Wabash CarbonSAFE

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U.S. Department of Energy

National Energy Technology Laboratory

2021 Carbon Management and Oil and Gas Research Project Review Meeting

August 2021

Presentation Outline

Technical Status, Project Background

Accomplishments to Date

- Review
- Recent work
  - Characterization
  - Modeling
  - Other Assessments and Reporting

Summary: Key Findings, Challenges

Next Steps

Technical Status

Project Background

Phase II: Assess the feasibility of developing a commercial-scale geological storage complex at Wabash Valley Resources (WVR) gasification facility near Terre Haute IN, that could store up to 50 million tonnes of industrially-sourced CO_2. (2/1/2019 – 3/31/2022)

- Task 1.0 – Project Management and Planning
- Task 2.0 – Risk Assessment and Monitoring
- Task 3.0 – National Risk Assessment Partnership (NRAP) Screening
- Task 4.0 – Stakeholder Engagement and Public Outreach
- Task 5.0 – Business and Economic Development Assessment
- Task 6.0 – Permitting and Compliance
- Task 7.0 – Subsurface Characterization
- Task 8.0 – Drilling and Well Testing
- Task 9.0 – Storage Complex Modeling
- Task 10.0 – Infrastructure Development
- Task 11.0 – Storage Complex Development Planning

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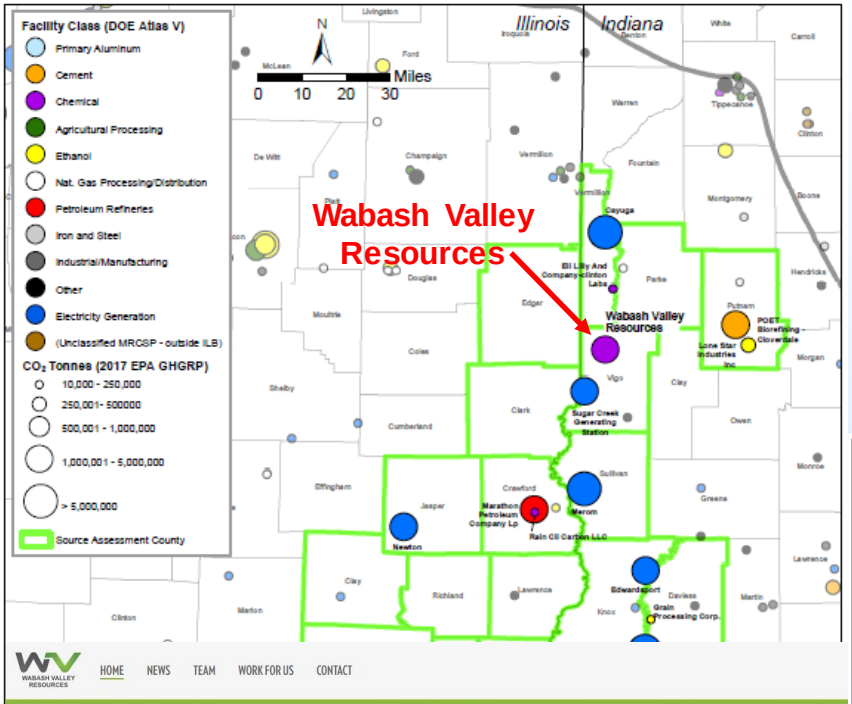
INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

