Midwest Geological Sequestration Consortium

Scaling up of Deep Saline Storage in Illinois: From the Illinois Basin – Decatur Project to the Illinois Industrial CCS project

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PRAIRIE RESEARCH INSTITUTE

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- The Midwest Geological Sequestration Consortium (MGSC) is a collaboration led by the geological surveys of Illinois, Indiana, and Kentucky.

- Landmark Graphics software via their University Donation Program and cost share plus Petrel software via Schlumberger Carbon Services.

MGSC

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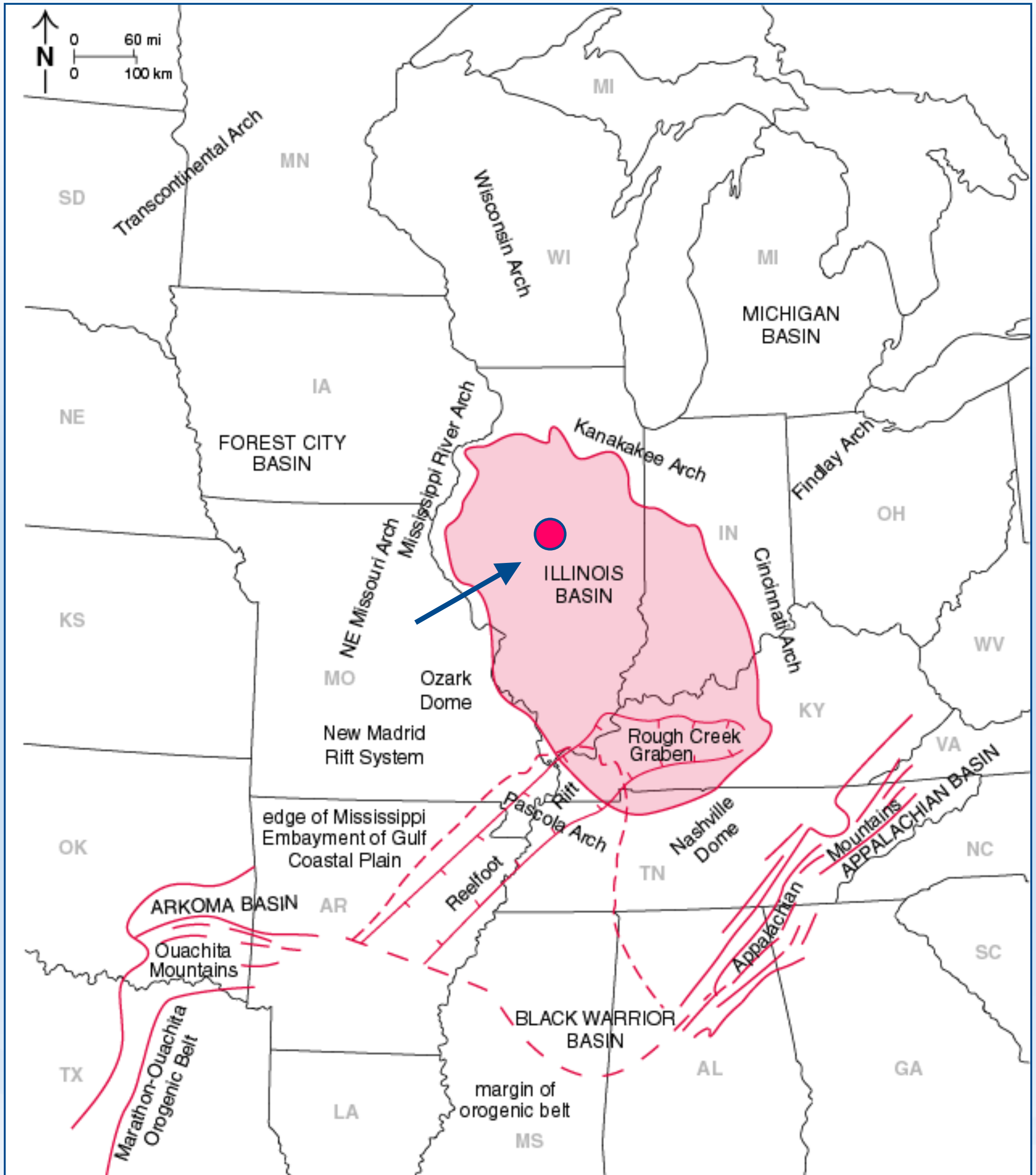
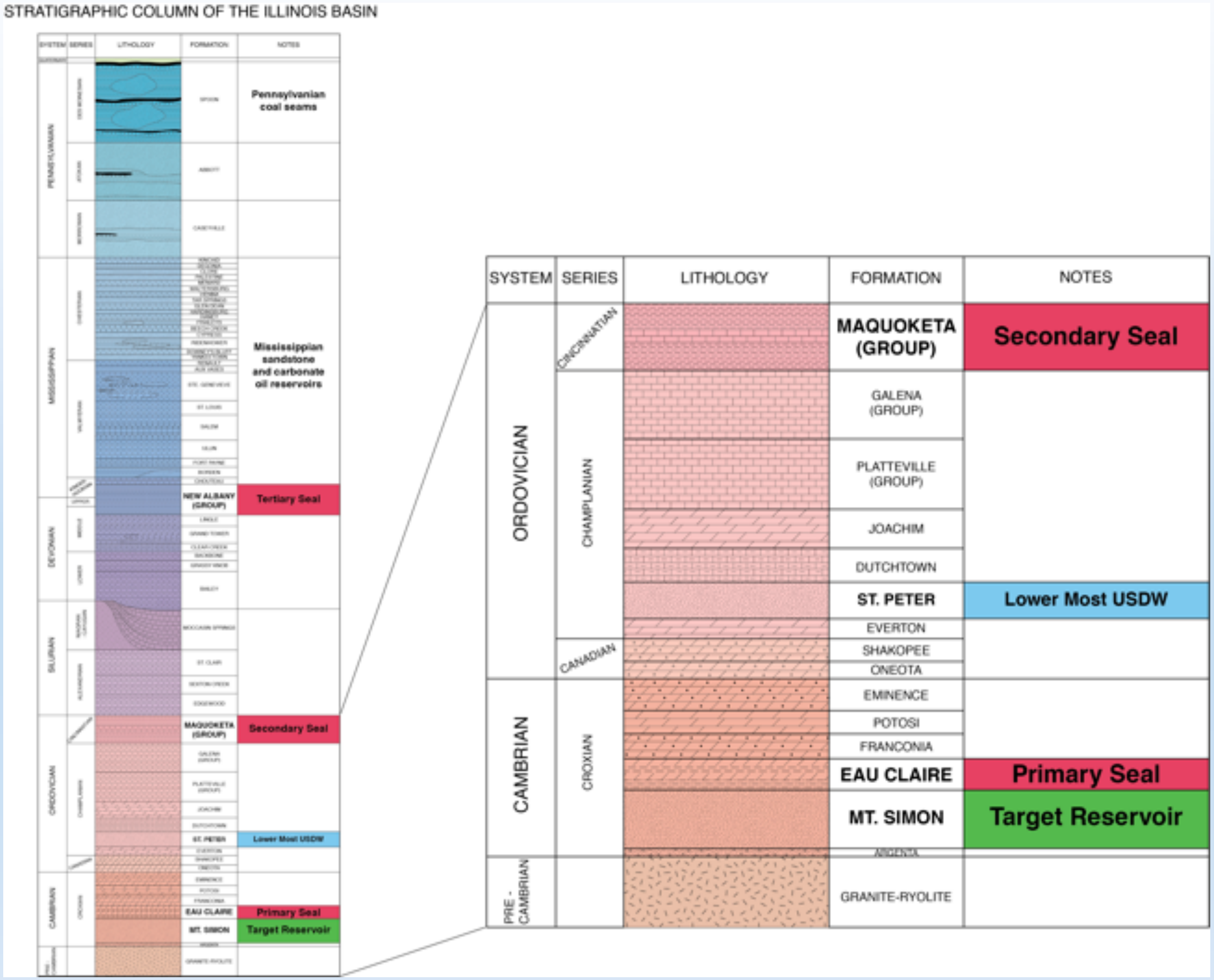
NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

Illinois Basin – Decatur Project Scope



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



Total Mt Simon Storage Capacity:
11 (E=0.4%) to 150 (E=5.5%) billion metric tons

CCS 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
- Status:
  - Post-injection monitoring

Illinois Industrial CCS Project

- Industrial-scale
- Volume: 5 million tonnes
- Injection period: 3 years
- Injection rate: 3,000 tons/d
- Compression capacity: 2,200 tonnes/day
- Status:
  - Pre-injection monitoring,
  - Permission to inject pending

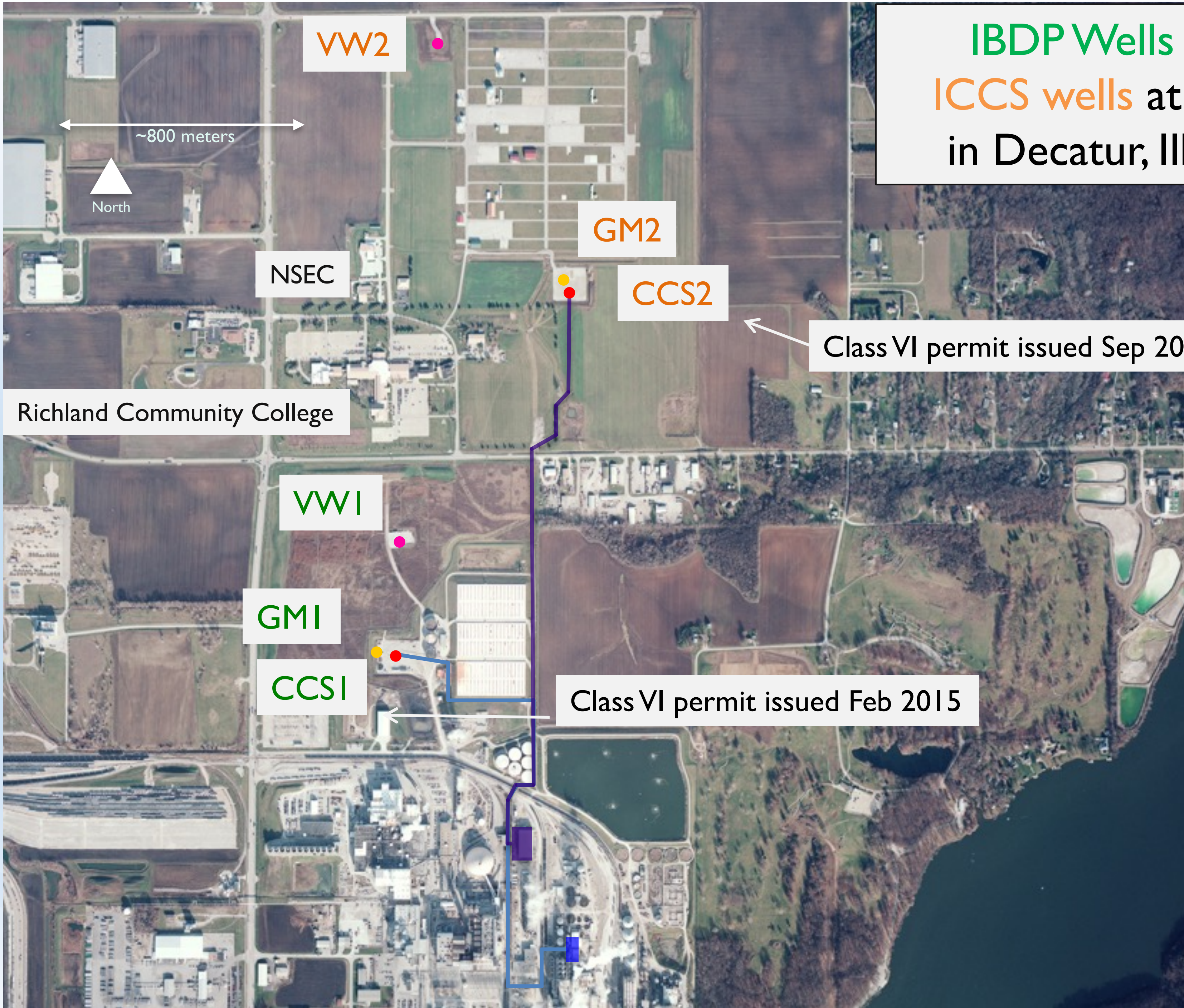
IBDP Goals and Objectives

- **Inject 1 million tonnes of CO_2** from an industrial source in a deep saline reservoir to demonstrate safety, effectiveness, and efficiency
- Inject a large mass of CO_2 of sufficient size to **monitor geophysically** and emulates larger volumes required for compression/dehydration, injection well construction, and environmental monitoring, which can be **extrapolated to commercial-scale operations**
- **Establish a workflow** for site characterization, permitting, drilling and completion, environmental monitoring, and outcome assessment that informs stakeholders on regional, national, and global scales about carbon storage and supports energy facility development
- Develop and utilize an active geologic model that evolves as new data are acquired and incorporates **advanced understanding of injected CO_2 and response of reservoir**, seal, and subsurface fluids

