Midwest Geological Sequestration Consortium

Midwest Geological Sequestration Consortium: Highlights from the Illinois Basin – Decatur Project

Sallie E. Greenberg, Ph.D.
Midwest Geological Sequestration Consortium
University of Illinois – Illinois State Geological Survey

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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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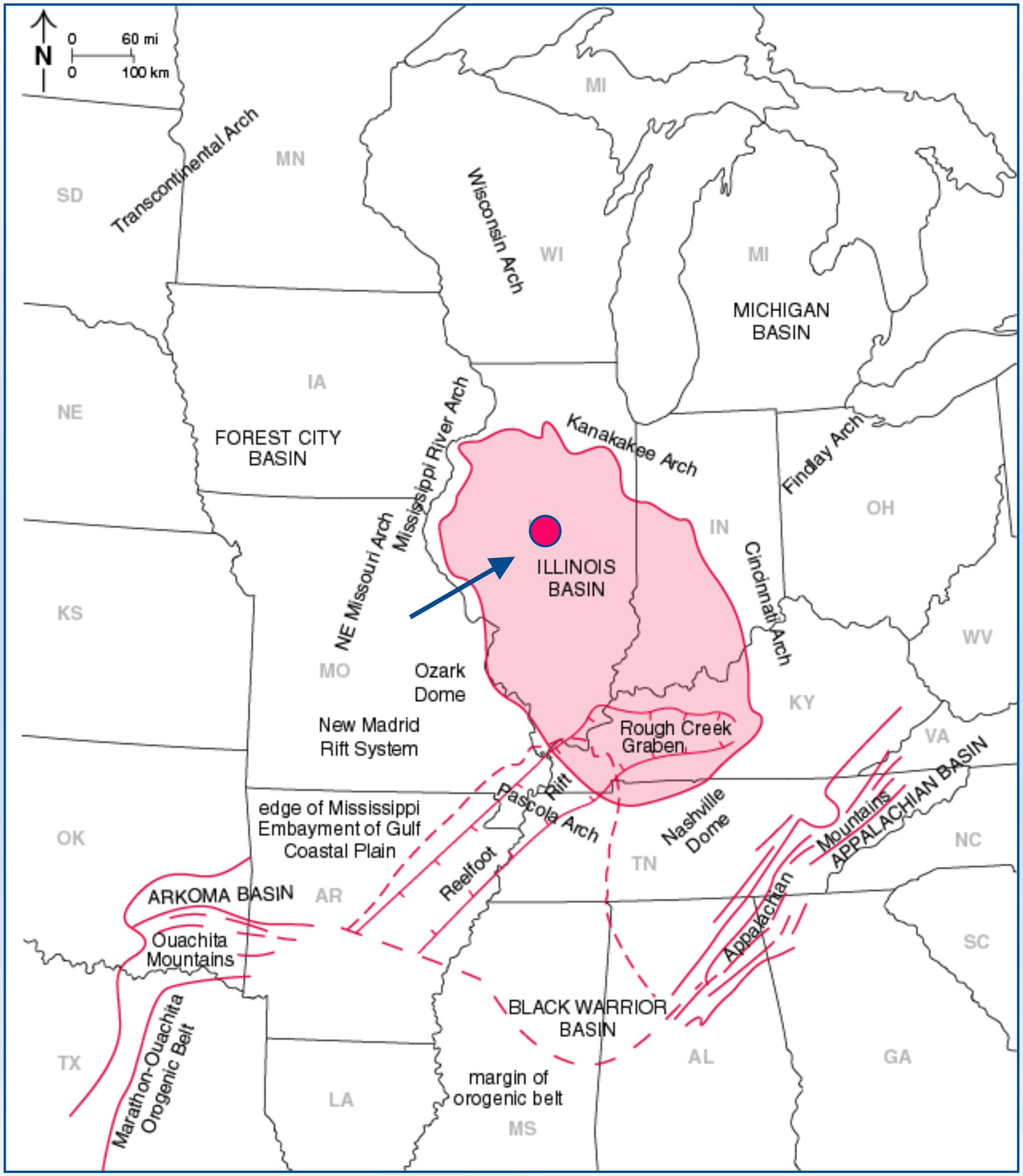
U.S. DEPARTMENT OF ENERGY

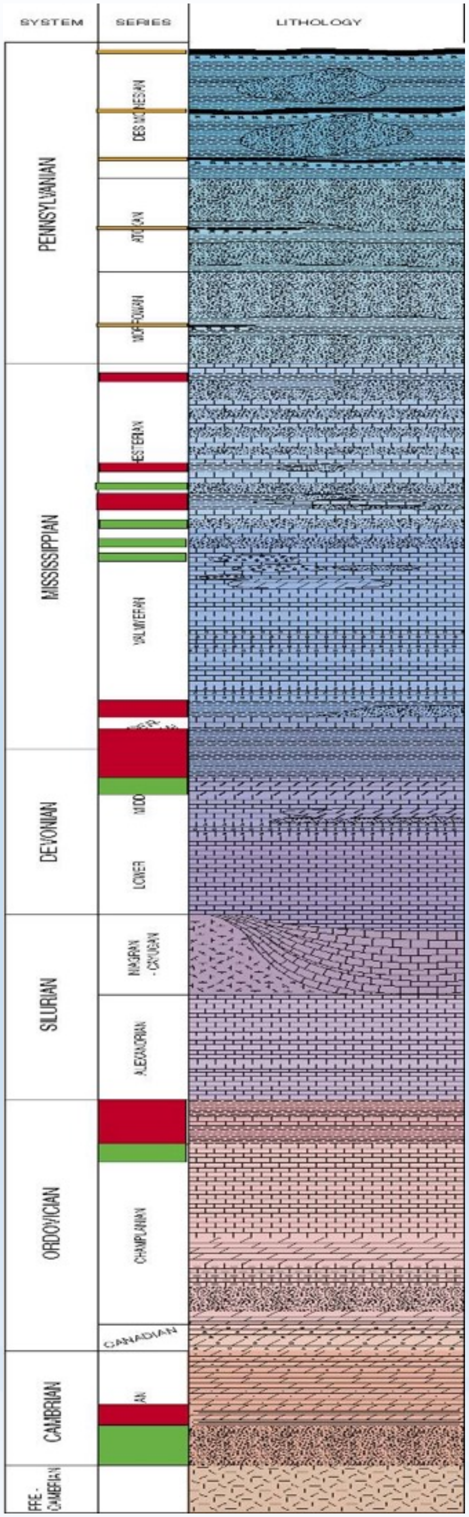
NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

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 7,000 +/- ft (2,000 +/- m) to test geological carbon sequestration in the Mt. Simon Sandstone, a saline reservoir, at Decatur, IL

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



Illinois Basin Stratigraphic Column

Pennsylvanian coal seams

New Albany Shale

back-up seals

Maquoketa Shale

St. Peter Sandstone

Eau Claire Shale seal

Mt. Simon Sandstone reservoir

Mount Simon Storage Capacity:

11 (E=0.4%) to 150 (E=5.5%) billion metric tons

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: November 2011 to 2014

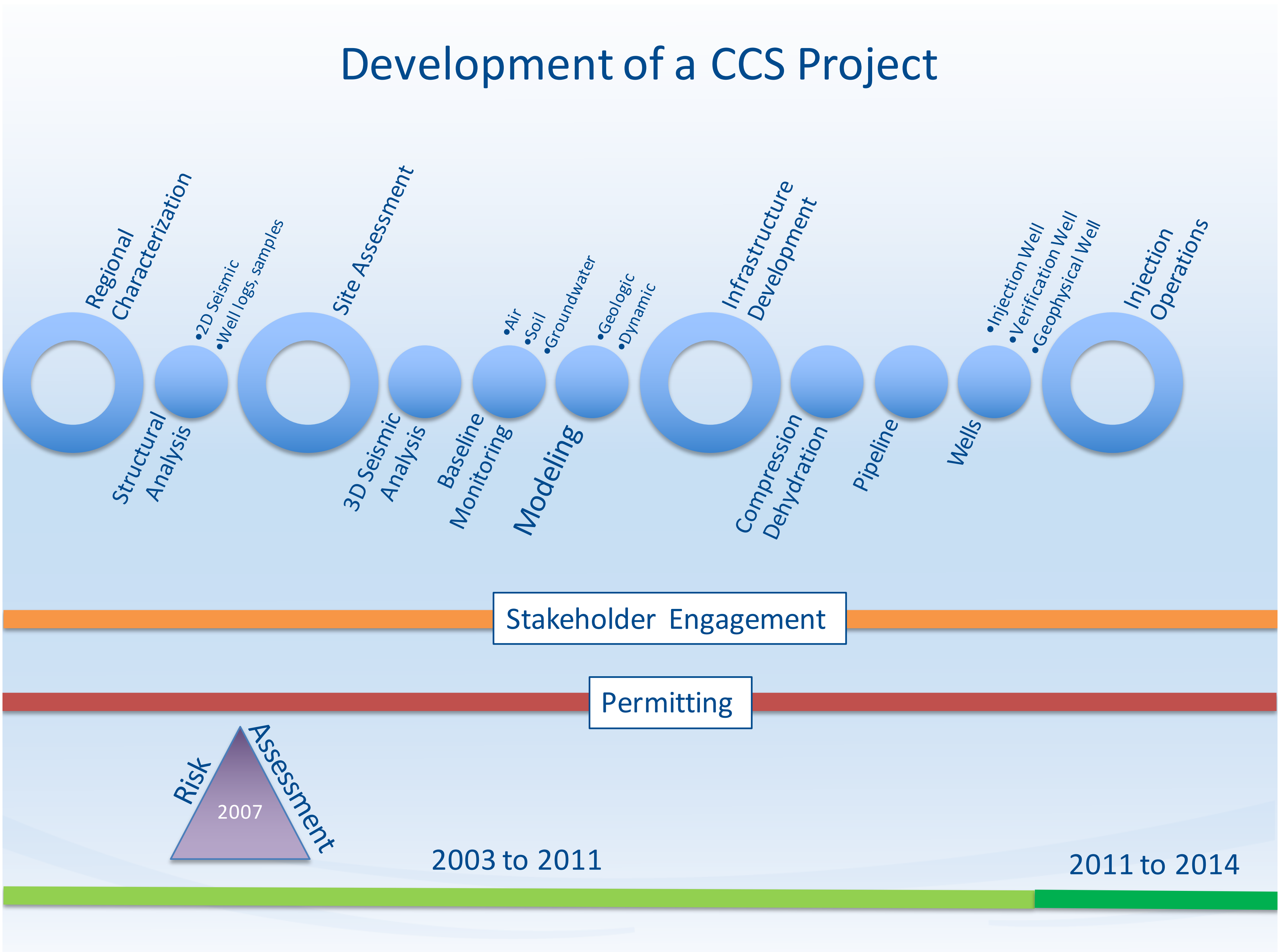
- IBDP is the first 1 million tonne carbon capture and storage project from a biofuel facility in the US
- Intensive post-injection monitoring under MGSC through 2017
- Industrial CCS Injection Monitoring through 2019