TRIMERIC CORPORATION

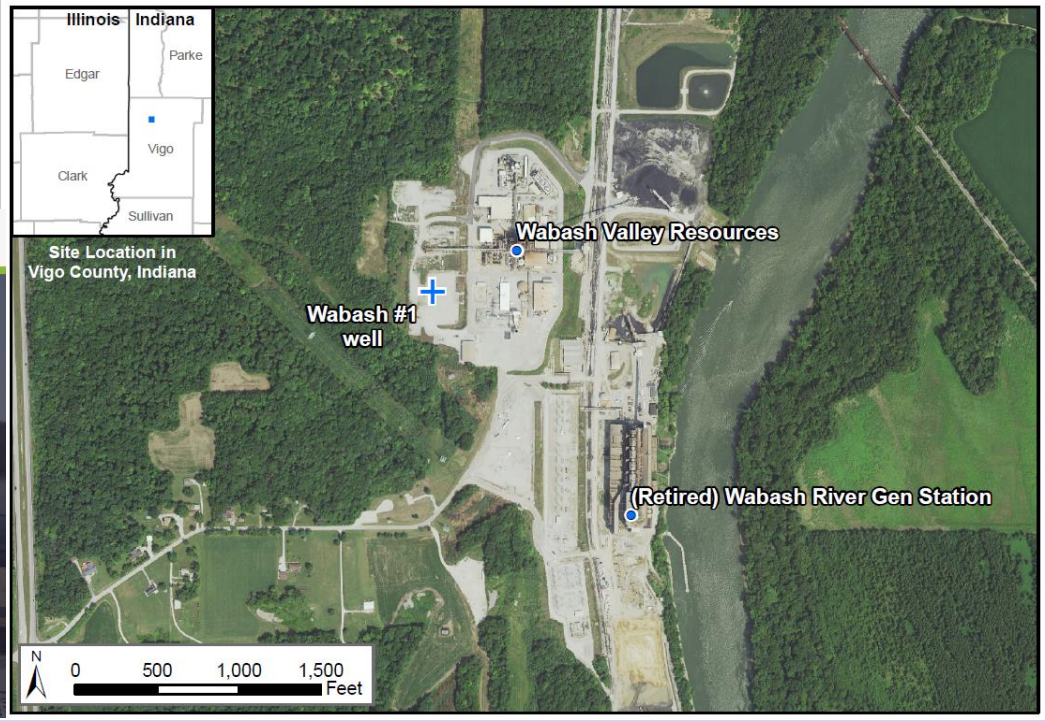
GEOSTOCK SANDIA
ENTREPOSE

U.S. DEPARTMENT OF ENERGY | NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Background



- Site at Former WRGS: IGCC Unit 1A (DOE 1995-1999); Commercial operations 1999-2016.
- Modification planned to produce net-zero carbon intensity hydrogen production for power generation, transportation fuels, chemical markets
- 1.65 million tons; 99% pure CO_2
- Target 2024 commercial operations



Project Background

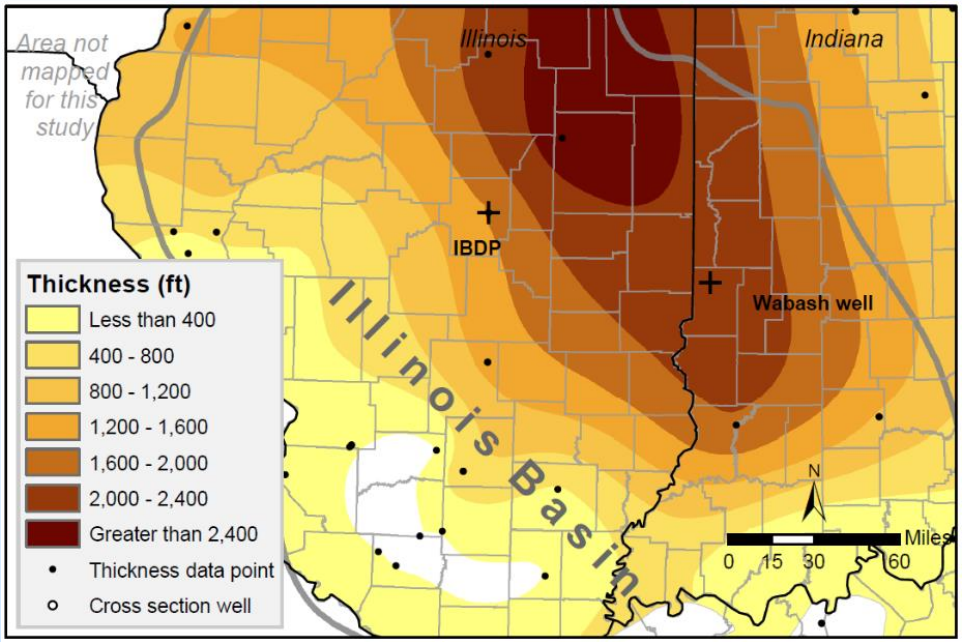
Mt. Simon Sandstone – target reservoir
Potosi Dolomite – secondary reservoir