ICCS Goals and Objectives

- **Inject 3-5 million tonnes of CO_2** from an industrial source in a deep saline reservoir to demonstrate commercial viability
- Refine monitoring systems to challenge existing technology with advanced monitoring systems to **monitor stored CO_2**
- **Establish a regional-wide economic driver and delivery system for captured CO_2**
- Serve as a **test bed for new technology**
- **Reduce cost, increase efficiency**

IBDP Wells and ICCS wells at ADM in Decatur, Illinois



Key IBDP Project Elements

Fully integrated bioenergy carbon capture and storage (BECCS) project

- Capture from biofuel source
- Pipeline 1.9 km
- Storage in deep saline reservoir at ~2,100m

Comprehensive monitoring, verification, and accounting (MVA) program for near-surface and deep subsurface

Conducted in three phases:

- Pre-injection: Site characterization, Infrastructure development, MVA baseline establishment, Permitting, Social site characterization and stakeholder engagement
- Injection: Operational injection, site care, MVA monitoring, stakeholder engagement
- Post-injection: MVA monitoring, site care, geophysical research, knowledge sharing, and publications

Illinois Basin – Decatur Project Site (on ADM industrial site)

- A Dehydration/ compression facility location
- B Pipeline route (1.9 km)
- C Injection well site
- D Verification/ monitoring well site
- E Geophone well

Operational Injection: 17 November 2011

- IBDP is the first 1 million tonne carbon capture and storage project from a biofuel facility in the US
- Injection completed November 2014
- Intensive post-injection monitoring under MGSC through 2017

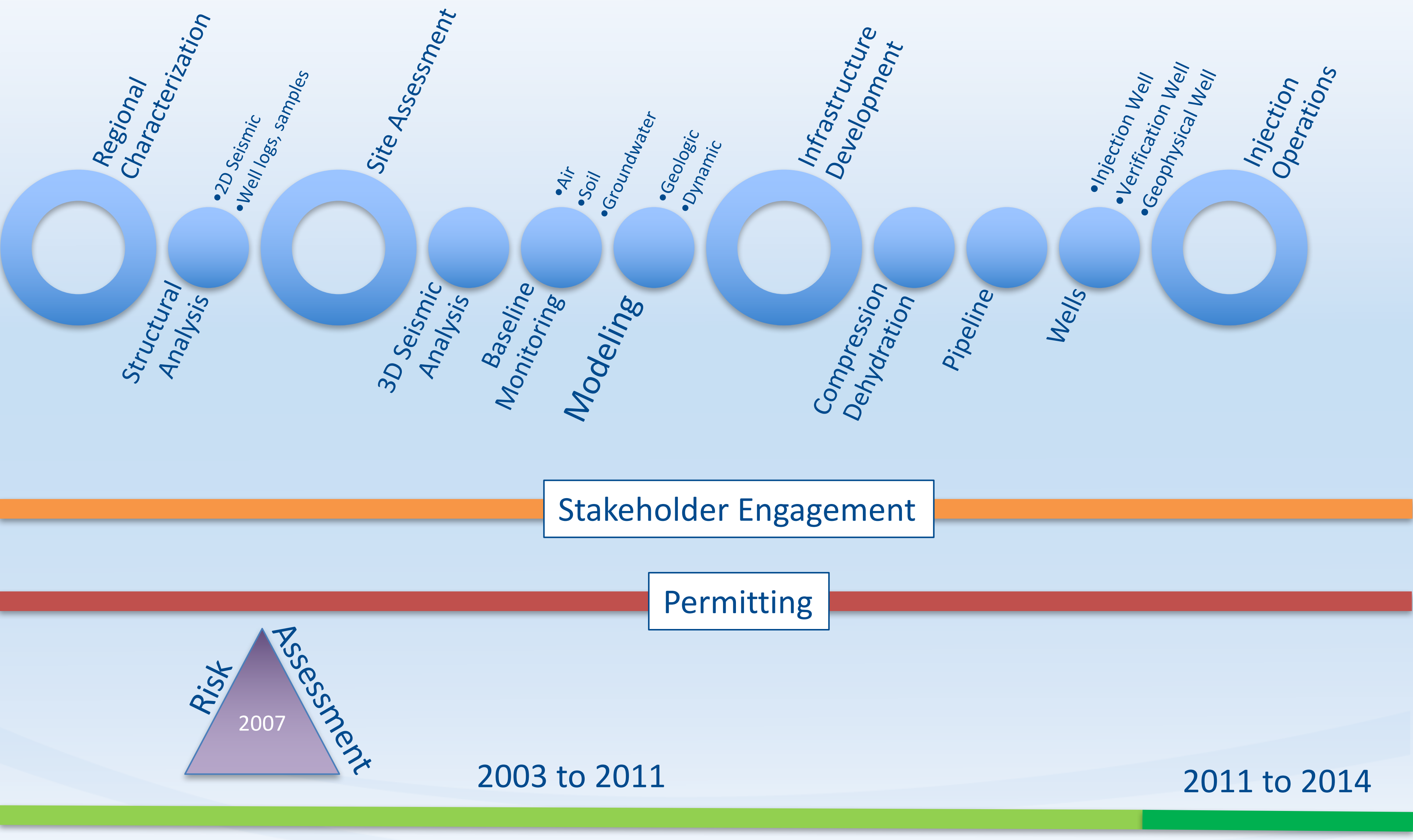
Total Injection
(26 November 2014):
999, 215 tonnes

Illinois Basin – Decatur Project Workflow

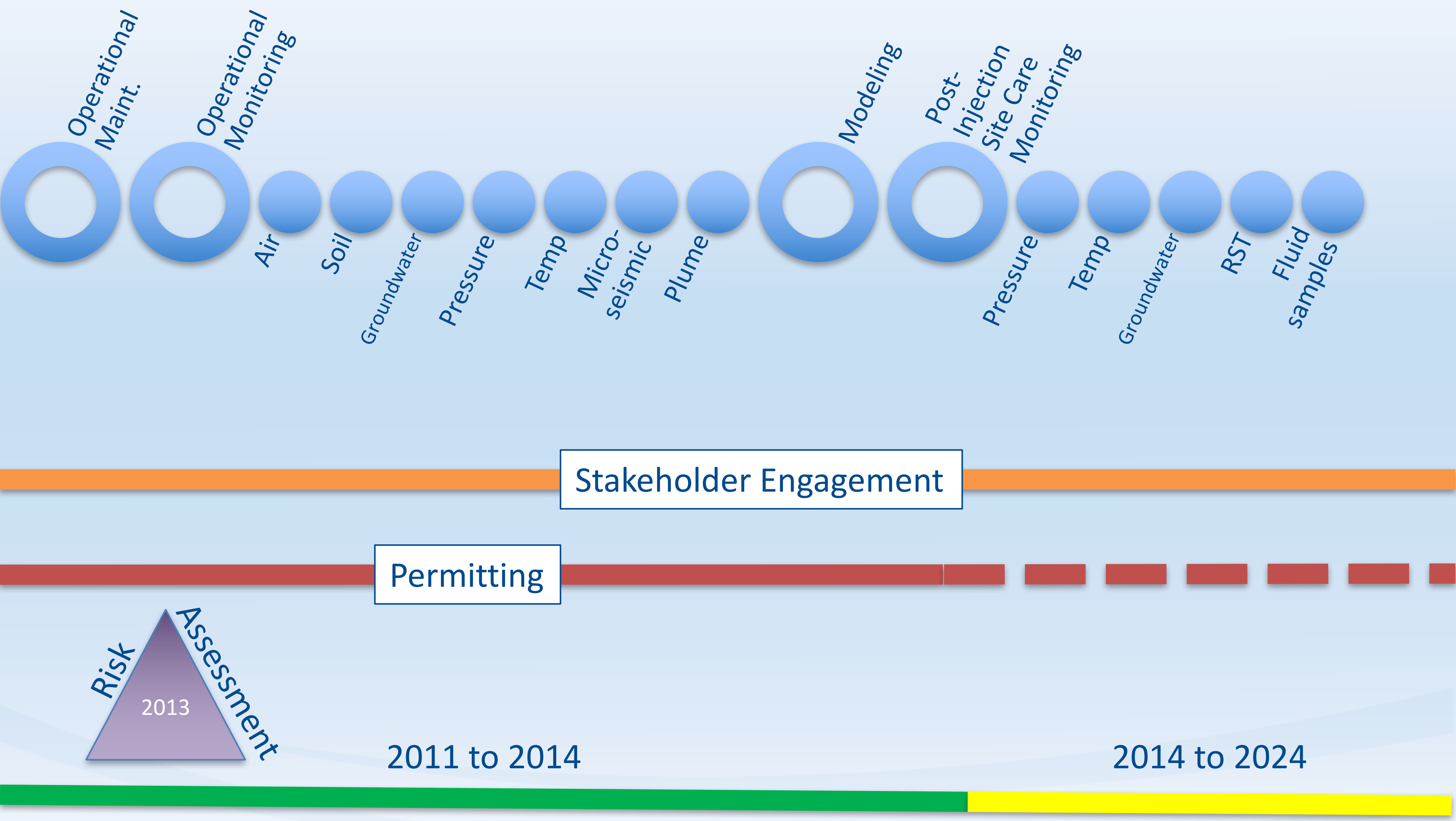
- Regional Characterization
- Site assessment
- Outreach and public engagement
- Permitting and building the IBDP test site
- Collect and analyze key monitoring baseline data
- Injection, monitoring, and modeling
- Post-injection monitoring, modeling, and analysis
- Research collaborations, knowledge sharing
- Compliance monitoring period

Completed On-going Current activities Upcoming activities

Development of a CCS Project



Development of a CCS Project



Successful Stakeholder Engagement

Groundbreaking effort, helped set global standards and establish best practices

- Began engagement early
- Made engagement a priority
- Integrated engagement into all aspects of project management
- Made sufficient investment in time and resources
- Sought to understand and consult community
- Created, evaluated, and refined communications plan
- Monitored and adapted as needed

Research Questions & Answers for Science & Society

- How do you know the CO_2 is staying where you put it?
- What happens in the event of earthquakes?
  - Induced seismicity
  - Fracture and catastrophic release of stored CO_2
- Where does formation water go when CO_2 is injected?
  - Increased pressure
- Does CO_2 injection fracture rocks during injection?
- What are long-term implications of project?
- Who is liable if something goes wrong with the project?
- How do you know it is safe?