Total Injection:
999, 215 tonnes

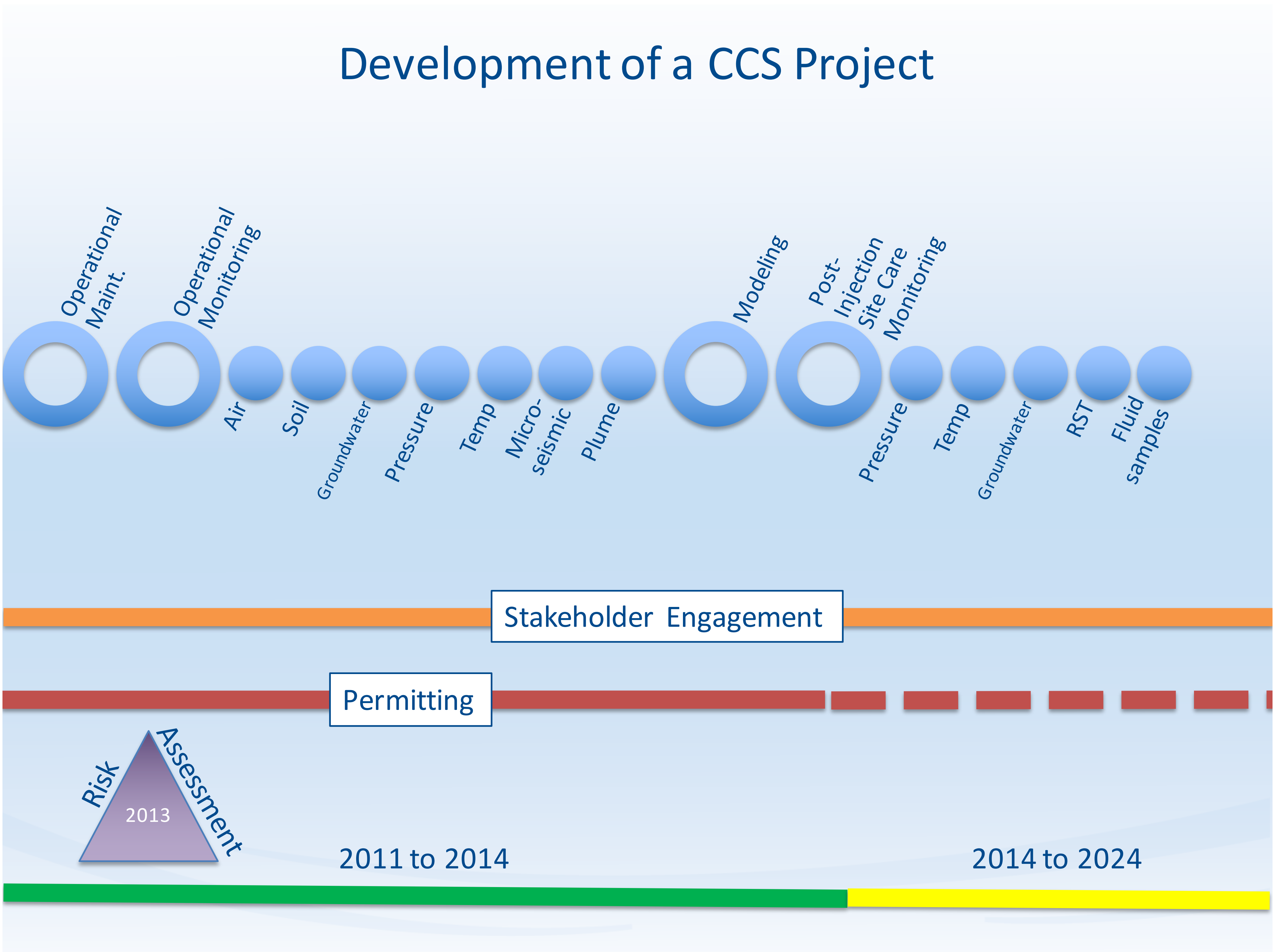
Illinois Basin – Decatur Project Workflow

- 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
Regional Characterization
•2D Seismic
•Well logs, samples
Structural Analysis
Site Assessment
3D Seismic Analysis
Baseline Monitoring
•Air
•Soil
•Groundwater
Modeling
•Geologic
•Dynamic
Infrastructure Development
Compression Dehydration
Pipeline
Wells
•Injection Well
•Verification Well
•Geophysical Well
Injection Operations
Stakeholder Engagement
Permitting
Risk Assessment
2007
2003 to 2011
2011 to 2014


Development of a CCS Project
Operational Maint.
Operational Monitoring
Air
Soil
Groundwater
Pressure
Temp
Micro-seismic
Plume
Modeling
Post-Injection Site Care Monitoring
Pressure
Temp
Groundwater
RST
Fluid samples
Stakeholder Engagement
Permitting
Risk Assessment
2013
2011 to 2014
2014 to 2024

Statement of Project Objectives (SOPO)

Task	Scope	Status (% Complete)	Open Subtasks (*n*)
1	Regional Characterization	100	1 of 12
2	Public Outreach and Education	70	2 of 6
3	Permitting and NEPA Compliance	90	1 of 11
4	Site Characterization and Modeling	90	2 of 14
5	Well Drilling and Completion	100	0 of 5
6	Infrastructure Development	100	0 of 12
7	CO_2 Procurement	100	0 of 1
8	Transportation and Injection Operations	100	0 of 3
9	Operational Monitoring and Modeling (MMV/MVA)	100	0 of 6
10	Site Closure	100	Define as needed
11	Post Injection Monitoring and Modeling	20	1 of 5
12	Project Assessment	30	2 of 2
13	Post-Test Site Planning	50	1 of 1
14	Project Management	70	2 of 2

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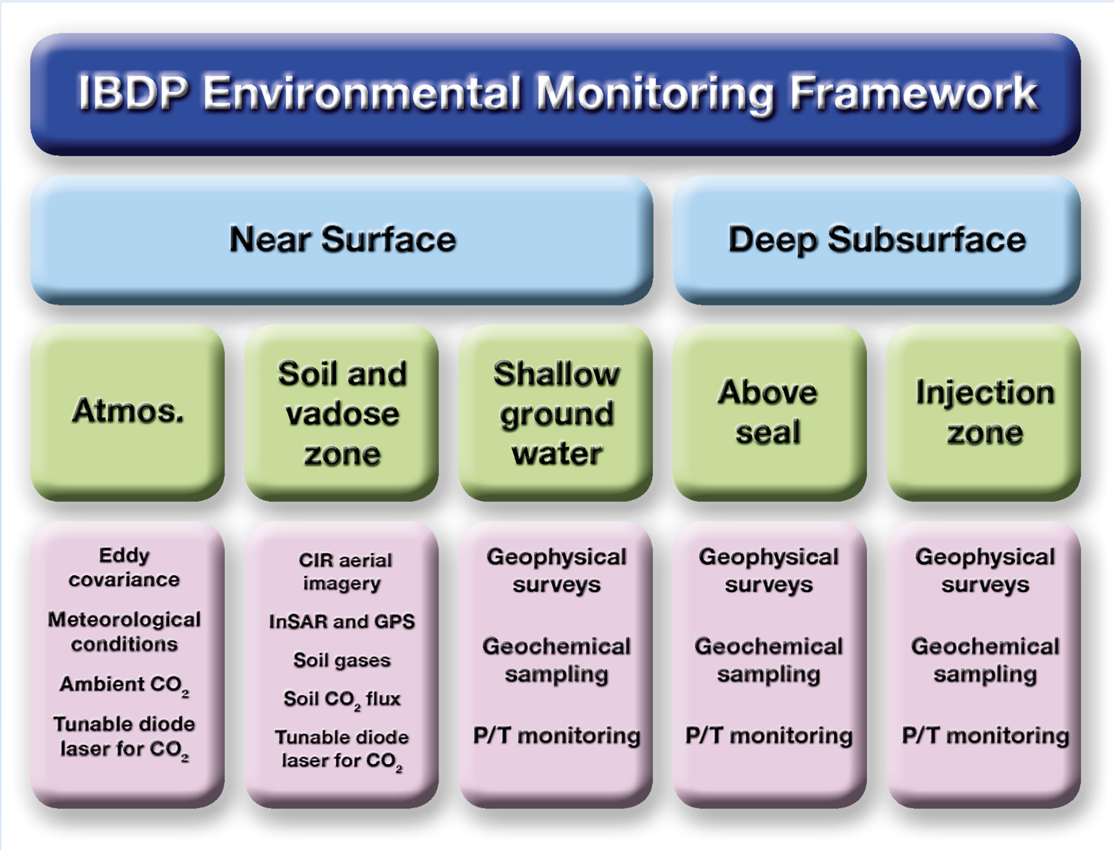
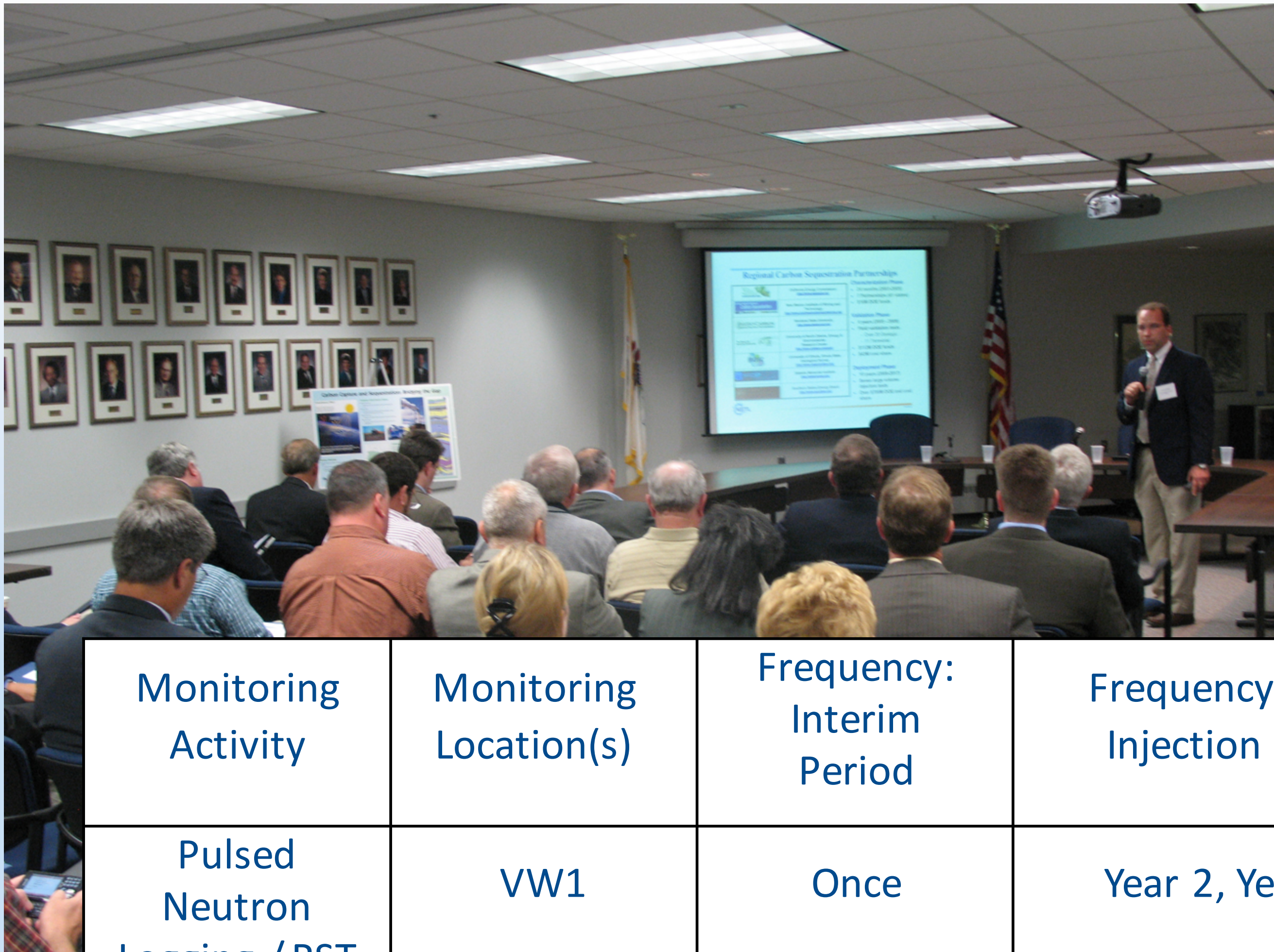
Post-Injection Activities (Since November 2014)

