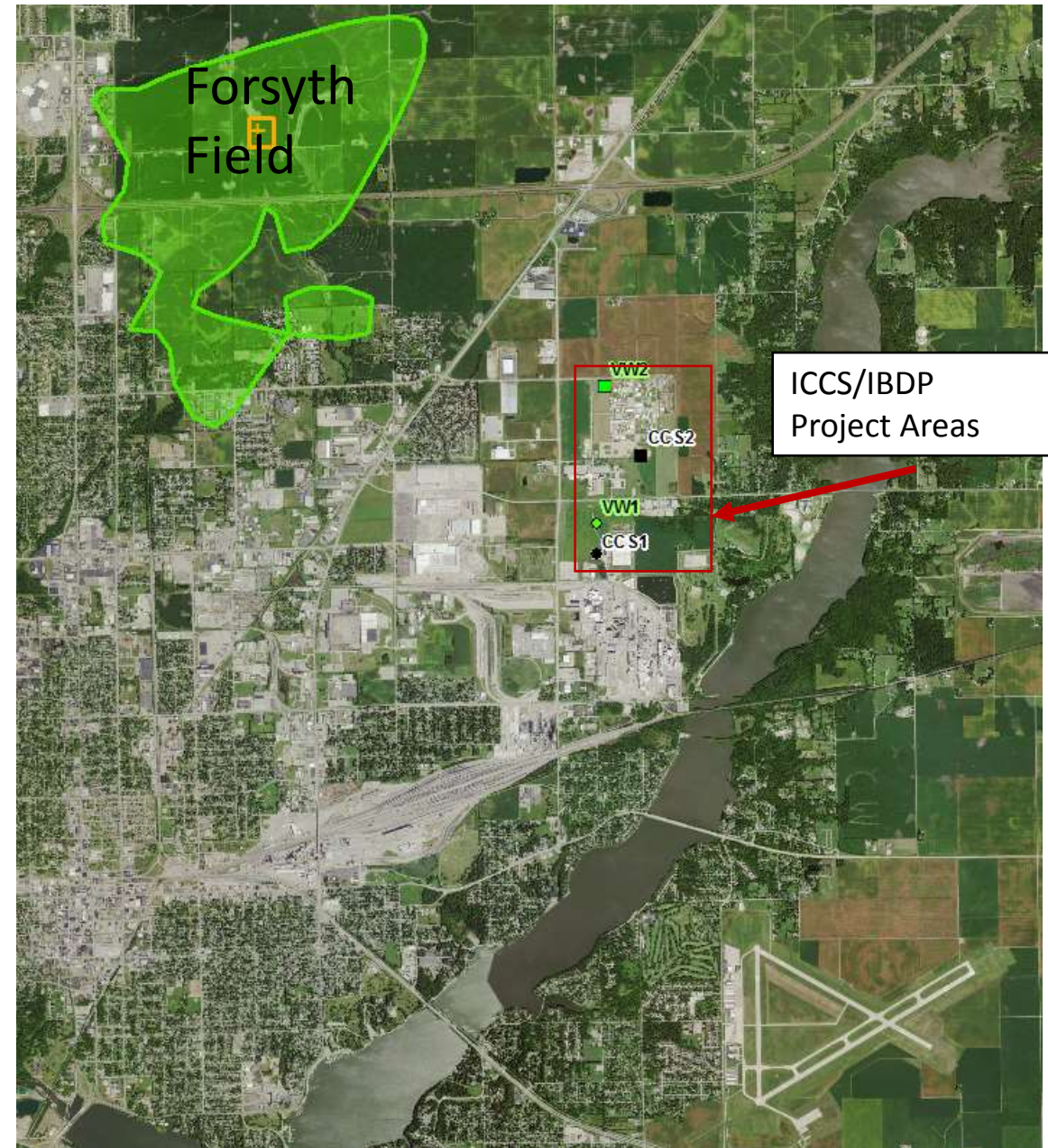
Program Components

- DAS (digital acoustic sensors) seismic imaging (VSP & surface reflection)
- Permanent rotary surface source
- Hybrid geophone/DAS microseismic array
- DTS (distributed temperature sensors) well integrity monitoring
- Integration into the existing systems.
- Sparser surface infrastructure



CarbonSAFE Illinois

- Develop Commercial-Scale storage hub
 - >50 million tonne Storage Complex
- Examine CO2 EOR potential
- OBJECTIVES
 - Address gap in around development of large-scale carbon storage
 - Validate technologies to ensure containment
 - Improve storage capacity estimates for industry investment decisions





Storage Development

- Learning from the oil & gas industry are directly applicable
 - Complementary skills, resources and equipment
- Choose the best geology for large-scale storage
 - Determine need for pressure management
- Monitoring strategy (risk based) is moving toward sparser, less surface intense methods
- Permitting still can be a hurdle
- ISO 27914 - Standards for Geological Storage of CO₂
 - Provide operator, regulatory, and investment confidence
- Identify DRIVERS – policy / economic / utilization



THANK YOU

- The Midwest Geological Sequestration Consortium is funded by the U.S. Department of Energy through the National Energy Technology Laboratory via the Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588)
- 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.
- CarbonSAFE Illinois is funded by the U.S. Department of Energy (DE-FE00029381)