IBDP Risk Assessment and Project Uncertainties

2008 Pre-Injection

- Identify FEP's and Scenarios
- Geologic Uncertainty
- Operational Uncertainty
- Regulatory Uncertainty
- Social Uncertainty

2013 Update

- New/Update FEP's and Scenarios
- Risk Treatments
- Regulatory Uncertainty
- Change in Scope
- Long-term Funding
- Knowledge Sharing
- Complacency Potential
- Institutional Memory Loss

2016 Post-Injection Updates

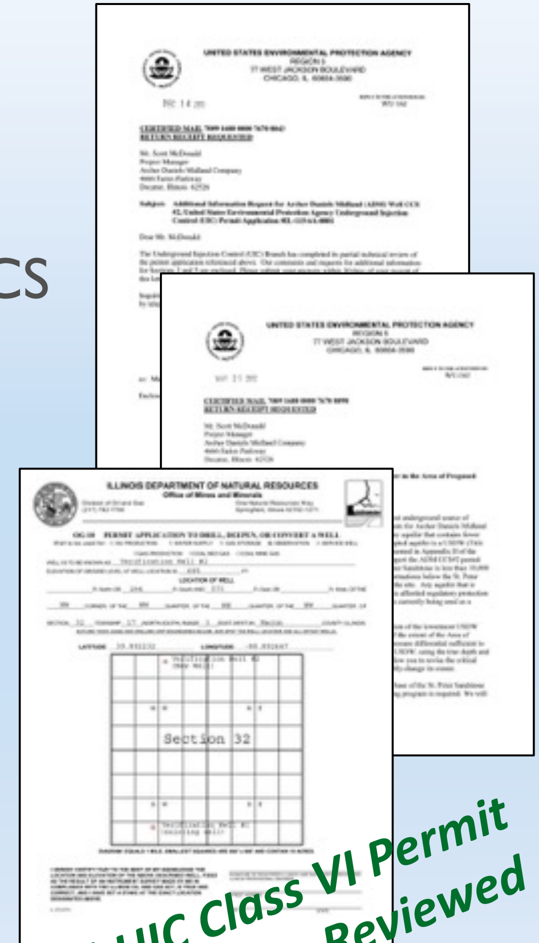
- New/Update Risks
- Risk Treatments
- Annual Review

- Government changes
- Well integrity
- Funding

Permitting of wells for two projects provides precedent for future projects

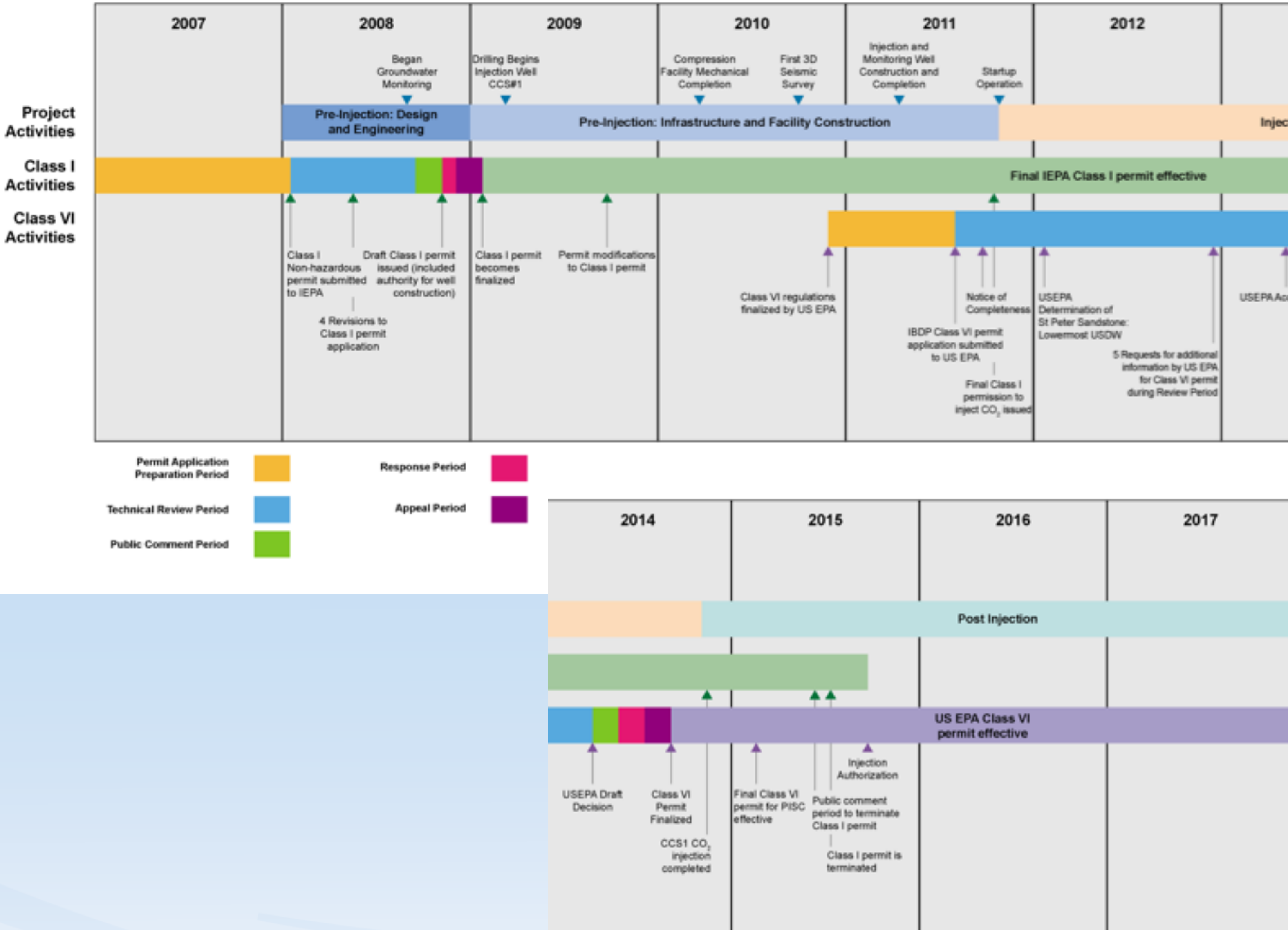
- Permitting has been rate-limiting step for both projects
- Permits for IBDP Post-injection Site Care and ICCS injection + Post-injection tied together
- Project expansion due to delay in injection start

- 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: Expected Jan to Apr 2017



1st UIC Class VI Permit Application Reviewed by the USEPA

Project Timeline and Scope

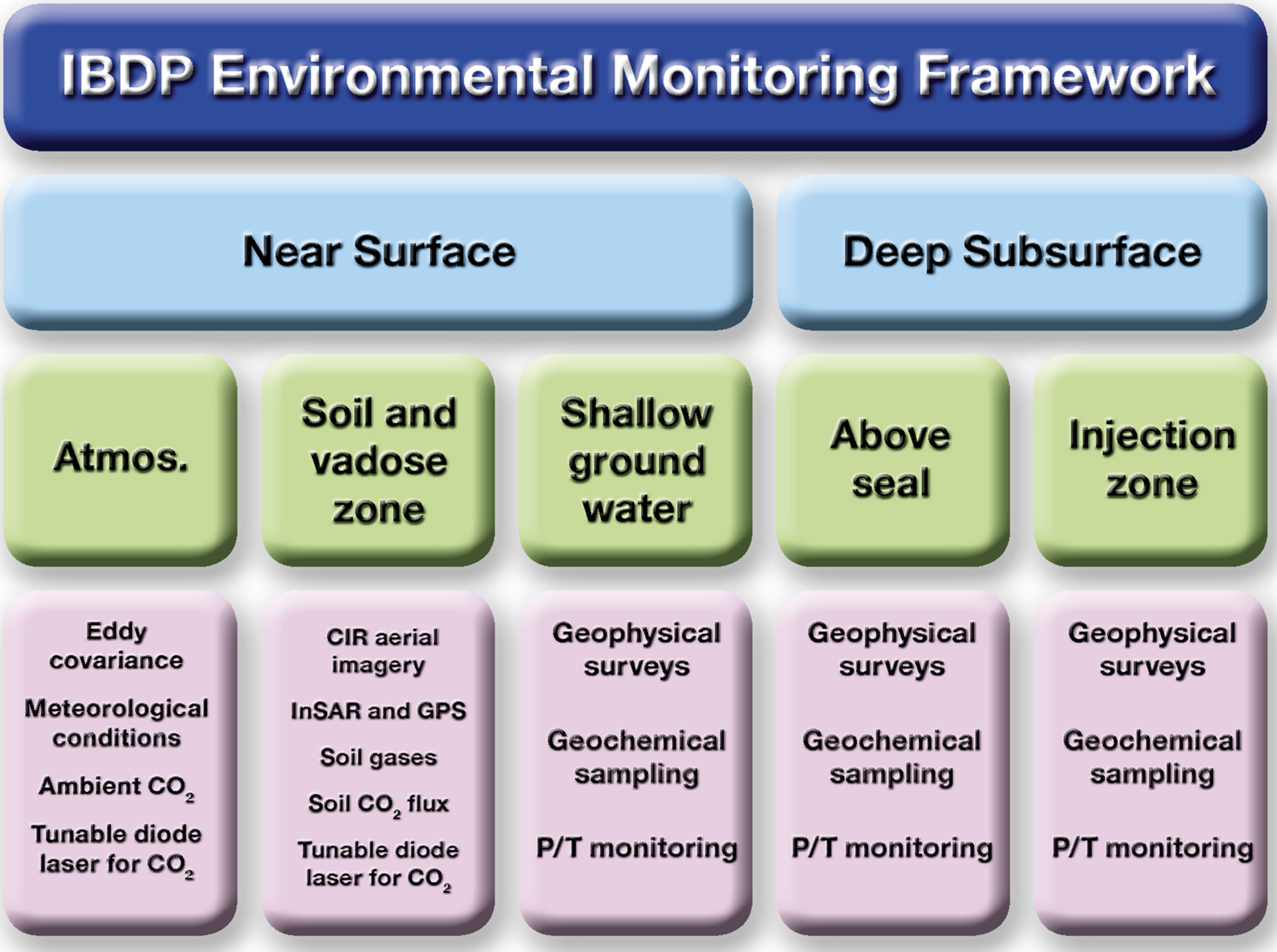


2018-2020

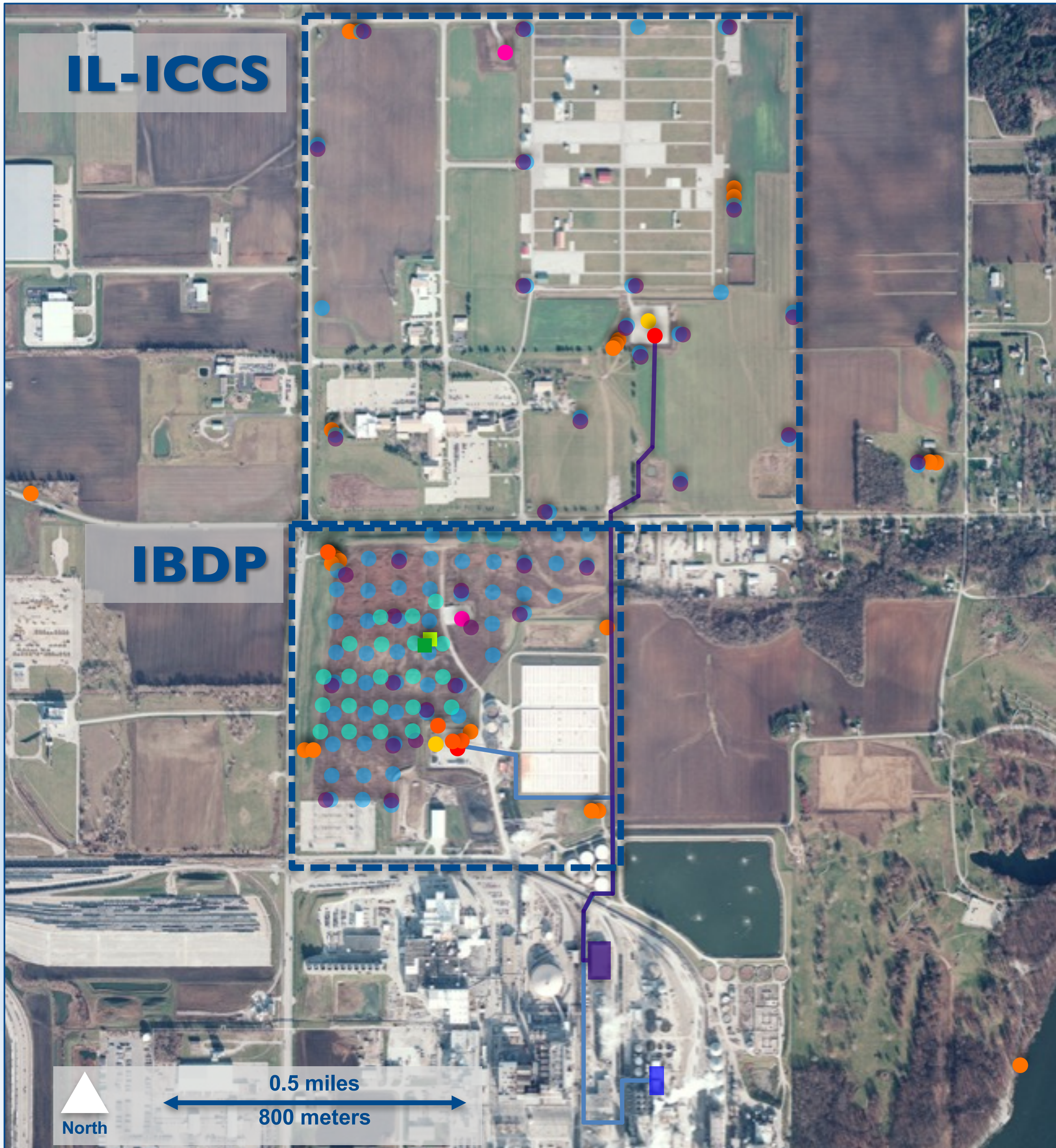
Compliance Monitoring

Post-Injection Activities

- 3D Surface Seismic Survey – January 2015
- Post-injection VSP, permit interim period – January 2015
  - Working to improve comparisons between repeat VSPs
- Post-injection near surface monitoring
  - Moving from injection monitoring to reduced program
- Recompletion of VW1 deep monitoring well
- Knowledge and data sharing best practices
  - Publications
  - National and international research collaborations
  - Collective and teaching data sets
  - Workshops