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

St. Peter-Knox Storage Complex

Mt. Simon Storage Complex

Cambro-Ordovician Storage Complex



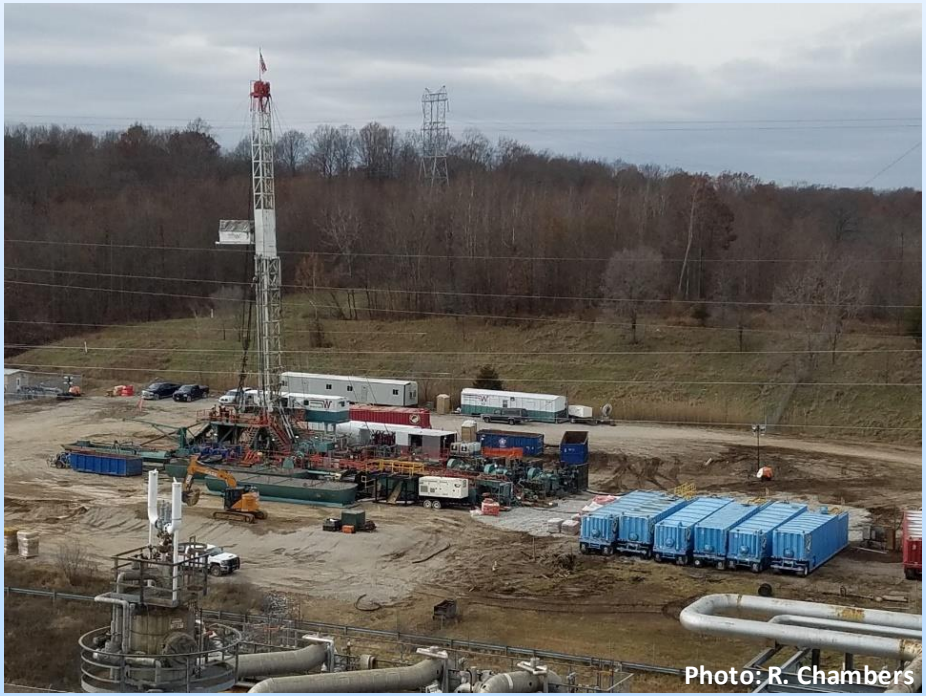
Few deep wells in ILB through Mt. Simon

- Data collection necessary, characterization
- Fill data gaps, expand storage resource

Accomplishments to Date

Review

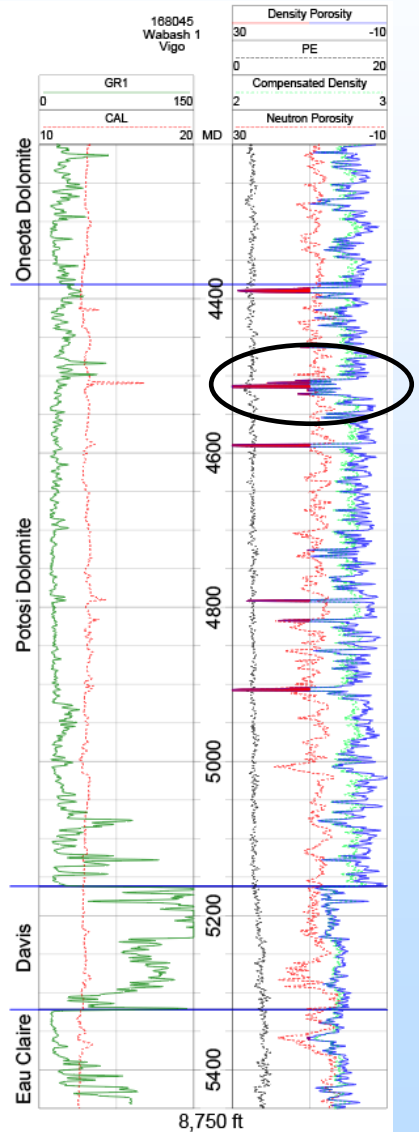
- 2 x 10 miles 2D seismic acquisition summer 2019
- Wabash #1 TD 8,739 ft 02/07/2020; Plugged 7/31/2020
- Difficult drilling; did not reach crystalline basement
- Cored 245 ft (target reservoir + 2 seals) + RSWC
- Full suite of geophysical logs; limited in Potosi Dol.
- Two DSTs + Mt.Simon modeling prior to cased-hole well testing…