- Post-injection near surface and deep monitoring
- Post-injection modelling and data evaluation
  - 3D Surface Seismic Survey – 2015
  - Post-injection VSP (permit interim period) – 2015
  - RTAC to Well Watcher Migration - 2016
  - Recomplete VW1 – 2016/2017
  - Final static and dynamic models – 2016
  - Near-surface monitoring analysis and recommendations - 2016
  - Passive/active monitoring project (US-Norway) – 2016-2017
  - Peer-reviewed articles, technical and final reports
  - Partnership and project closure
- Knowledge and data sharing best practices
- Preparing IBDP site for long-term commercial viability
- Permit monitoring for ADM Industrial CCS project

Post-injection Monitoring – Locke and Collaborators

- Near-surface comparison with baseline
- Regulatory compliance for the IBDP PISC
- Recommendations for commercial-scale MVA operations based on IBDP experiences





Permitting

IL EPA UIC Class I to US EPA UIC Class VI

Monitoring Activity	Monitoring Location(s)	Frequency: Interim Period	Frequency: CCS2 Injection Phase	Frequency: CCS2 Post- Injection Phase
Pulsed Neutron Logging / RST	VW1	Once	Year 2, Year 4	Year 1, Year 3, Year 5, Year 7, Year 10
Fluid Sampling	VW1	Once	Year 1-3 : Annual Year 4-5 : None	None
Pressure/ Temperature Monitoring	VW1	Continuous	Year 1-3 : Continuous Year 4-5 : None	None

VWI Sampling

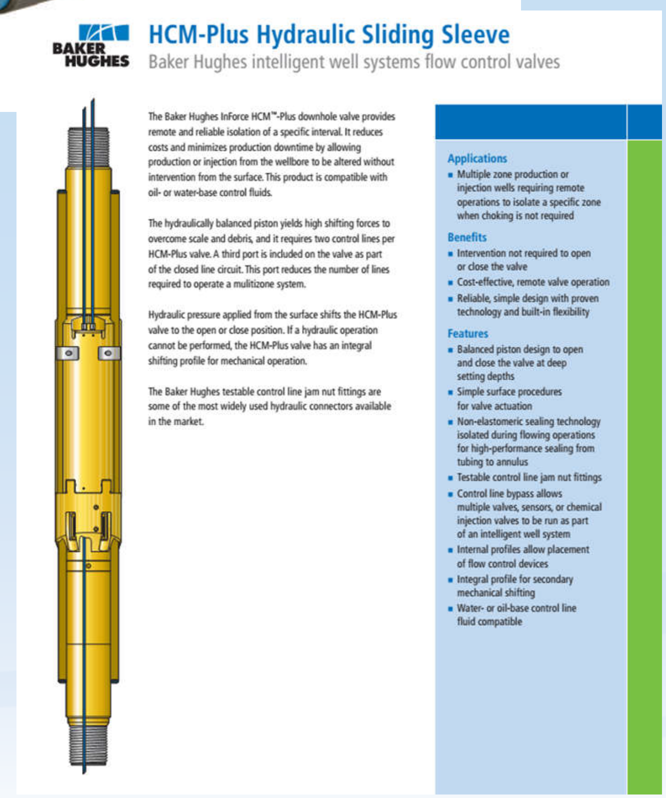
- Developed procedures and identified critical sample integrity tests
- Developed fluid quality data to characterize deep Illinois Basin brines
- 2013: TDS increase
- 2014-2015: sampling and mitigation efforts
- 2015 results: mitigation not effective

Zone	Swab (5/3/11 - 5/18/11)	WB1 (6/15/11 - 7/6/11)	WB2 (9/12/11 - 9/19/11)	WB3 (3/5/12 - 3/14/12)	WB4 (7/12/12 - 7/25/12)	WB5 (11/14/12 - 11/15/12)	WB6 (2/20/13 - 2/21/13)	WB7 (7/11/13 - 7/18/13)	WB8 (7/18/14 - 8/4/14)	WB9 (9/10/14 - 9/12/14)	WB10 (11/8/15- 12/03/15)
11	1	1	1	0	1	0	0	2	6	0	2
10	1	2	2	0	3	1	0	2	8	2	1
9	1	1	1	1	1	0	0	0	4	0	2
8	1	2	1	1	1	0	0	0	4	0	2
7	1	3	1	1	0	0	0	0	3	0	2
6	1	1	1	1	1	0	0	2	1	0	2
5	1	1	1	1	1	0	0	2	1	0	1
4	1	3	1	1	2	2	2	2	2	0	1
3	3	1	1	1	0	0	0	0	0	0	0
2	2	1	1	2	0	0	0	0	0	0	0

Source: ISGS and Schlumberger

Date	Zone	Round	Field Alkalinity (mg/L)	TDS (mg/L)	Br (mg/L)	Cl (mg/L)
07/17/12	9	WB 4	86	147,300	476	91,030
08/01/14	9	WB 8	84	155,700	489	92,230
11/13/15	9	WB 10	80	150,000	520	89,000
7/19/12	10	WB 4	59	91,680	200	54,223
11/14/12	10	WB 5	50	82,030	176	46,550
07/15/13	10	WB 7	128	181,800	318	111,200
08/04/14	10	WB 8	124	158,800	504	93,710
11/08/15	10	WB 10	76	120,000	390	98,000
7/20/12	11	WB 4	30	80,970	150	49,930
07/13/13	11	WB 7	172	138,400	76	76,570
07/22/14	11	WB 8	147	156,100	493	93,600
11/08/15	11	WB 10	144	110,000	340	62,000

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

Research priorities:

- Monitor injection of multiple plumes within Mt. Simon in order to **determine and observe reservoir response** via pressure, temperature, geophysical, geomechanical, and geochemical means.
- **Demonstrate and test monitoring equipment and methodologies** for deployment at the near and deep subsurface through a comprehensive MVA program.
- **History match and determine plume development response** through active and passive seismic monitoring in order to further understand reservoir microseismic response

Project management priorities:

- **Deliver project on-time and within budget**
- **Reduce short- and long-term risk to project**

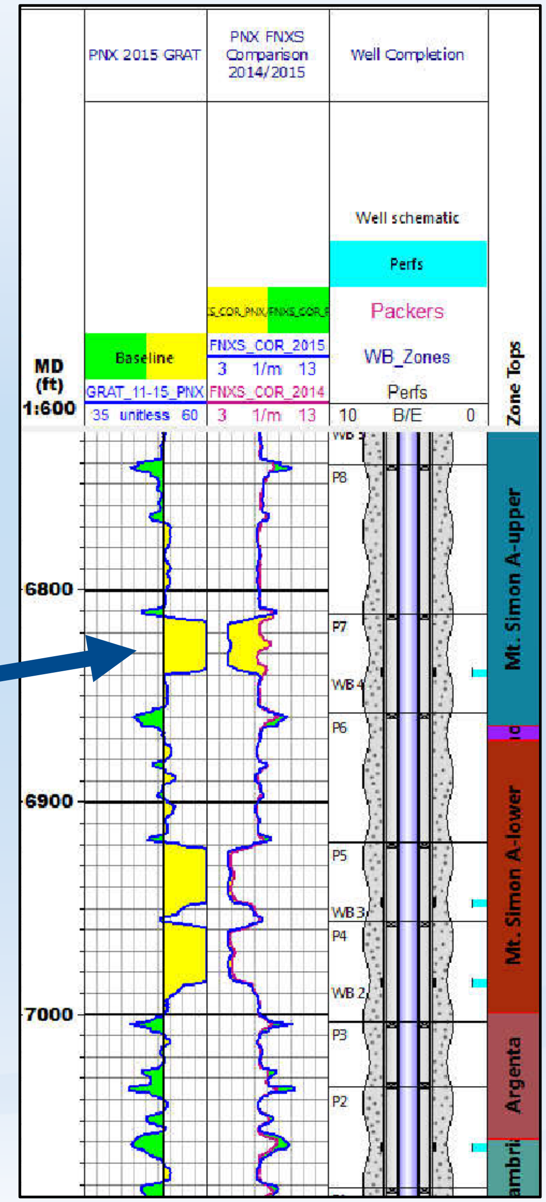
Permit priorities:

- **Perform Injection phase monitoring by fluid sampling** in two zones (one in Mt. Simon and one in Ironton/Galesville)
- **Perform continuous pressure and temperature monitoring**
- **Conduct direct and indirect plume monitoring**

Post-injection Monitoring – Malkewicz and Collaborators

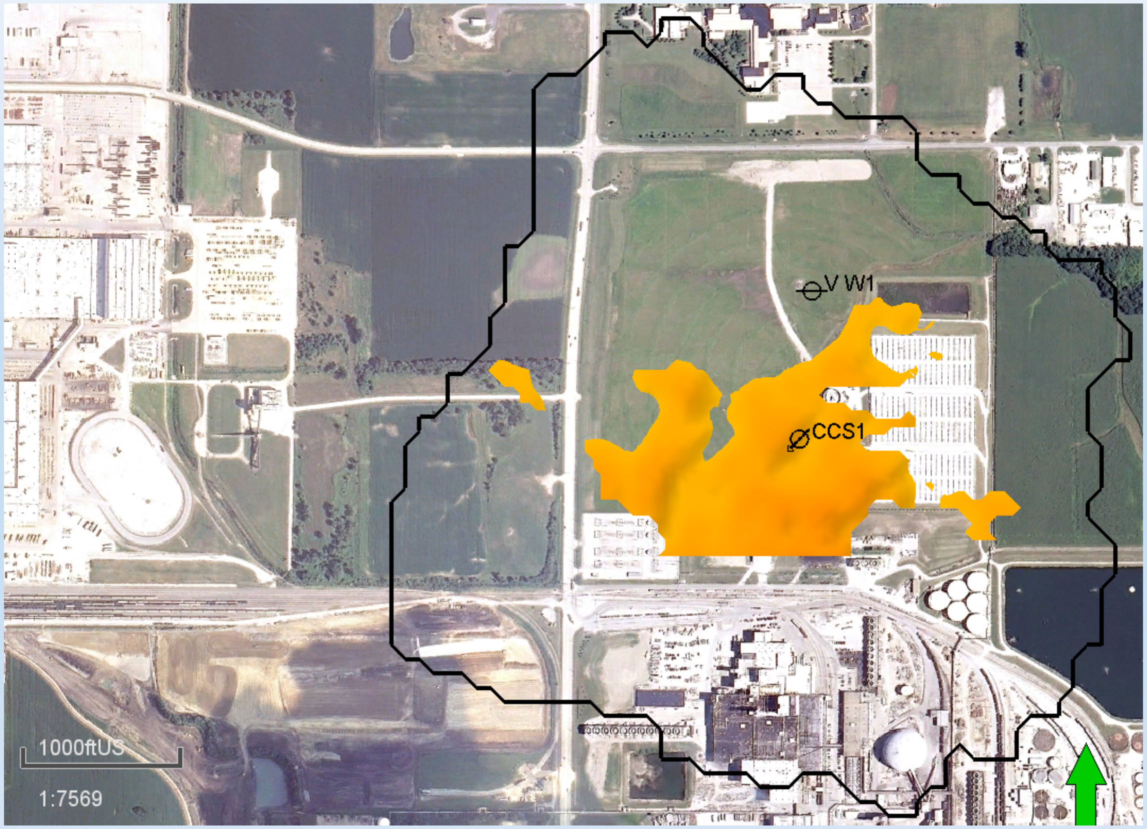
	CCS1	VW1	GM1	Remarks
2009 August	✓	✗	✗	Preliminary Evaluation
2011 March	✓	✓	✗	Pre-injection
2011 September	✓	✓	✓	Pre-injection
2012 March	✓	✓	✓	CO_2 breakthrough
2012 July	✓	✓	✗	Breakthrough Monitoring
2012 November	✓	✓	✗	Breakthrough Monitoring
2013 July	✓	✓	✓	Annual Monitoring
2014 July	✓	✓	✓	Annual Monitoring
2014 December	✓	✓	✓	End of Injection.
2015 November	✗	✓	✗	Diagnose VW#1
2017 TBD	✓	✓	✗	Planned Regulatory
2019 TBD	✓	✓	✗	Planned Regulatory

VW1 11/2015 Pulsed Neutron



Integration of Modeling Efforts – Zaluski, Will, and Collaborators

- Concurrent IBDP Modeling Efforts:
  - Geologic (static)
  - Reservoir simulation
  - Geomechanical
  - Coupled hydro-mechanical



Preliminary consolidated time-lapse attribute interpretation (orange) and outline of modeled plume (black polygon) in Q1 2015.

Recent Publications

- International Journal of Greenhouse Gas Control
  - 4 microseismic papers
- McBride, J.H., Leetaru, H.E., Keach, R.W., II, and McBride, E.I., 2016, Fine-scale structure of the Precambrian beneath the Illinois Basin: Geosphere, v. 12, no. 2, p. 1–22.
- American Geophysical Union Chapter
- Trimeric cost analysis

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Data integration, reservoir response, and application

Robert Will[a,†], Valerie Smith[b], Don Lee[c], Ozgur Senel[d]

[a] Schlumberger Carbon Services, 1875 Lawrence Street, Suite 810, Denver, CO 80202, USA
[b] Schlumberger Carbon Services, 905 West Union Road, Norwich, OH 43767, USA
[c] Schlumberger, 1325 South Dairy Ashford, Houston, TX 77077, USA
[d] Schlumberger, Rohas Perkasa, No. 9 Jalan P. Ramlee, West Wing, 19th Floor, Kuala Lumpur, Malaysia

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Microseismic data acquisition, processing, and event characterization at the Illinois Basin – Decatur Project

Robert Will[a,†], George El-Kaseeh[b], Paul Jaques[c], Michael Carney[b], Sallie Greenberg[d], Robert Finley[d]

[a] Schlumberger Carbon Services, 1875 Lawrence St. Suite 810, Denver, CO 80202, USA
[b] Schlumberger Carbon Services, 14090 Southwest Freeway Suite 240, Sugar Land, TX 77478, USA
[c] Schlumberger Madingley Road, Cambridge CB3 0EL, UK
[d] Illinois State Geological Survey, University of Illinois at Urbana-Champaign, 615 East Peabody Drive, Champaign, IL 61821, USA

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Trigger
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ABSTRACT

Microseismic monitoring at the Illinois Basin – Decatur Project (IBDP) is accomplished using a combination of commercially available components that are integrated to provide real-time analysis and remote processing capabilities by means of a purpose-built data management system and secure web portal. The processing workflow consists of real-time, remote access, and in-house processing components, which provides a seamless path from in-field quality control to final locations with short turn-around times. Event location is performed using an adaptation of the Geiger method, which is designed to be robust for the sparse but localized observation sets typically encountered with injection monitoring. Observed microseismicity displayed distinct linear clustering and increased in distance from the injection well over time, presenting challenges for location accuracy of more distal events. The velocity model, a key component in event location and characterization, evolved through early stages of the project as new wells were drilled providing the opportunity for improved observation geometry and acquisition of additional controlled energy source points for model calibration. The experience gained at IBDP highlights the importance of field systems and processing flows that allow adaptation to evolving operational conditions and microseismic event activity.