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 CO_2
Tunable diode laser for CO_2
CIR aerial imagery
InSAR and GPS
Soil gases
Soil CO_2 flux
Tunable diode laser for CO_2
Geophysical surveys
Geochemical sampling
P/T monitoring
Geophysical surveys
Geochemical sampling
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 Monitoring Activity Summary

	Monitoring Activity	Freq.	Pre-injection			Injection				Post-Injection					
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Surface	Aerial imagery	SA		x	x	x	x	x	x	x	x	x	x	x	x
	Eddy covariance	C					x	x	x						
	Soil flux - network	W-Q		x	x	x	x	x	x	x					
	Soil flux - multiplexer	C			x	x	x	x	x	x					
	Tunable diode laser- single path	C					x	x							
	Tunable diode laser- multi path	C								x					
	InSAR	BW				x	x								
	Continuous GPS	C					x	x	x						
Near-Surface	Soil gas sampling	Q-A				x	x	x	x	x	x				
	Shallow groundwater sampling	M-Q-SA		x	x	x	x	x	x	x	x	x	x	x	x→
	Shallow electrical earth resistivity	A	x	x	x										
Subsurface	Pressure/temp. - VW1 and CCS1	C				x	x	x	x	x	x	x	x	x	x→
	Pulsed neutron (CCS1, VW1)	Q-A		x		x	x	x	x	x			x		x→
	Deep fluid sampling (VW1)	SA				x	x	x	x	x		x	x	x	
	Passive seismic monitoring (GM1)	C			x	x	x	x	x	x	x	x	x	x	x→
	Seismic/3D VSP imaging	SA-A			x	x	x	x	x	x					x→
	Mechanical integrity (CCS1, VW1)	A			x	x	x	x	x	x					x

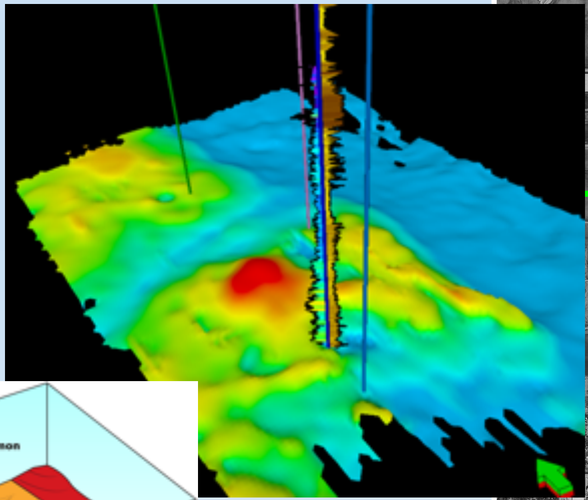
Red text = USEPA UIC Class VI required permit for an IBDP well (GM1, VW1, CCS1), x = planned, → = permit activity required beyond 2020;
Purple text = on-going MGSC, not permit required

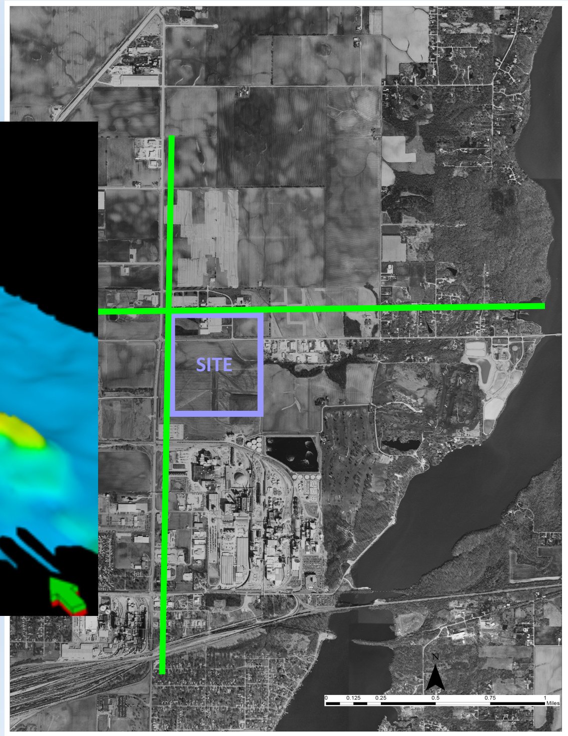
Abbreviations: C = Continuous, W = Weekly, BW = Biweekly, M = Monthly, Q = Quarterly, SA = Semi-Annually, A = Annually,

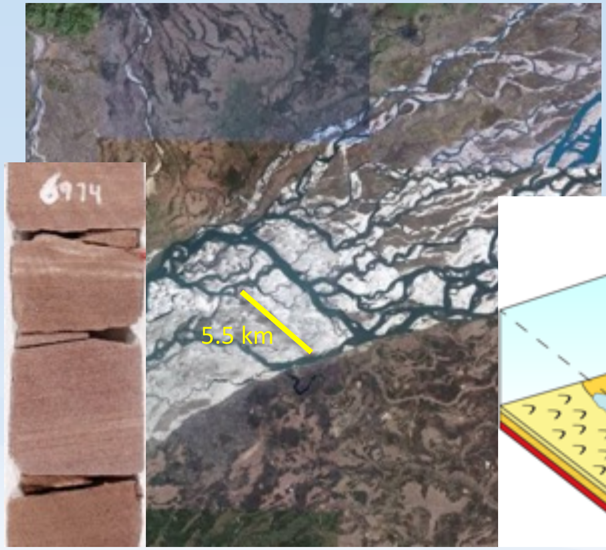
Site Characterization

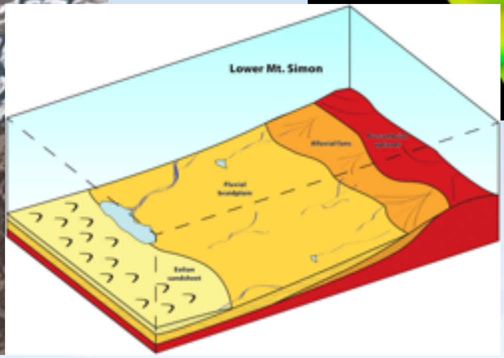
- Successive collection of available and new data to build comprehensive understanding of site
- Conduct 2D, 3D, and 4D seismic surveys
- Plan and drill wells
- Integrative data acquisition
- Core description and analysis
- Depositional environments