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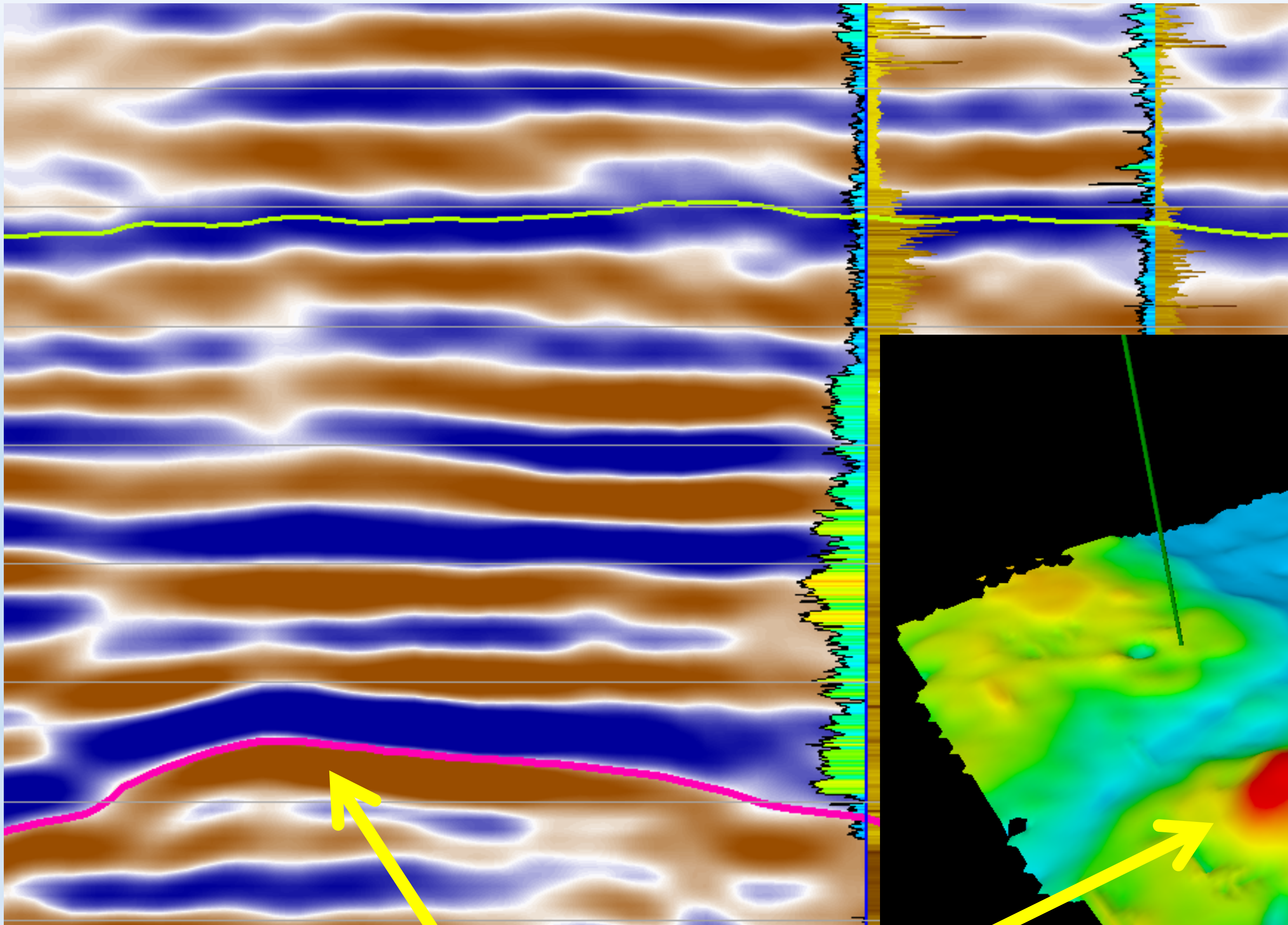
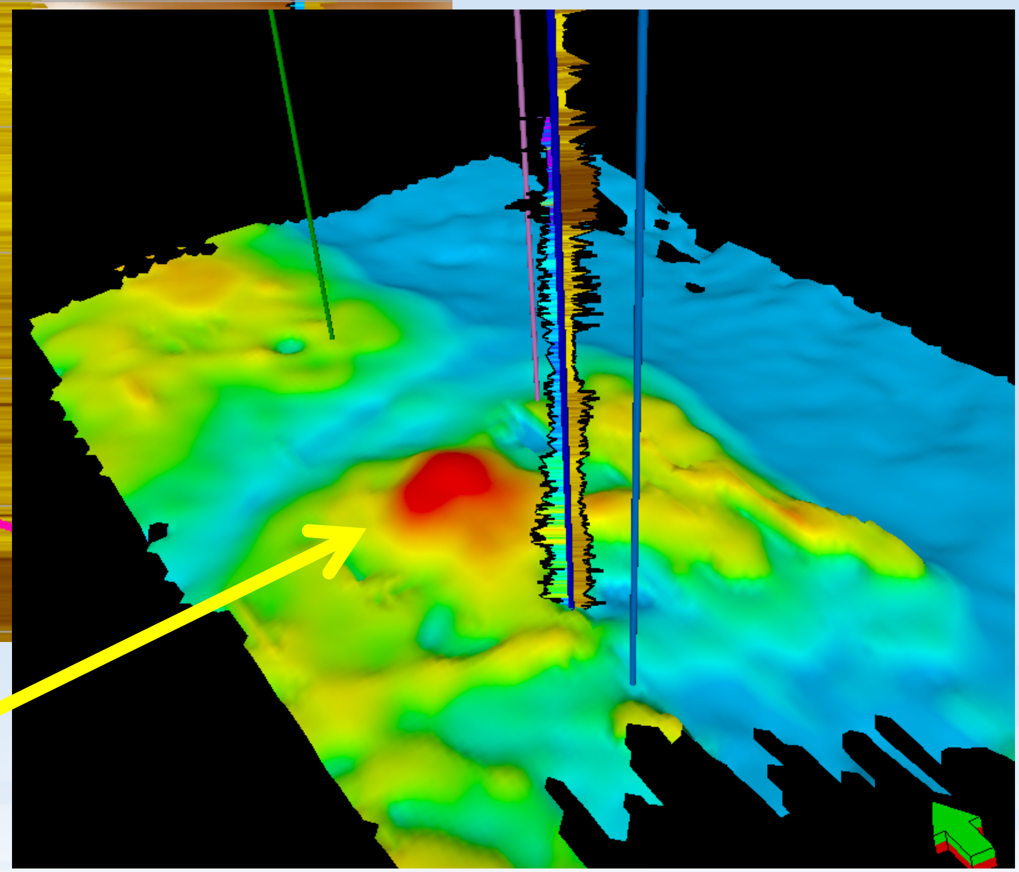
1. Introduction

The Illinois Basin – Decatur Project (IBDP) is a United States

mechanisms" are parameterized using rock mechanics theory in which emitted energy characteristics are functions of in situ stress magnitude and orientation, rock properties, displacement distance

Refining Understanding of Precambrian Structure using 3D Seismic Volume – McBride, Leetaru, and Collaborators





Eroded Precambrian surface

Images from Leetaru, ISGS

Comprehensive view of work done on microseismic activity: Pre- through post-injection – Bauer, Will, and Collaborators

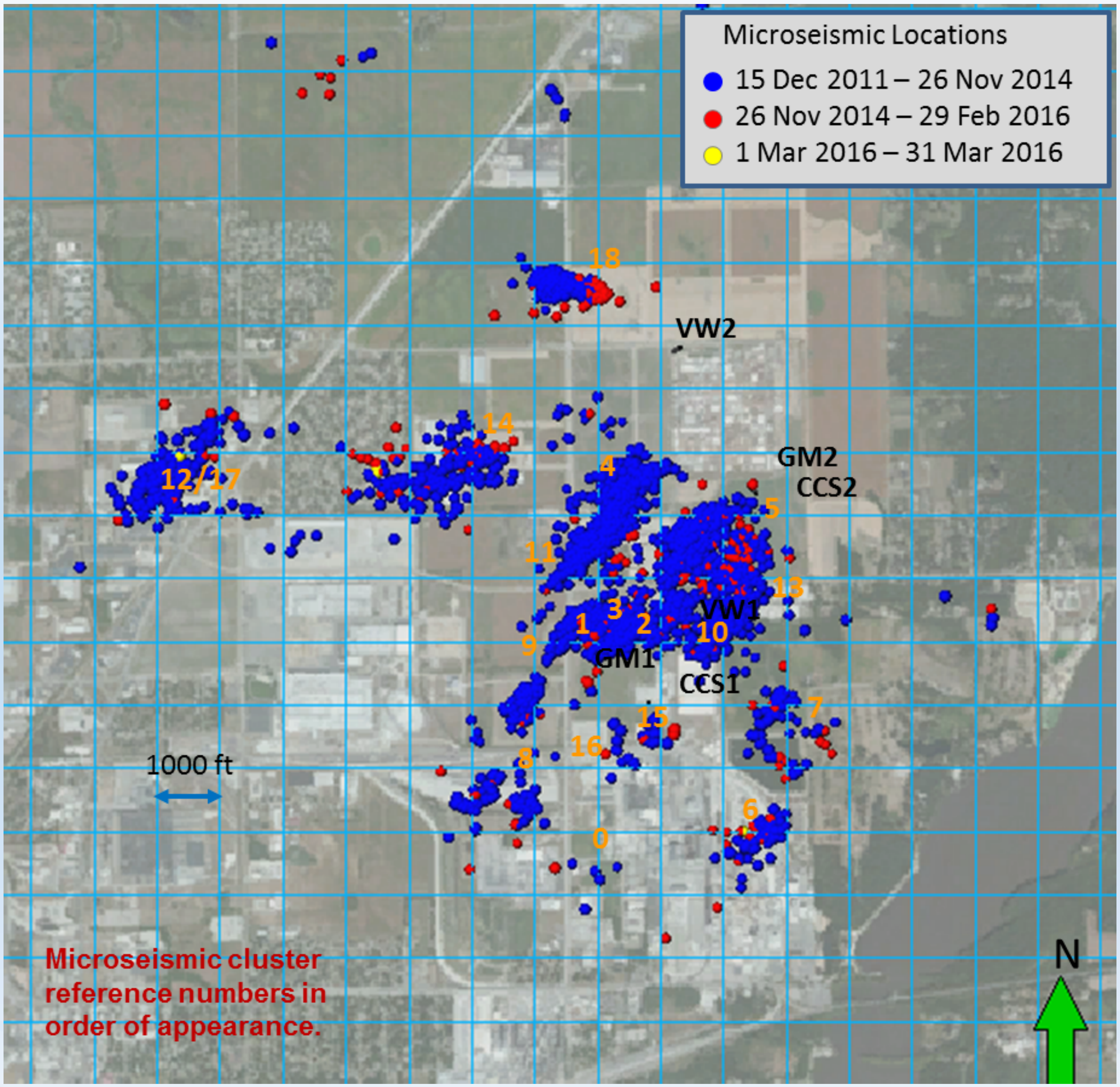


Image provided by Schlumberger Carbon Services

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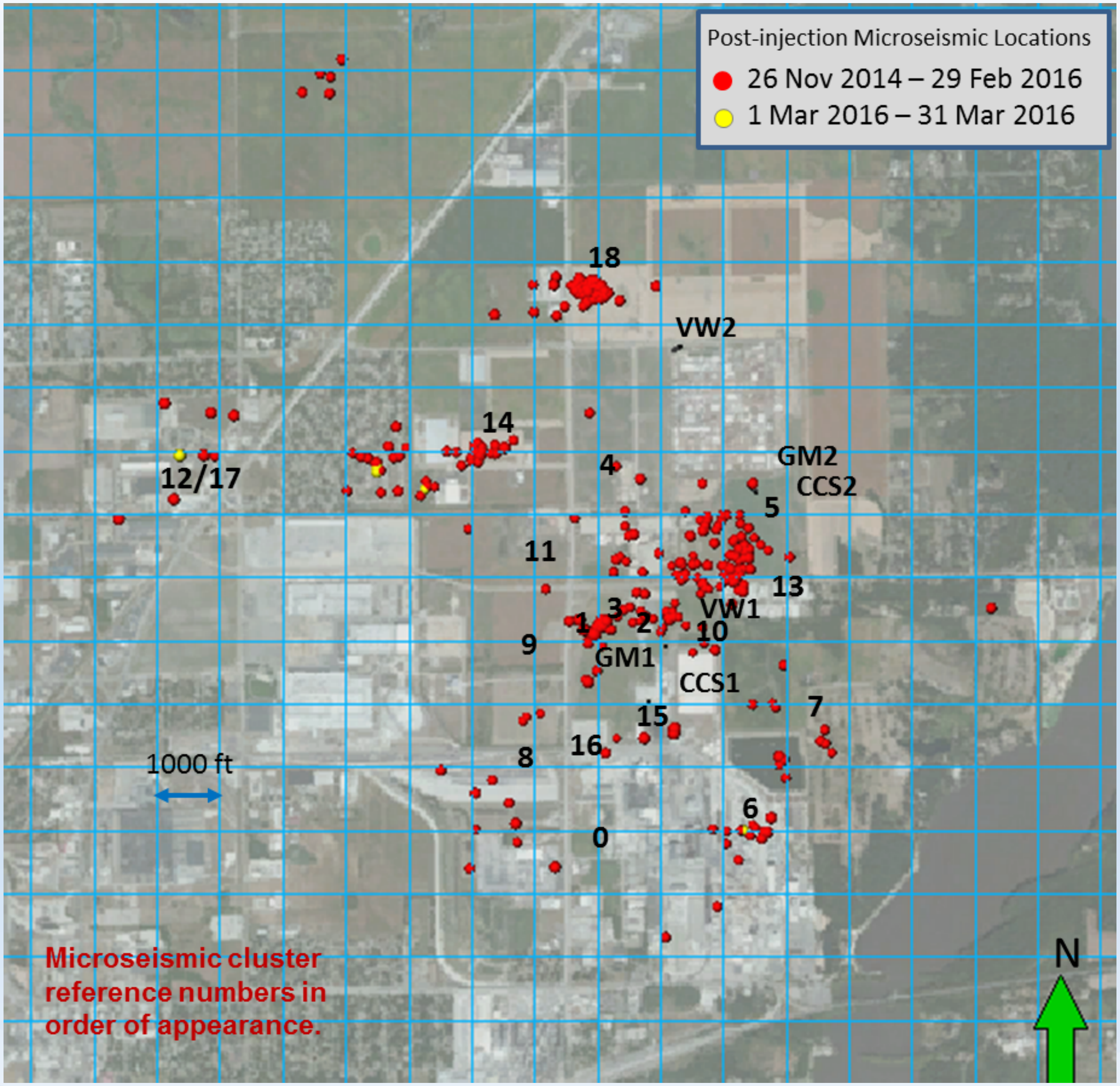
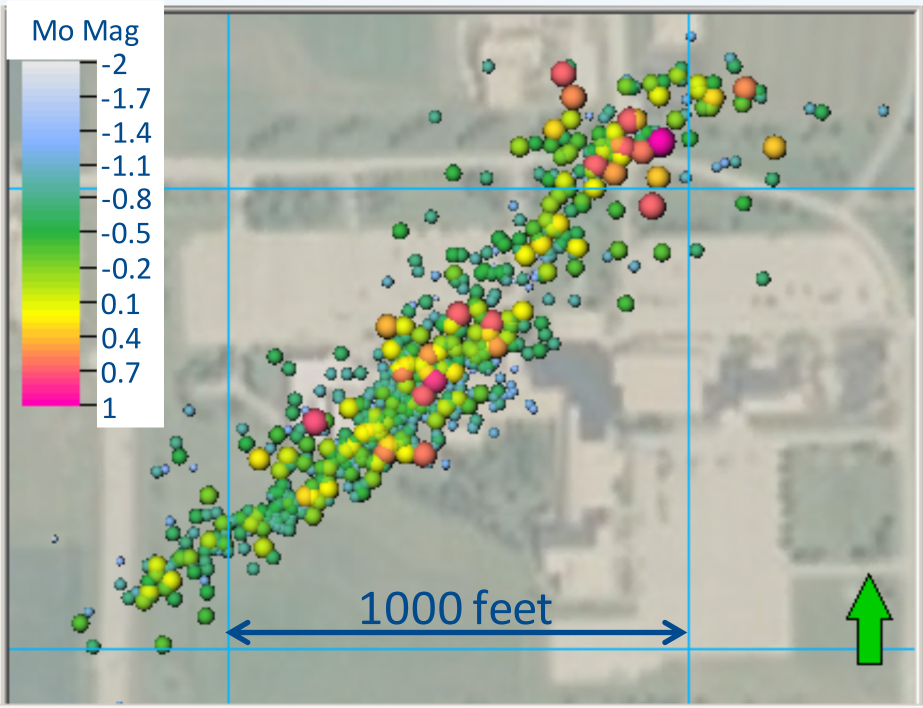
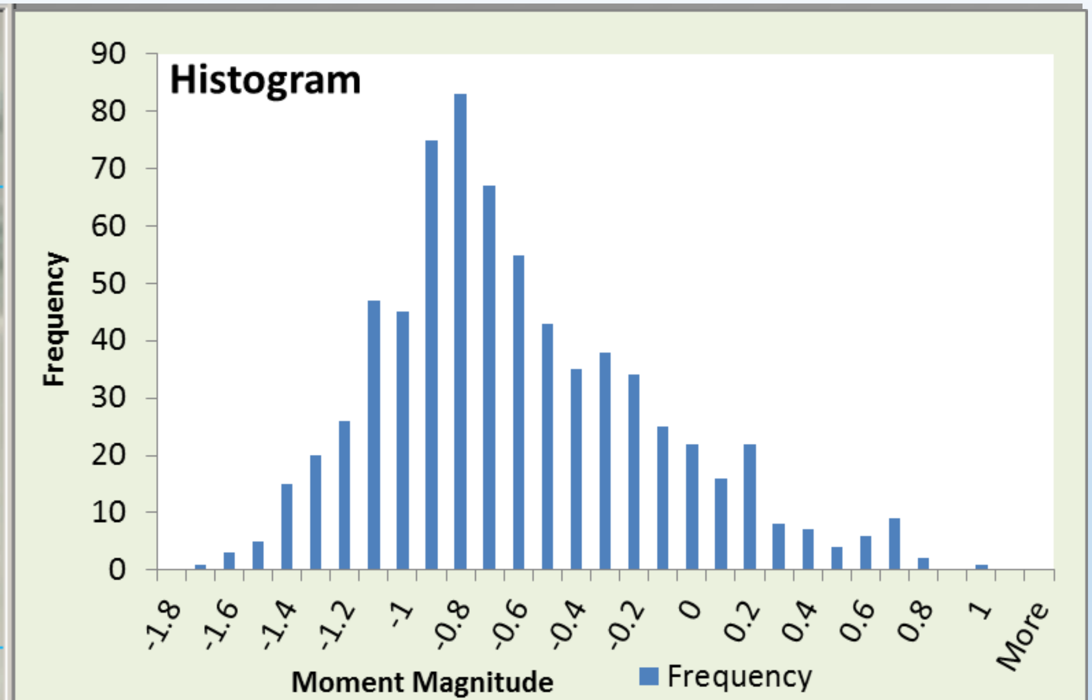
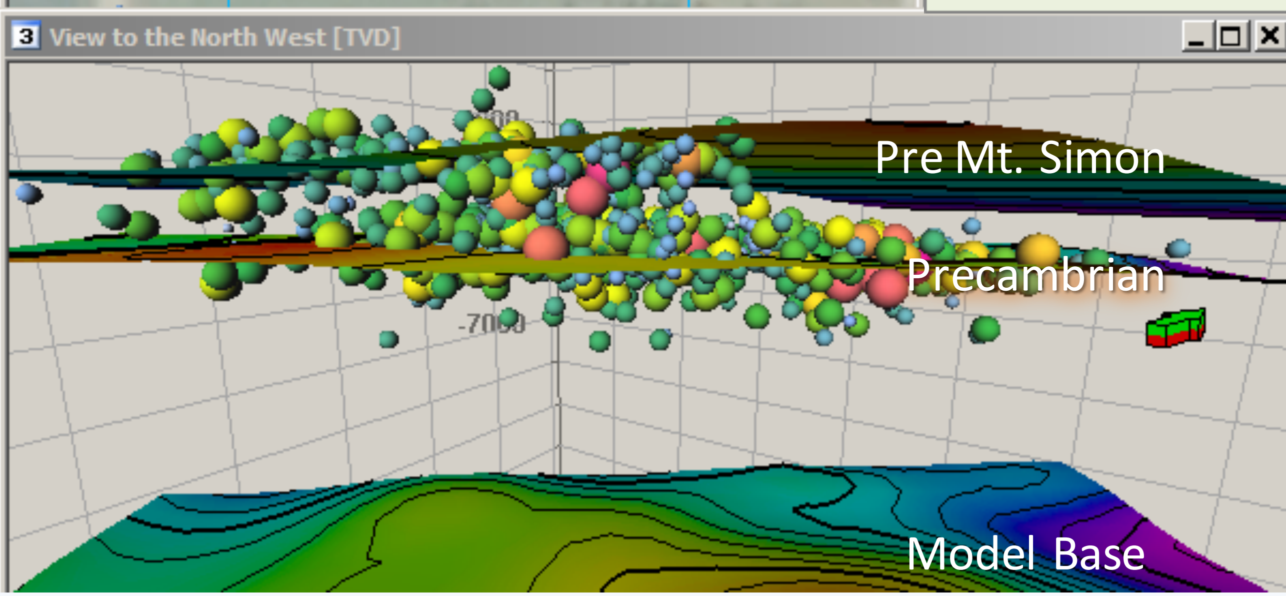


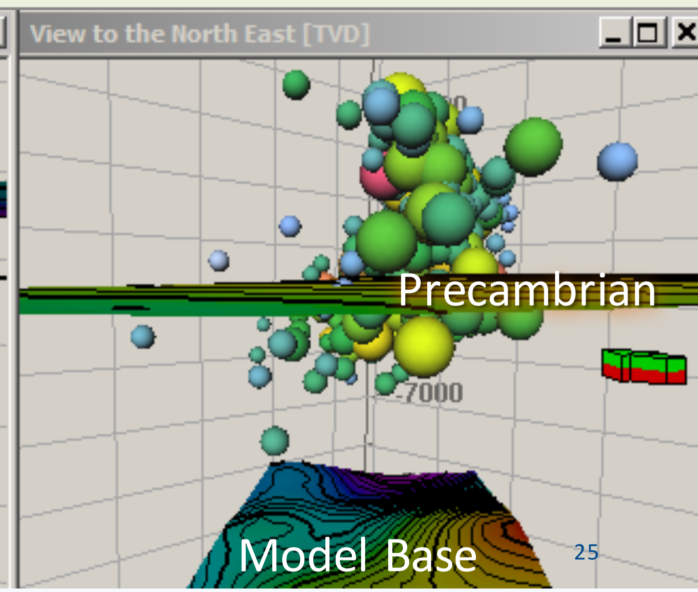
Image provided by Schlumberger Carbon Services