Precambrian structure





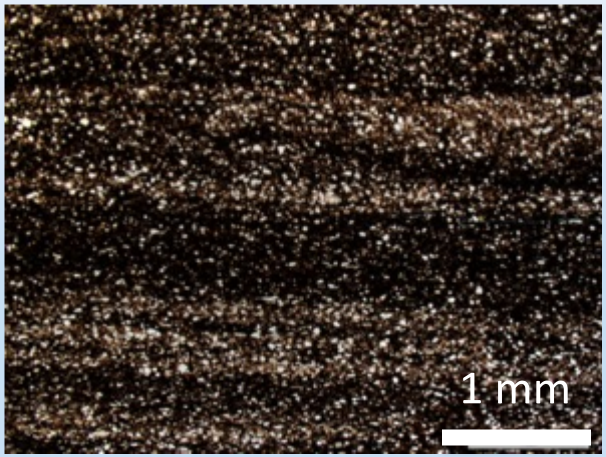




Mount Simon Depositional Analogue: Brahmaputra River System

Mudstone Baffle Between Injection Zones

10 cm



6,863-6,863.25

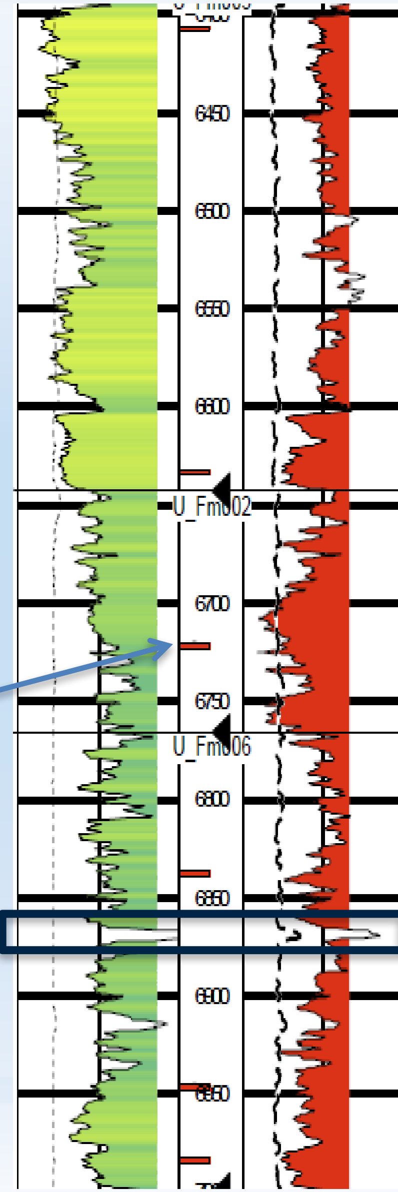
Porosity: 1.5%

K_v: <0.01 mD

K_h: 4.13 mD in siltstone laminae

Zone 5

VW1



ICCS Injection Zone

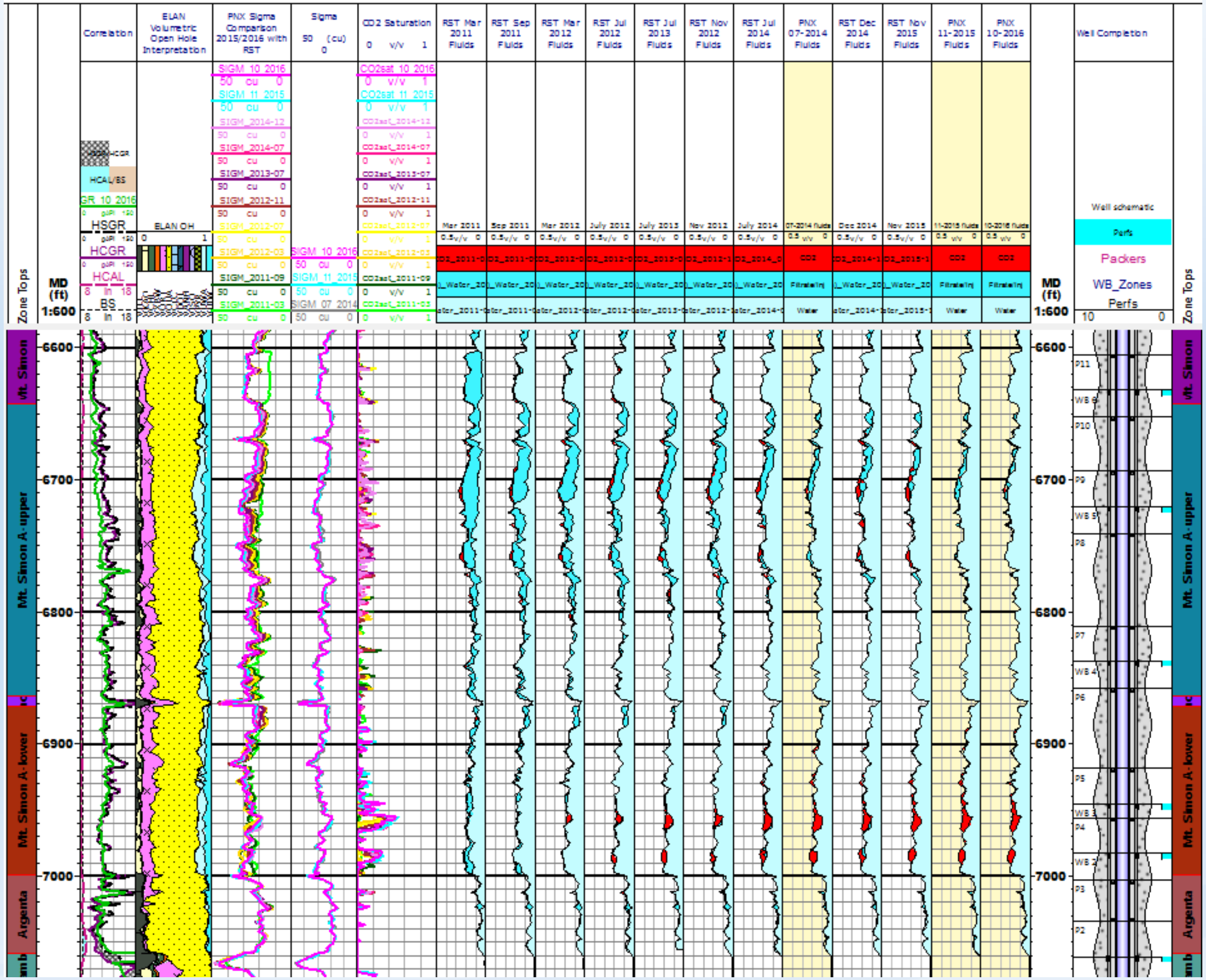
Baffle

IBDP Injection Zone

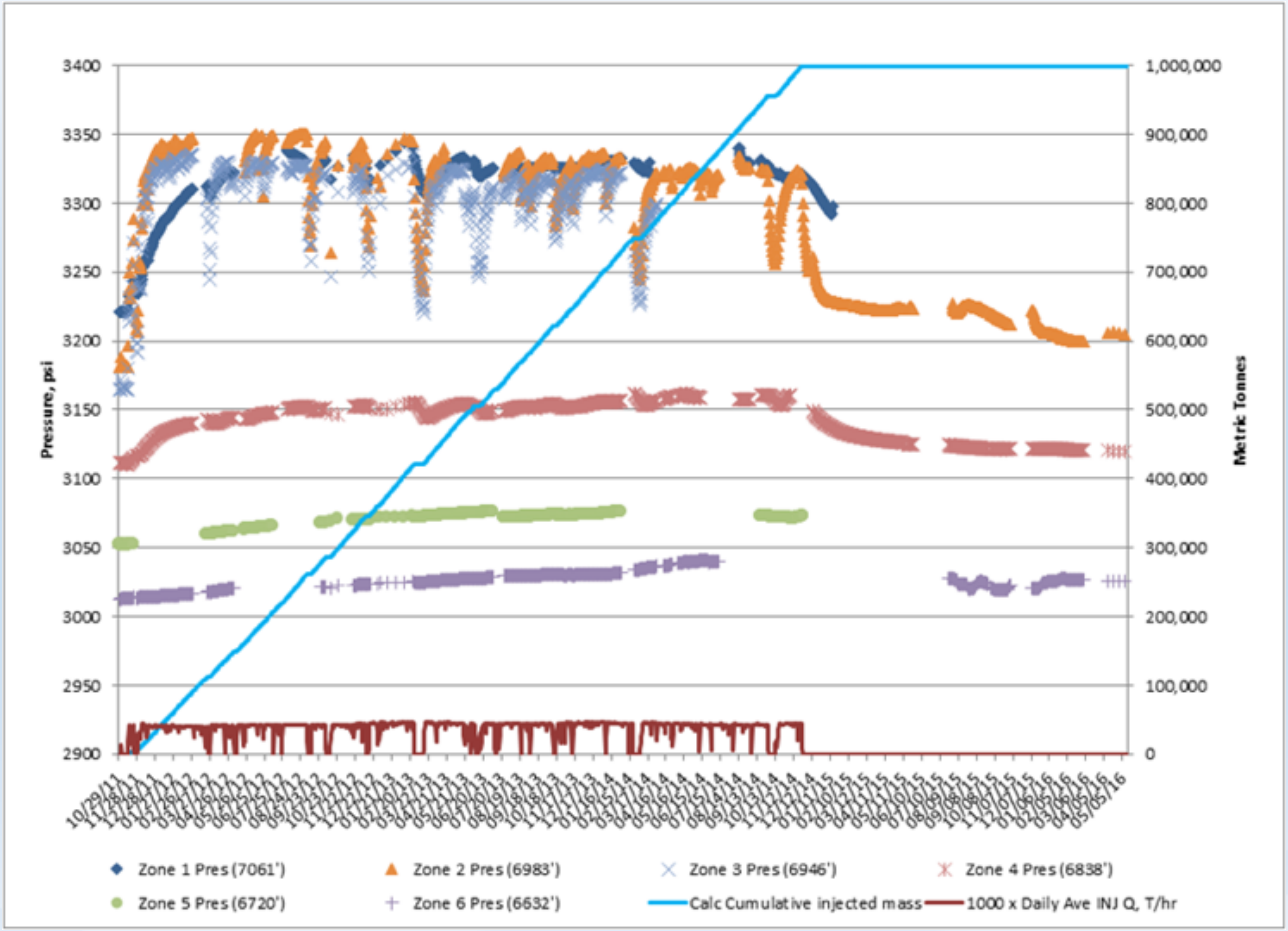
VW1 Pulsed Neutron Logging

RST Monitoring Mar 2011 and Nov 2015

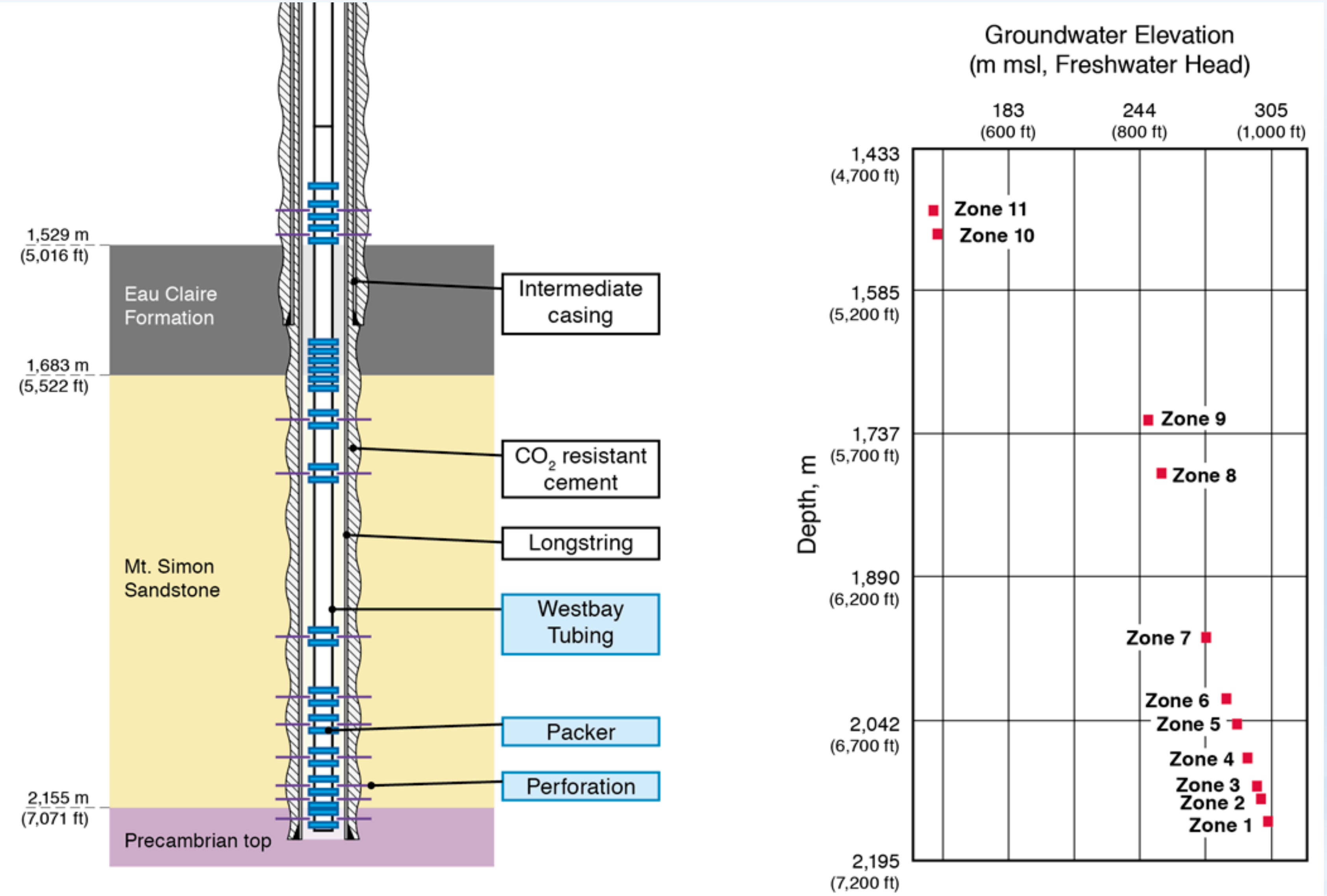
- CO_2 arrival before Mar 2012
- CO_2 saturation increasing though Nov 2015
- CO_2 above the "LPS" is uncertain



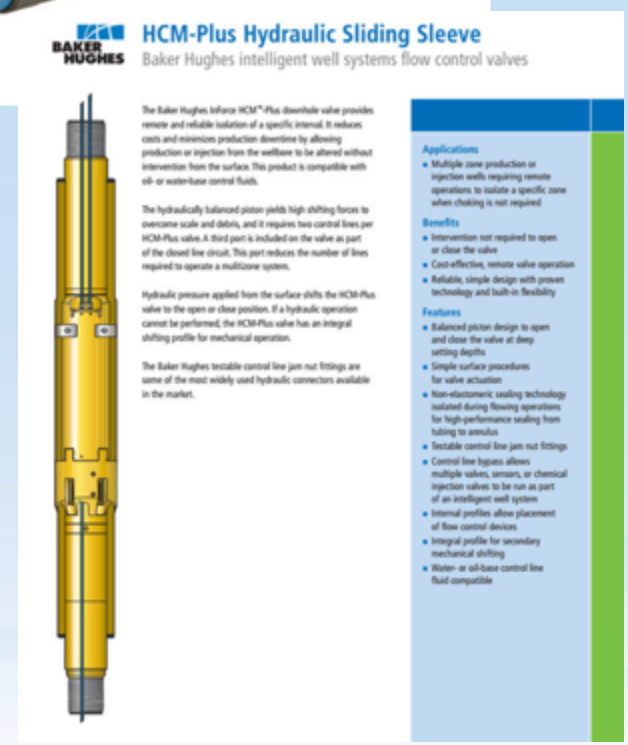
Pressure Response in VW1 Monitoring Well



Deep Monitoring Well - VW1 Westbay Completion



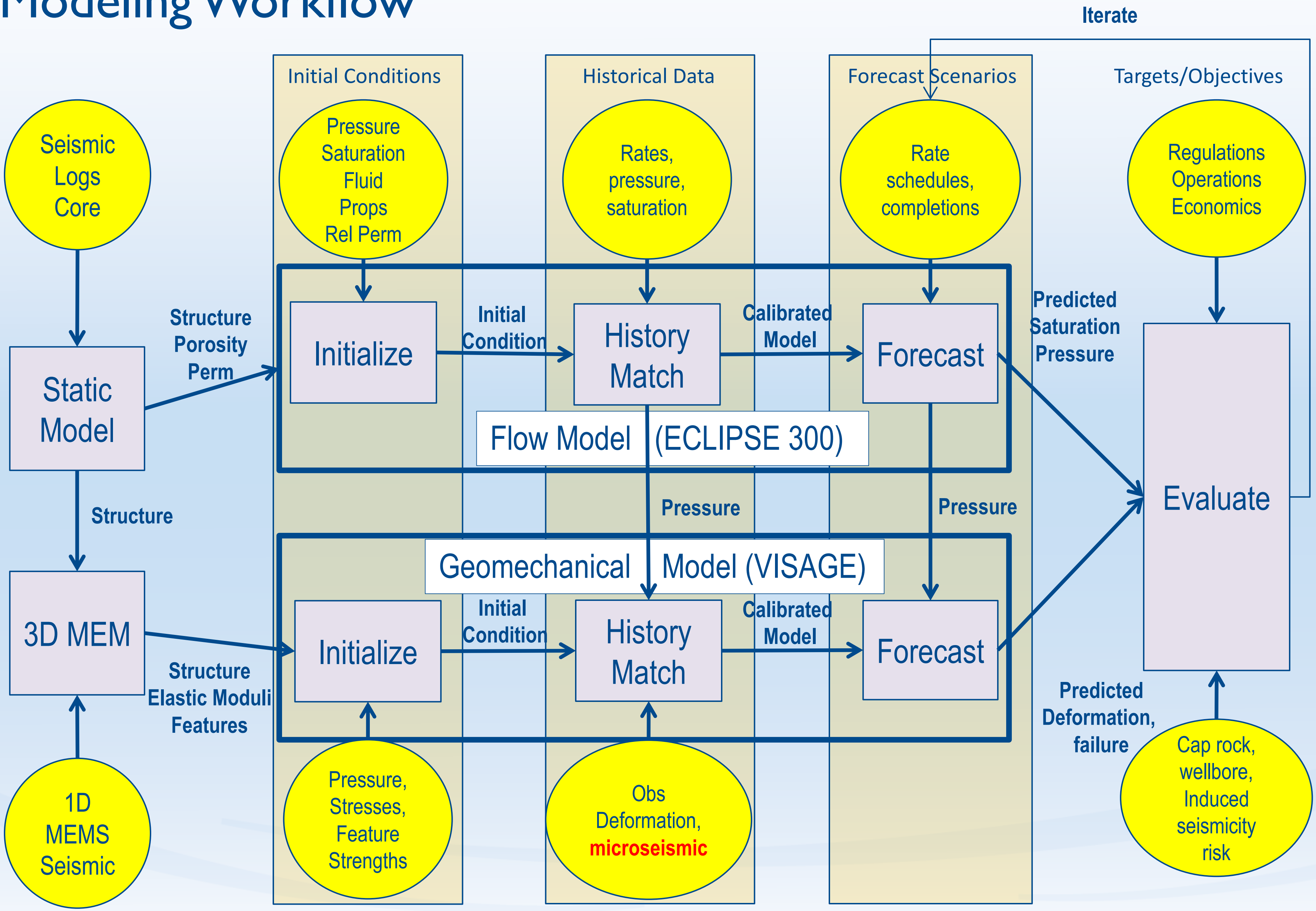
Recompletion of VW1 Monitoring Well



- 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

Modeling Workflow

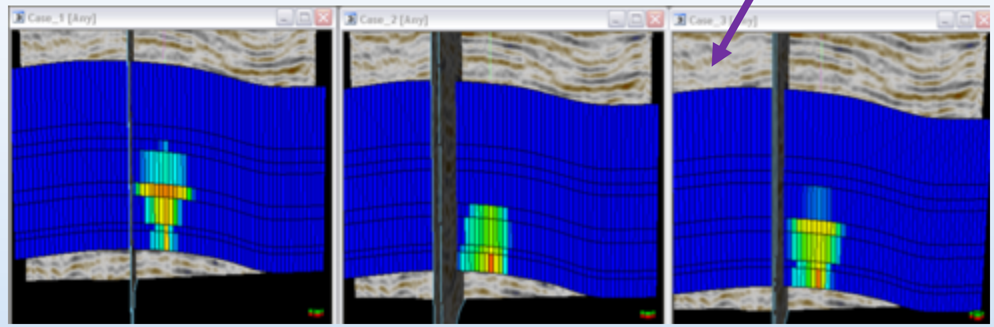


Reservoir Model and Plume Forecasting

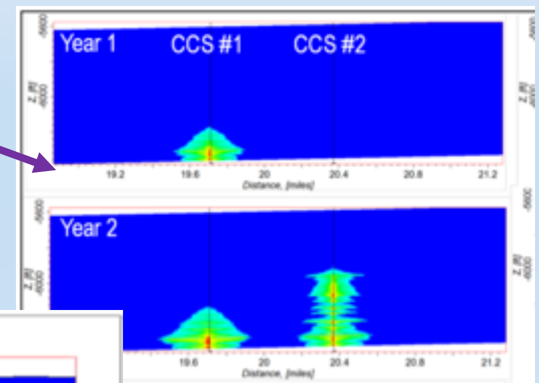
Six different model and plume forecast summaries conducted after major data sources collected and important project milestones

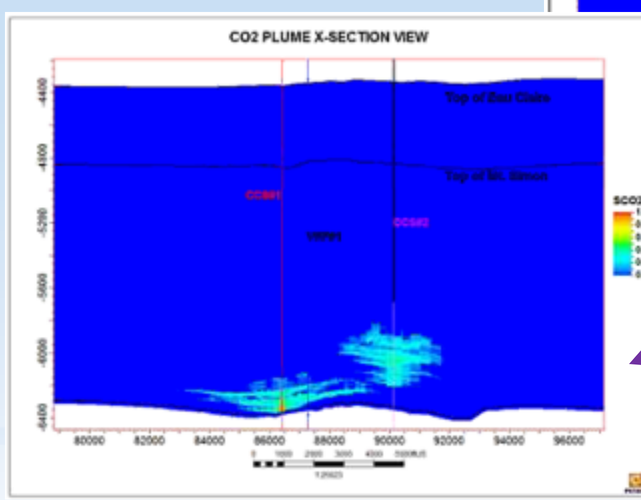
- Successive drilling and logging of new wells
- Core analysis and sampling data
- New seismic data acquisition
- Improvements in seismic processing
- EPA requests for plume forecasting updates

Pre-CCS1 Drill & Pre-injection



Post-CCS1 Drill & Pre-injection

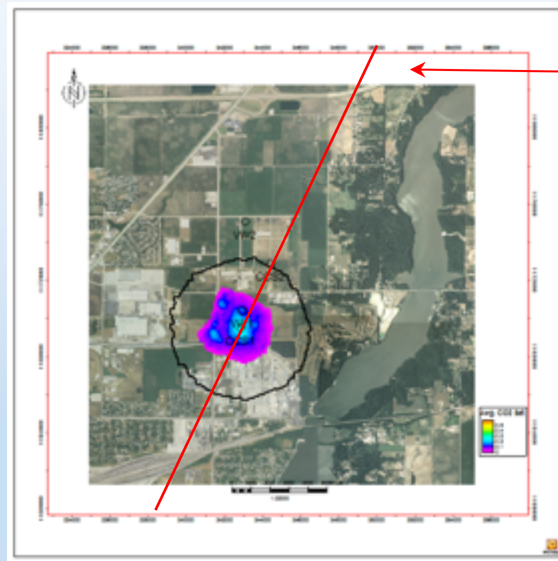




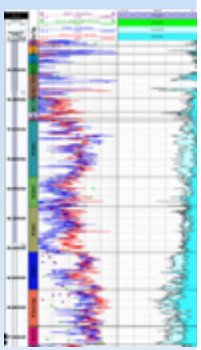
Post-CCS1 & VW1 Drill & Post-CCS1 injection

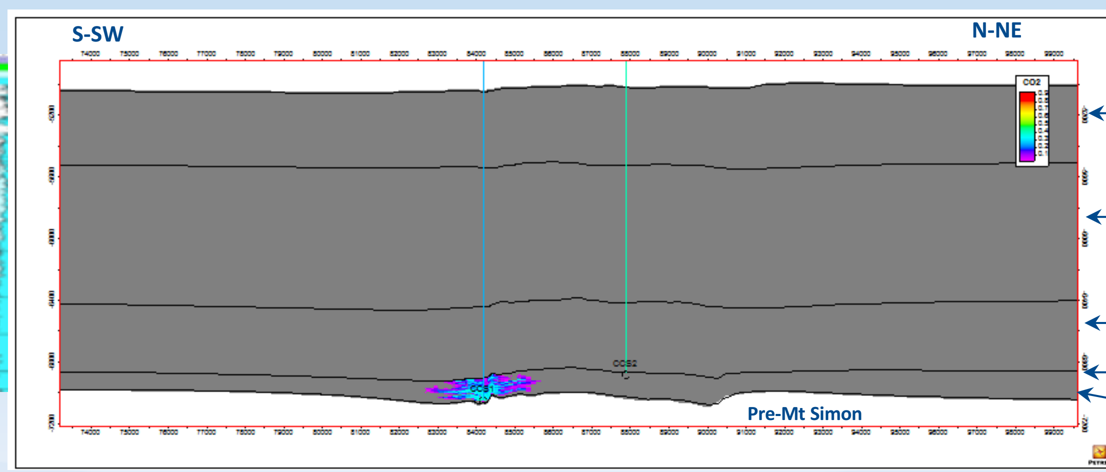
Extent of Plume & Saturation Cross Section
January 1, 2013 (year 1)

- Incremental update to previous version
- Created to update CCS2 Class VI plume forecasts
- Used final CCS2 perforation scheme
- Assumed CCS2 commence injection Jan 1 2015 at end of CCS1 injection)

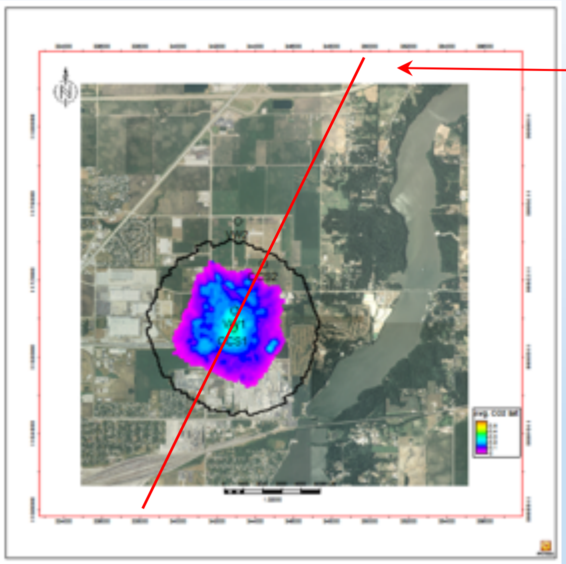


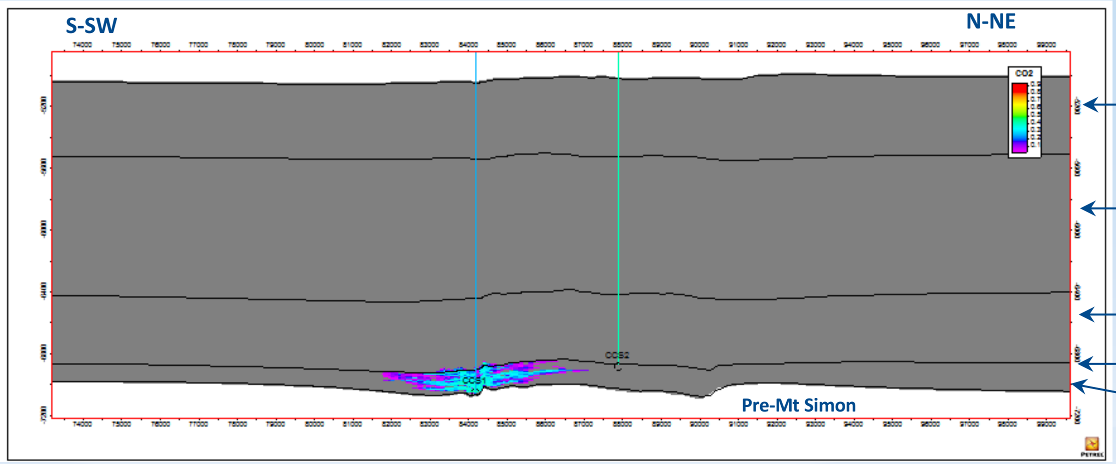
$DP_{if} \geq 86$ psi
$SCO_2 \geq 1.0\%$



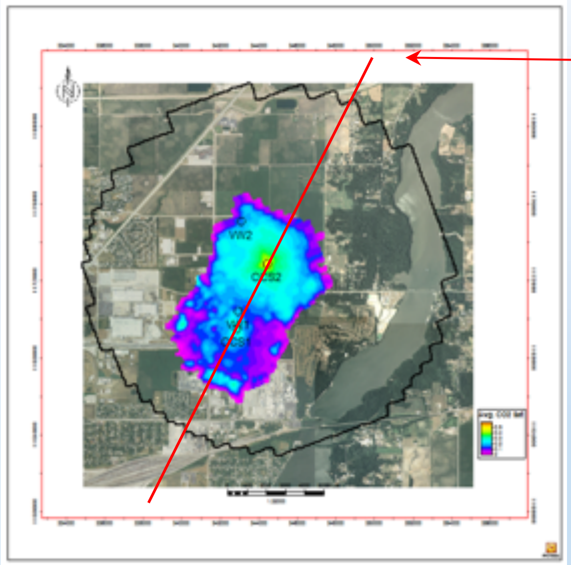


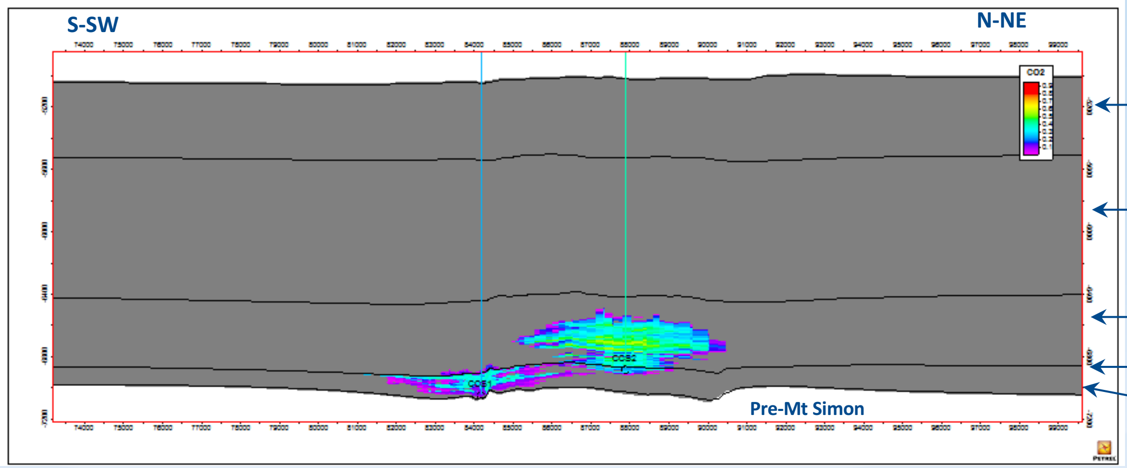
Extent of Plume & Saturation Cross Section
January 1, 2015 (year 3, end of CCS1 injection)