Microseismic Cluster 4 Activity: March 18, 2012 – January 2, 2013





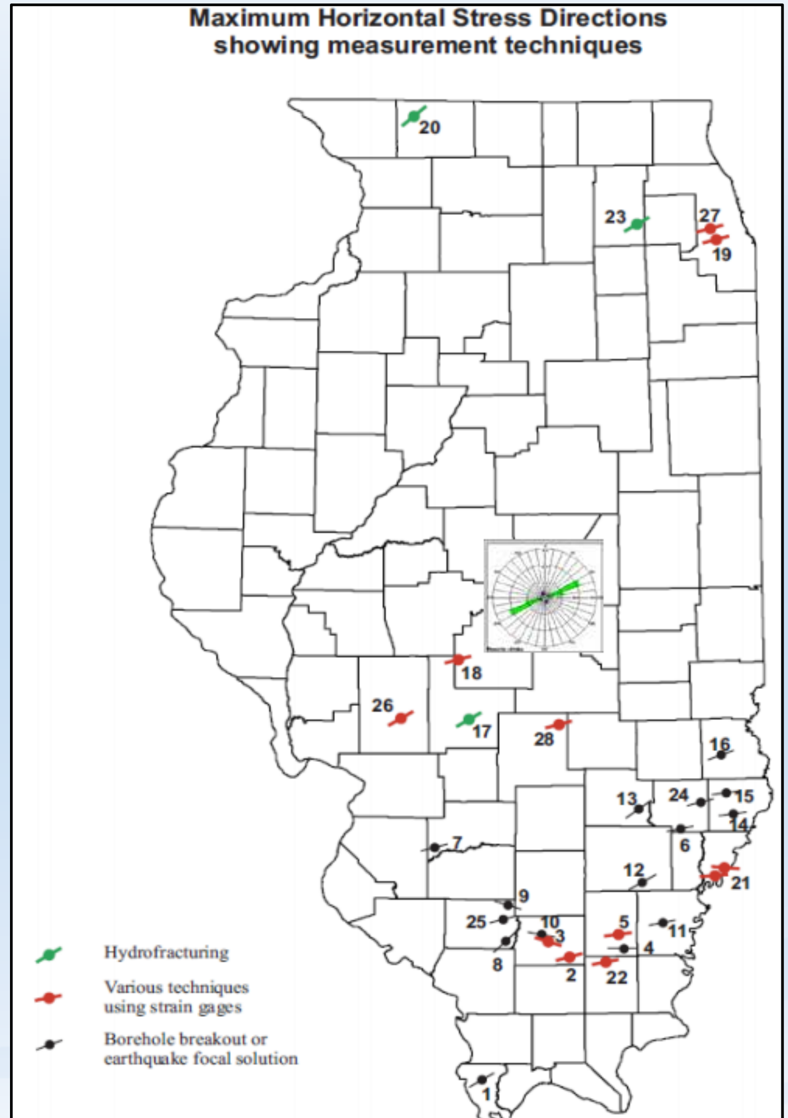




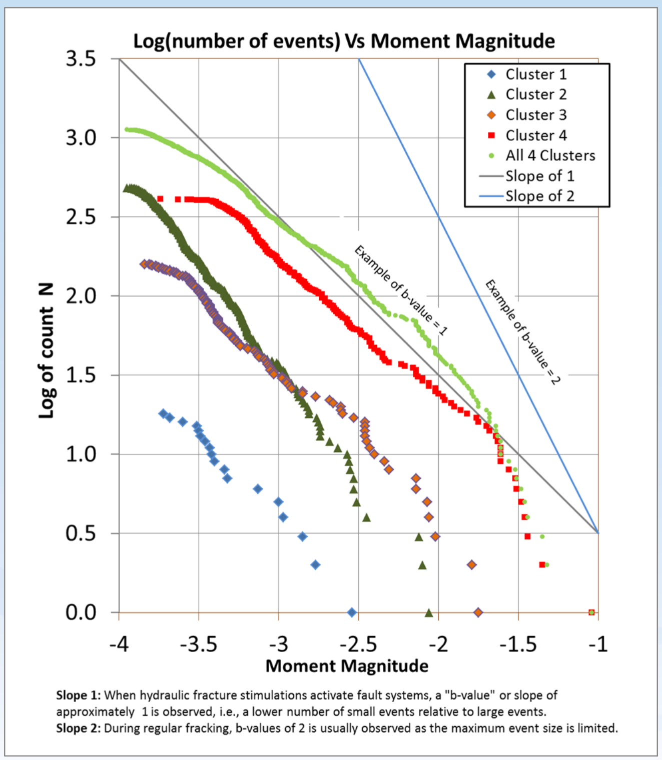
Strike-Slip Event Mechanism "Working Model"

- Gutenberg-Richter analysis on microseismic events suggests tectonic mechanism.
- Cluster orientation consistent with regional and site-specific stress measurements for strike-slip motion.

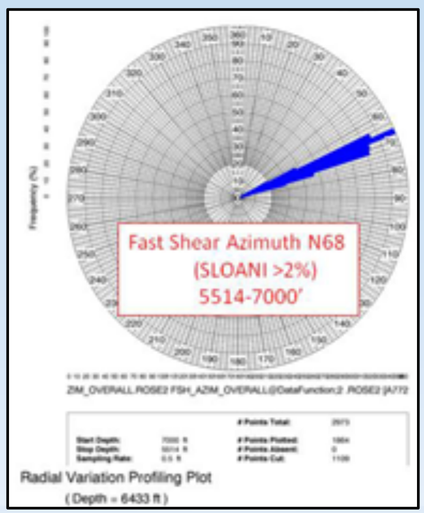
Regional Measurements



Gutenberg-Richter



Sonic Anisotropy



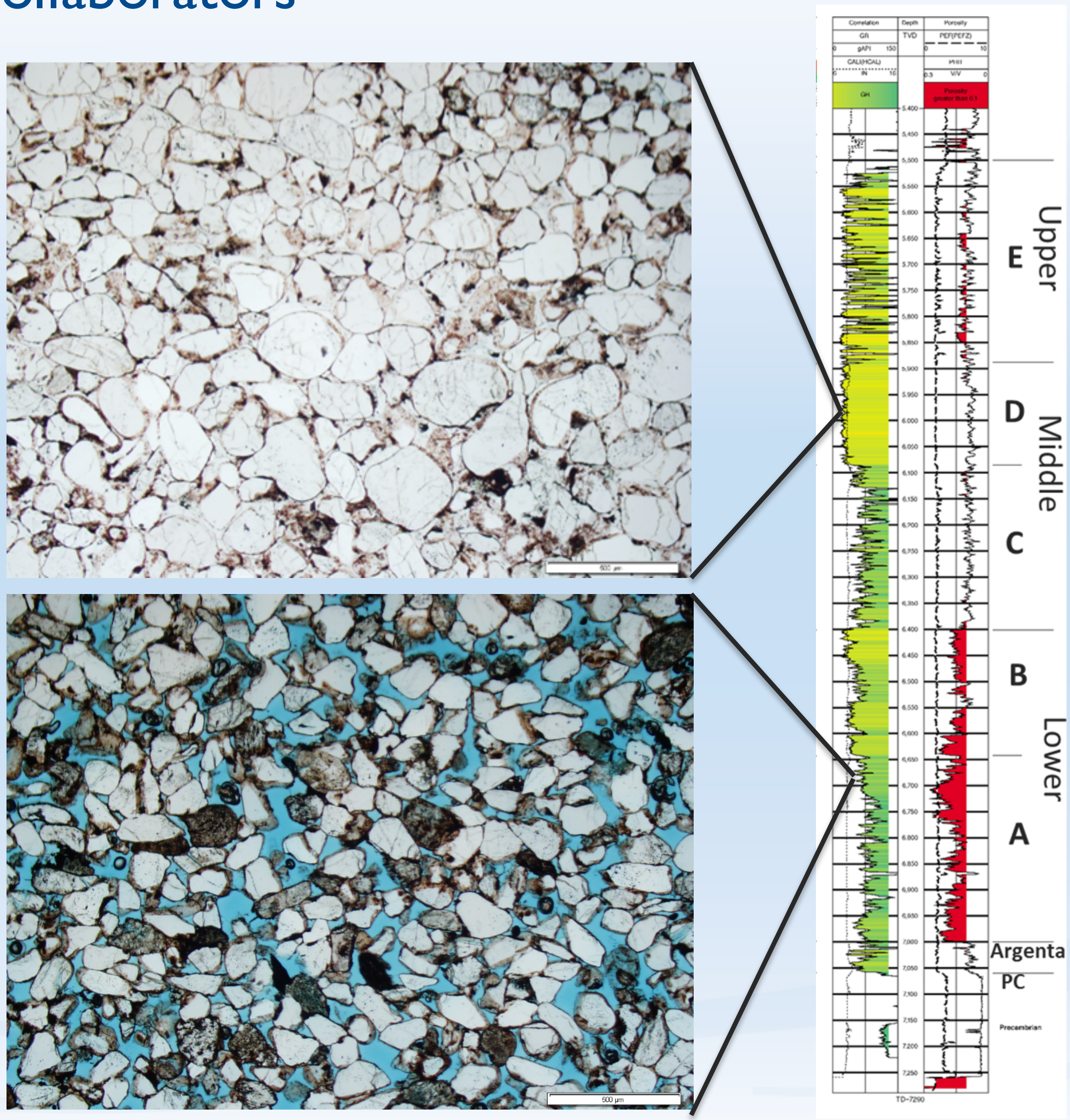
IBDP Capital and Operating Costs / Tonne Injected
for Compression, Dehydration, and Transmission Facilities

Cost Categories	Costs, (2009 – 2014) US $ / tonne
Capital Costs	20.34
Electrical Power	7.76
Operating Labor	1.32
Supervisor Labor	0.20
Maintenance	1.22
Other Operating Costs	0.61
Total	31.45

- Important statements regarding this table:
  - Capital costs are amortized over the three-year injection period, amortization period would be much longer on a typical commercial project
  - All costs in this table except for capital costs are derived using typical industry values as actual values are either confidential or not available
  - Host site provided Plant Overhead functions, which would be an additional estimated $ 2.01 / tonne at a green-field location
  - If scaling costs for future projects, suggest using mid-2010 for capital costs and late-2014 for operating costs

Refined view of Lower Mt. Simon Depositional and Diagenetic History - Freiburg and Collaborators

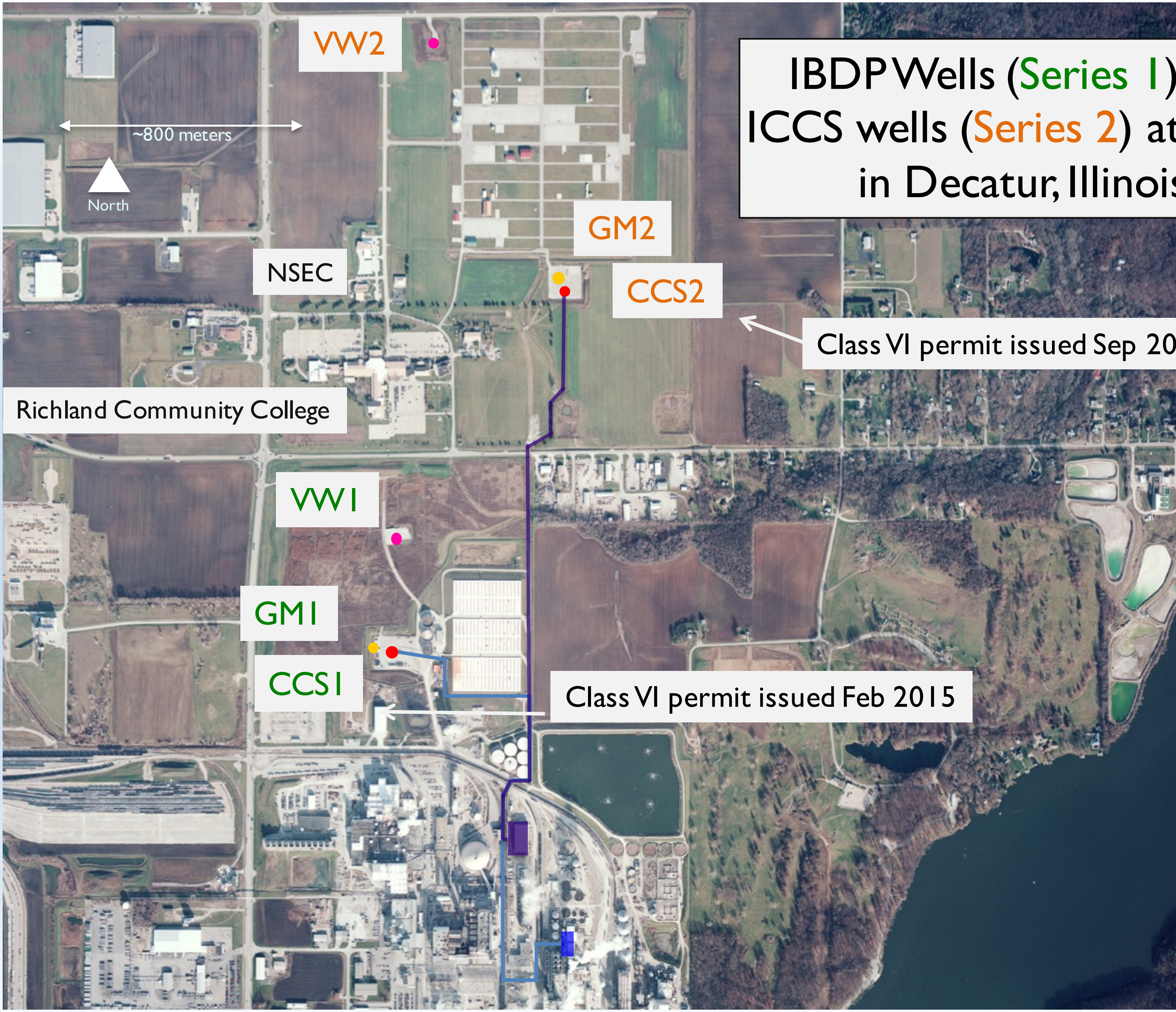
- Diagenetic controls on reservoir properties
- Depositional interpretation



CCS in Decatur, IL USA

Illinois Basin – Decatur Project	Illinois Industrial CCS Project
• Large-scale demonstration	• Industrial-scale
• Volume: 1 million tonnes	• Volume: 5 million tonnes
• Injection period: 3 years	• Injection period: 3 years
• Injection rate: 1,000 tonnes/d	• Injection rate: 3,000 tons/d
• Compression capacity: 1,100 tonnes/day	• Compression capacity: 2,200 tonnes/day
• Status: Post-injection monitoring	• Status: Pre-injection monitoring

IBDP Wells (Series 1) and ICCS wells (Series 2) at ADM in Decatur, Illinois

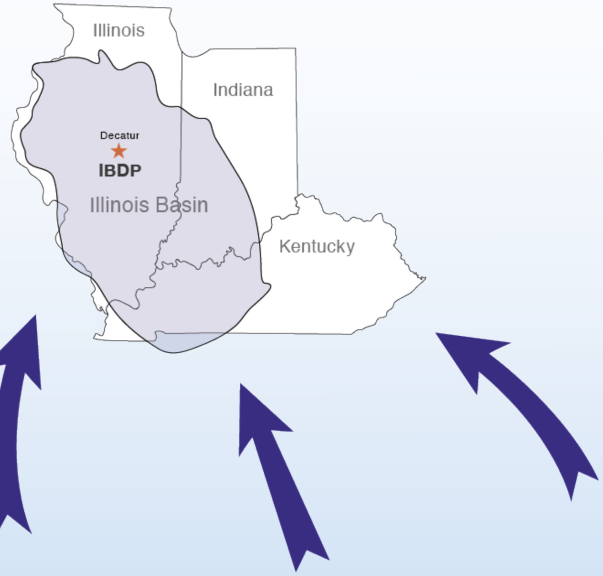


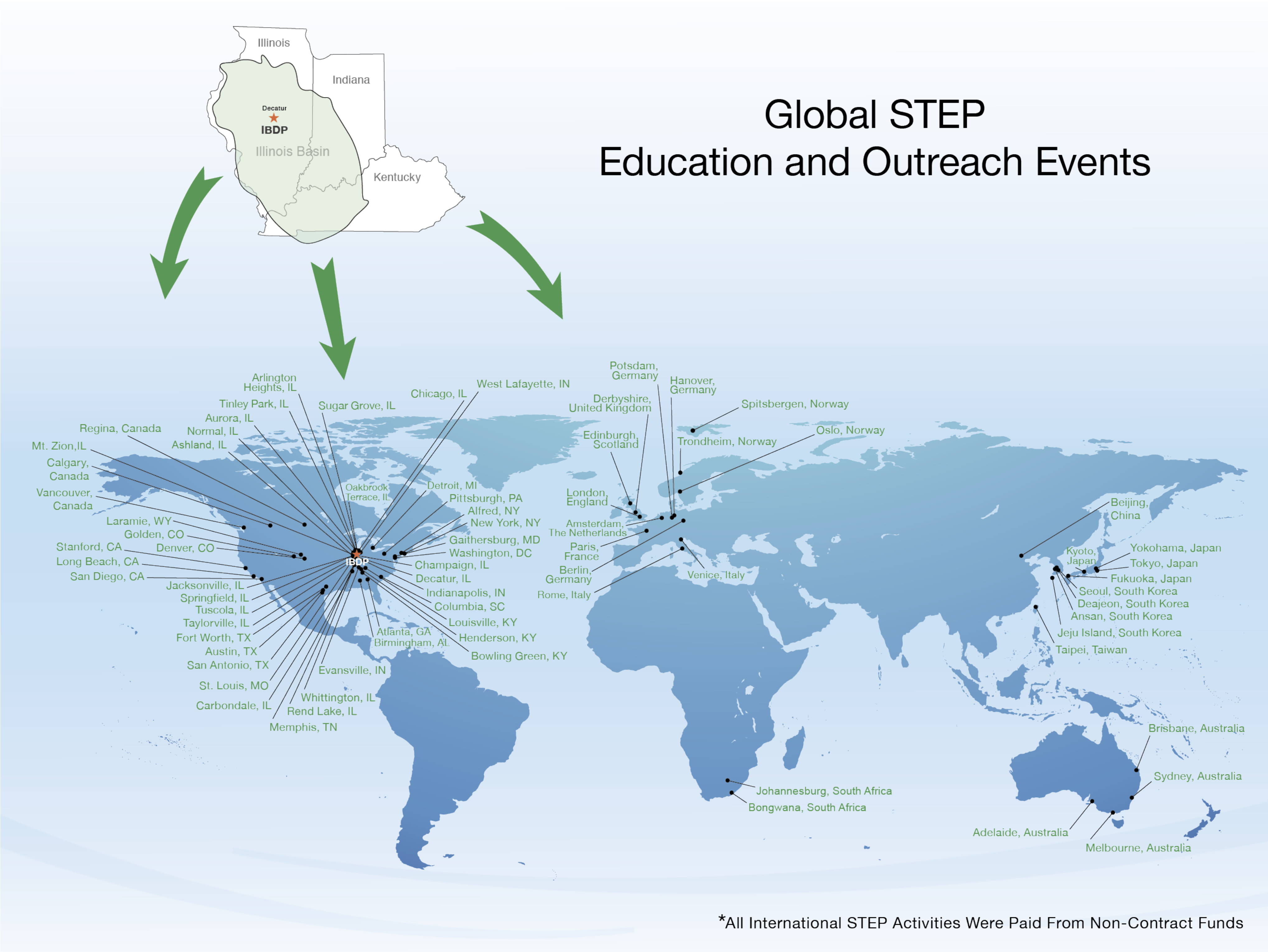
By the numbers:

- A million tonnes stored and…
- More than **17,000 feet** of wells have been drilled
- More than **800 feet** of core have been collected
- Near-surface groundwater monitoring efforts have resulted in more than **70,000 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

Global Participants Attending STEP-IBDP Events





Global STEP
Education and Outreach Events
Illinois
Indiana
Kentucky
Decatur
IBDP
Illinois Basin
Arlington Heights, IL
Tinley Park, IL
Aurora, IL
Normal, IL
Ashland, IL
Regina, Canada
Mt. Zion,IL
Calgary, Canada
Vancouver, Canada
Laramie, WY
Golden, CO
Denver, CO
Stanford, CA
Long Beach, CA
San Diego, CA
Jacksonville, IL
Springfield, IL
Tuscola, IL
Taylorville, IL
Fort Worth, TX
Austin, TX
San Antonio, TX
St. Louis, MO
Carbondale, IL
Memphis, TN
Rend Lake, IL
Whittington, IL
Evansville, IN
Sugar Grove, IL
Chicago, IL
West Lafayette, IN
Oakbrook Terrace, IL
Detroit, MI
Pittsburgh, PA
Alfred, NY
New York, NY
Gaithersburg, MD
Washington, DC
Champaign, IL
Decatur, IL
Indianapolis, IN
Columbia, SC
Louisville, KY
Henderson, KY
Bowling Green, KY
Atlanta, GA
Birmingham, AL
IBDP
Potsdam, Germany
Hanover, Germany
Derbyshire, United Kingdom
Spitsbergen, Norway
Edinburgh, Scotland
Trondheim, Norway
Oslo, Norway
London, England
Amsterdam, The Netherlands
Paris, France
Berlin, Germany
Rome, Italy
Venice, Italy
Johannesburg, South Africa
Bongwana, South Africa
Beijing, China
Kyoto, Japan
Yokohama, Japan
Tokyo, Japan
Fukuoka, Japan
Seoul, South Korea
Deajeon, South Korea
Ansan, South Korea
Jeju Island, South Korea
Taipei, Taiwan
Brisbane, Australia
Sydney, Australia
Adelaide, Australia
Melbourne, Australia
*All International STEP Activities Were Paid From Non-Contract Funds

Midwest Geological Sequestration Consortium

ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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