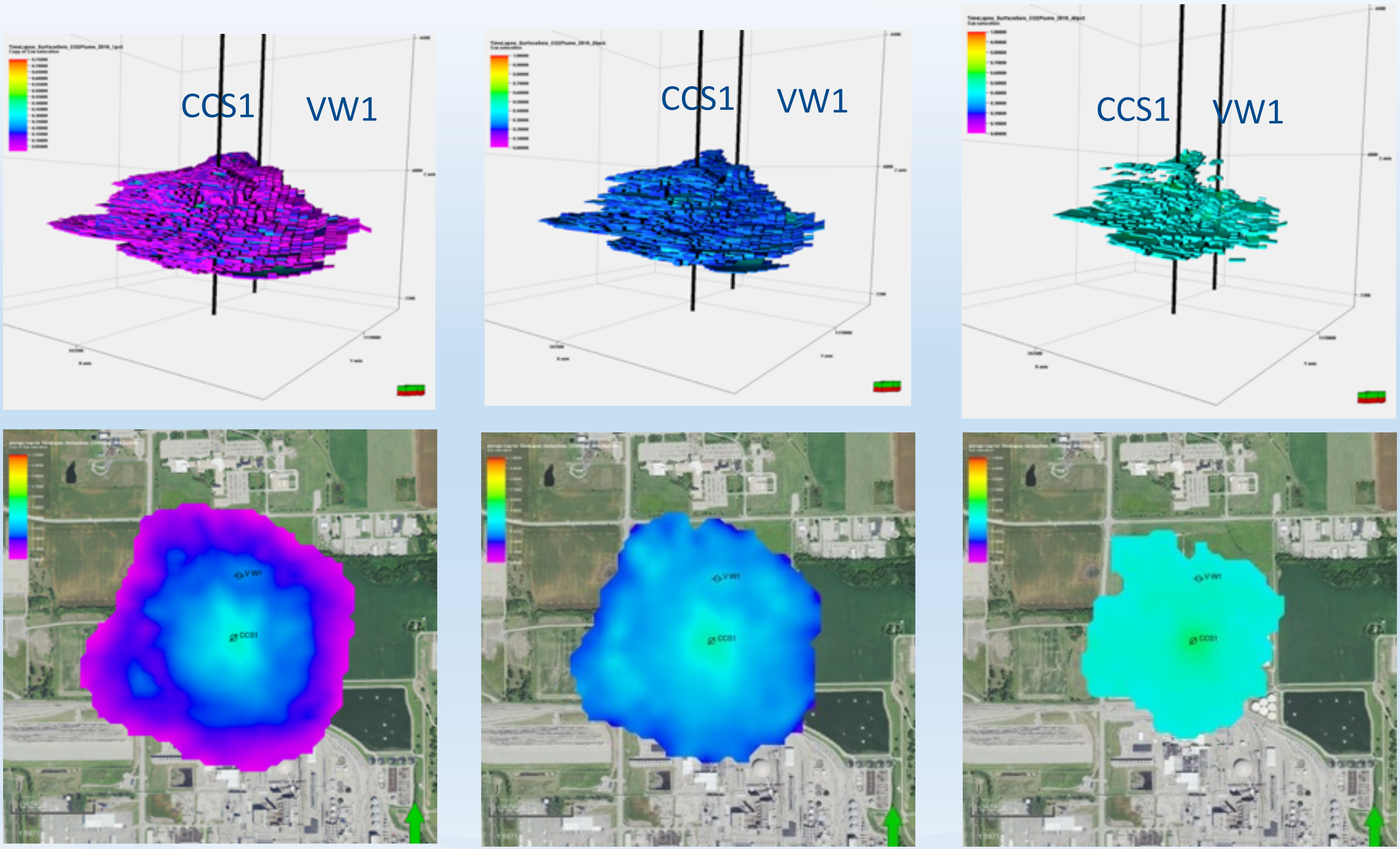
Extent of Plume & Saturation Cross Section
January 1, 2020 (year 8, end of CCS2 injection)





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

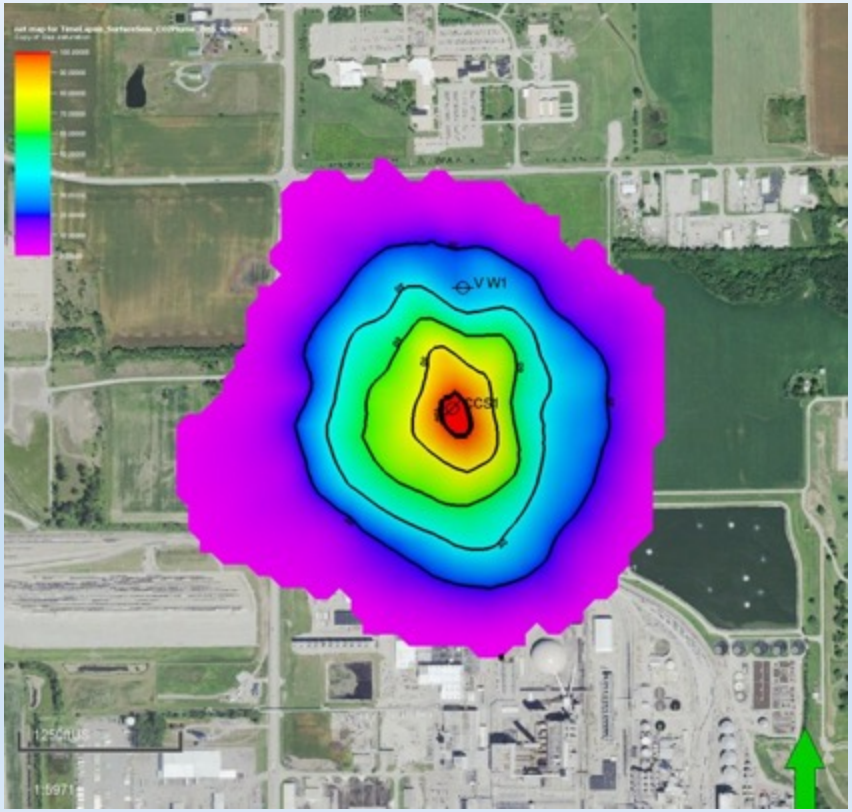
3D Reservoir Simulation Estimates of CO_2 Saturation at Time of 2015 Monitor Survey



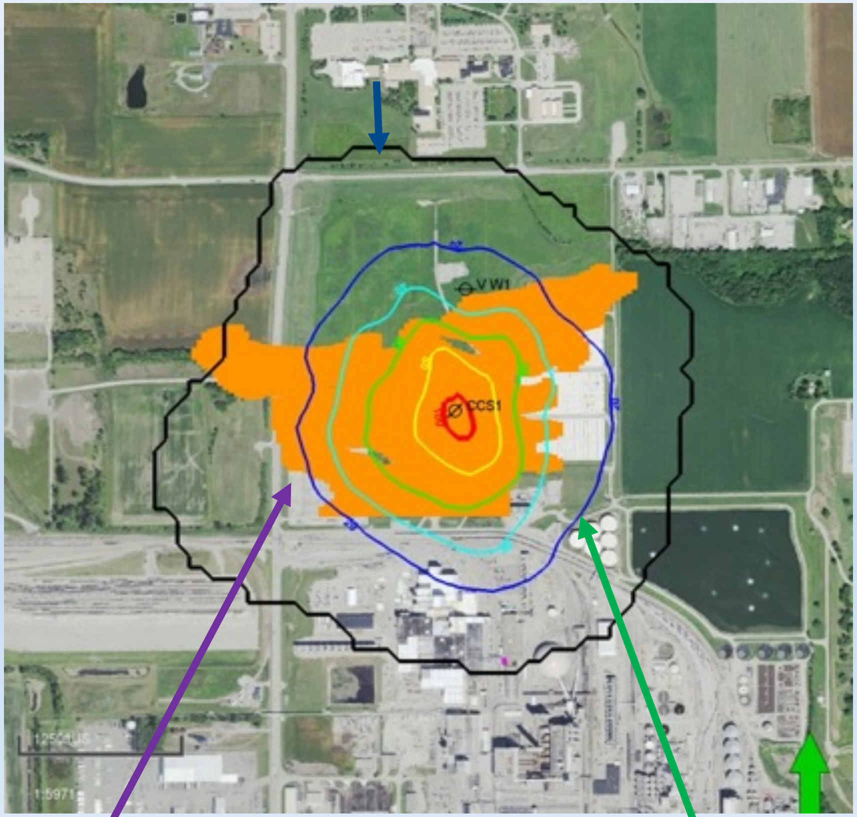
1%, 20%, and 40% CO_2 Saturation Cut-Off Visualization Filters, respectively

Co-visualization of reservoir simulation results with time-lapse seismic attributes informs estimates of the seismic detection limit.

Simulated Net CO2 Saturation (integrated S_g x thickness)



Outline of plume as defined by 1 % CO2 saturation cut-off

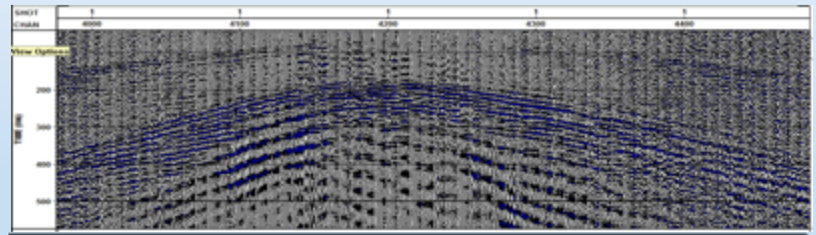


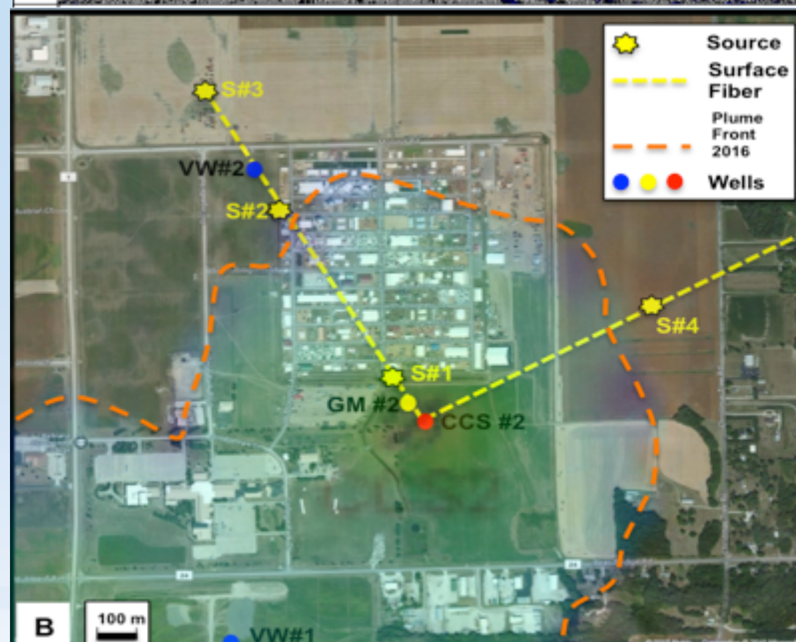
ILLINOIS INDUSTRIAL CARBON CAPTURE & STORAGE

Intelligent Monitoring System (IMS)

Program Objectives

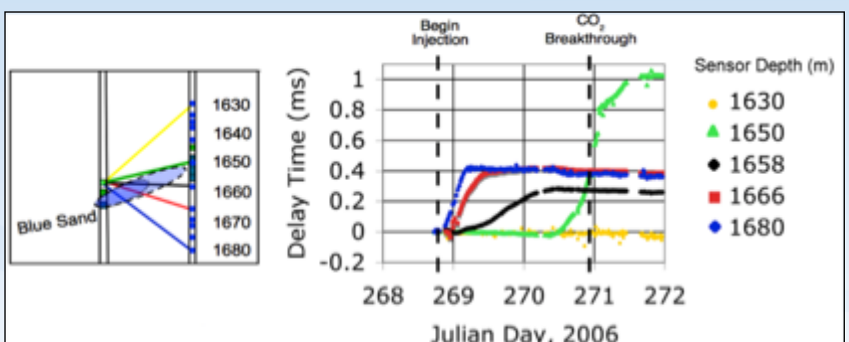
- Develop and validate software tools that advance CCS-specific IMS by enabling access, integration and analysis of real-time surface and subsurface data for decision-making and automation of process
- Demonstrate integration of system components to validate feasibility of real-world application to CCS.





Project Team Members

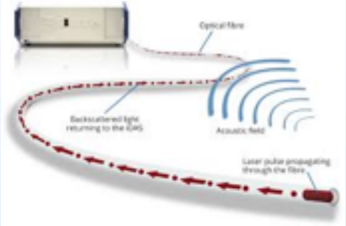
ADM | BERKELEY LAB | SILIXA | NETL | USGS science for a changing world | Richland Community College | Schlumberger Carbon Services | I ™



Testbed for Existing vs. New Technology

Conventional Seismic

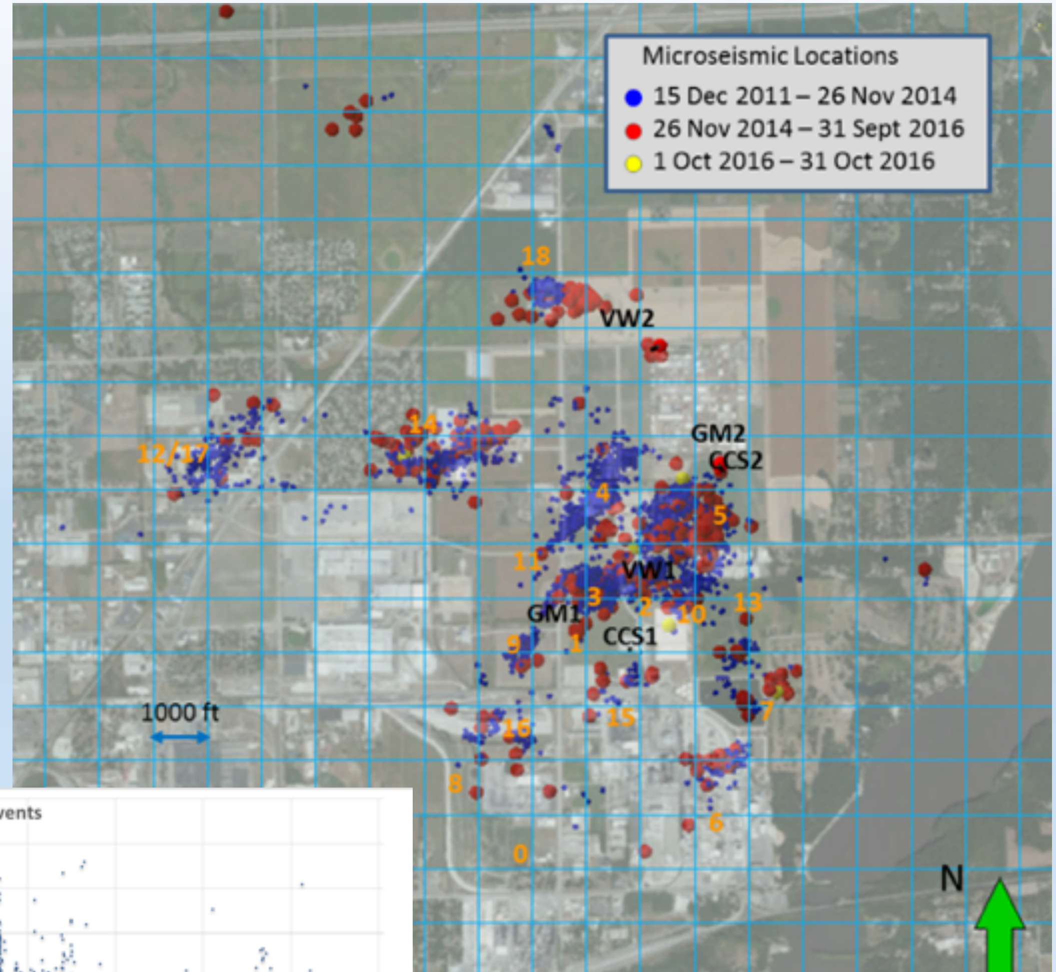
DAS Seismic

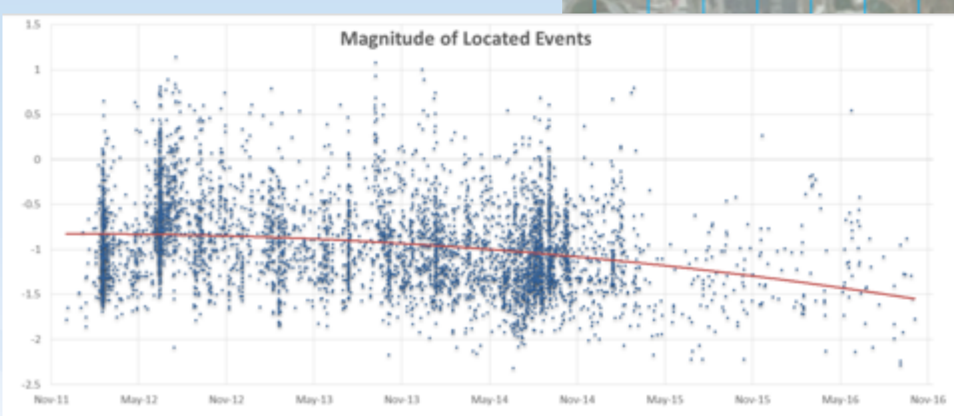


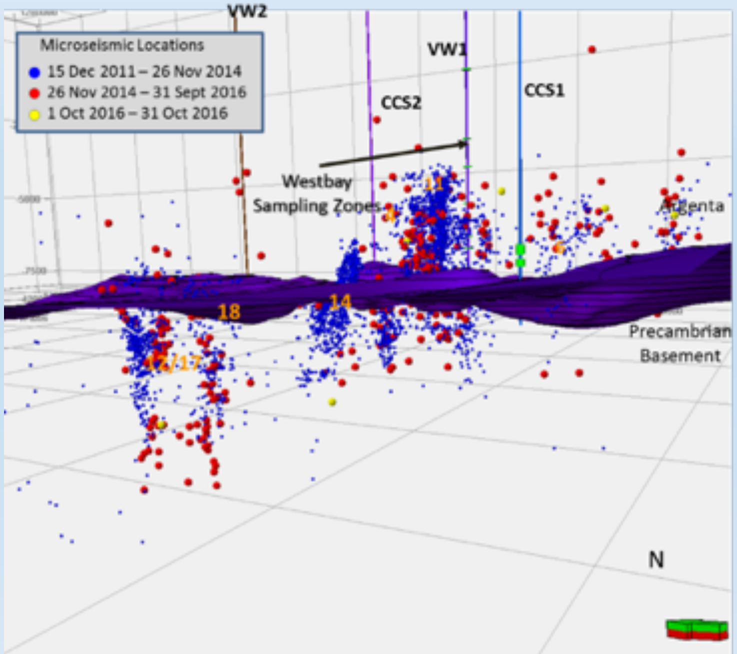
- Seismic surveys are considered the backbone technique for CO_2 storage monitoring programs.
- Stringing thousands of cables and running thumper trucks every few years can test the limits of good neighbors. Costs are high.
- Permanent reservoir monitoring offers a way to obtain higher quality information with minimal intrusion into surrounding lands –
- DAS provides high spatial and temporal resolution.
- Installation can be in horizontal directionally drilled boreholes beneath bodies of water, existing infrastructure.
- Excitation of DAS cables can be achieved through permanent fixed rotary sources for continuous monitoring.

Microseismic Activity at the Illinois Basin – Decatur Project

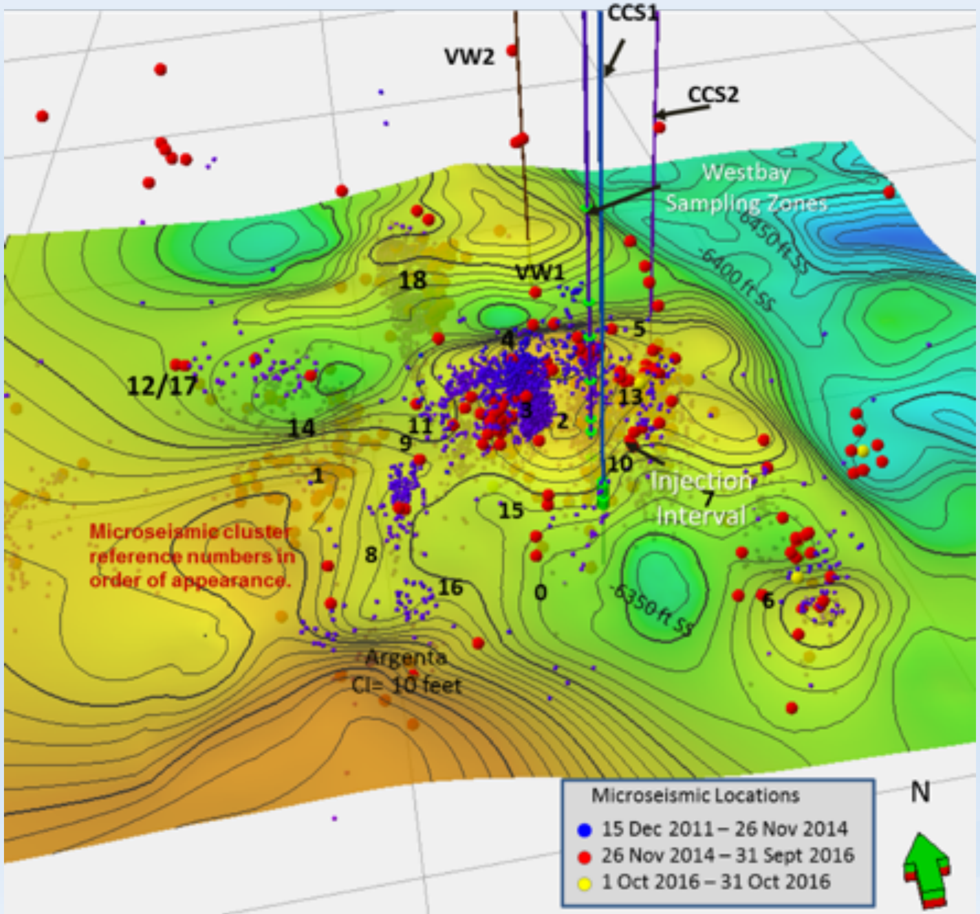
- Observed Microseismicity associated with injection
- Location critical to understanding reservoir response
- Original correlation between cluster development and pressure front under examination
- ICCS created stoplight map to mitigate potential associated risks from felt events







Microseismic Locations
15 Dec 2011 – 26 Nov 2014
26 Nov 2014 – 31 Sept 2016
1 Oct 2016 – 31 Oct 2016
VW2
VW1
CCS2
CCS1
Westbay
Sampling Zones
Argenta
18
14
Precambrian
Basement
N



CCS1
VW2
CCS2
Westbay
Sampling Zones
6450 ft SS
6400 ft SS
18
VW1
4
5
12/17
3
13
14
11
2
9
10
1
Injection
Interval
7
15
Microseismic cluster
reference numbers in
order of appearance.
8
16
0
6350 ft SS
6
Argenta
CI= 10 feet
Microseismic Locations
15 Dec 2011 – 26 Nov 2014
26 Nov 2014 – 31 Sept 2016
1 Oct 2016 – 31 Oct 2016
N

By the numbers:

A million tonnes stored and…

More than **5,100 meters** of wells have been drilled

More than **245 meters** of core have been collected

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 **700 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

Lessons Learned from IBDP

- Advanced technology deployment has associated risk. Technology choices can significantly impact long-term project operations
- Despite the challenges with the Westbay installation, highly relevant experience has been gained and a high quality fluid chemistry data set has been acquired
- Successful projects require significant resources to accomplish objectives
- Degree of risk could be different depending on nature of project (research, industrial, commercial)
- Community engagement requires dedicated personnel, continual monitoring, and significant time to build trust and provide information

Lessons Learned from IBDP

- Processes such as induced microseismicity may require increased spatial model discretization for specialized dynamic process modeling
- CO_2 plume geometry may require fine vertical discretization to history match saturation observations
- Microseismic baseline activities need to be monitored prior to injection, during injection, and post-injection to fully understand reservoir response and residual stress
- Monitoring efforts and information should undergo periodic project-wide reviews. External reviews may also be beneficial
- Knowledge of key reservoir characteristics evolves with additional data and site specific experience. Modeling workflows should account for rapid iteration with systematic improvement

Conclusions

- 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

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