Wabash #1 (IGWS-ID# 168045) Formation Tops	**MD (ft)**
Log reference: Kelly bushing (552 ft elev.)	0
Ground Level (537 ft surface elev.)	15
Pennsylvanian Bedrock, approximate	30
Sea Level (below KB)	552
Mississippian-Pennsylvanian Unconformity	748
St Louis Limestone	748
Salem	906
Harrodsburgh	957
Muldraugh	1,032
Borden	1,126
Chouteau/Rockford Limestone	1,638
New Albany Shale	1,642
Devonian Carbonates	1,742
Silurian	1,965
Maquoketa Group	2,386
Trenton Limestone	2,700
Platteville/Black River Group	2,863
Dutchtown	3,242
St. Peter Sandstone	3,326
Shakopee Dolomite	3,354
Oneota Dolomite	3,970
Potosi Dolomite	4,378
Davis	5,162
Eau Claire	5,322
Mount Simon Sandstone	6,277
Unidentified basalt	8,515
Unidentified sediments (Precambrian?)	8,535
T.D.	8,739

Accomplishments to Date

Review



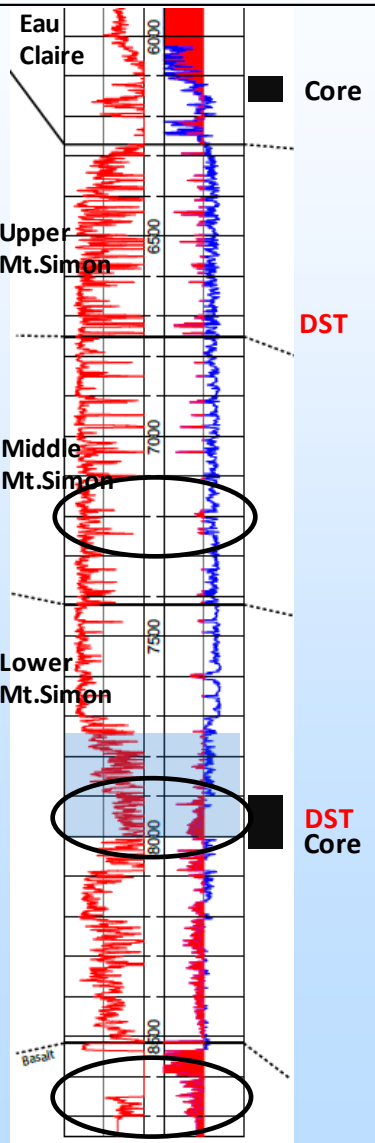
Pressure Fall-Off and Step Rate Testing:

- Potosi Dolomite (Knox Gp.)
  - Vuggy porosity in several zones
  - Test interval 4,505-4,525 ft MD
  - 24,000 md-ft over 10ft; <u>2,400 md*</u>

- Mt. Simon:
  - 7,192-7,202 ft
  - 53 md-ft over 10ft; <u>5.3 md</u>

← 7,976-7,996 ft
84 md-ft over 20 ft; <u>4.2 md</u>

- Sandstone below basalt:
  - 8,661-8,671; 8,681-8,691*
  - 66 md-ft over 20 ft; <u>3.3 md</u>



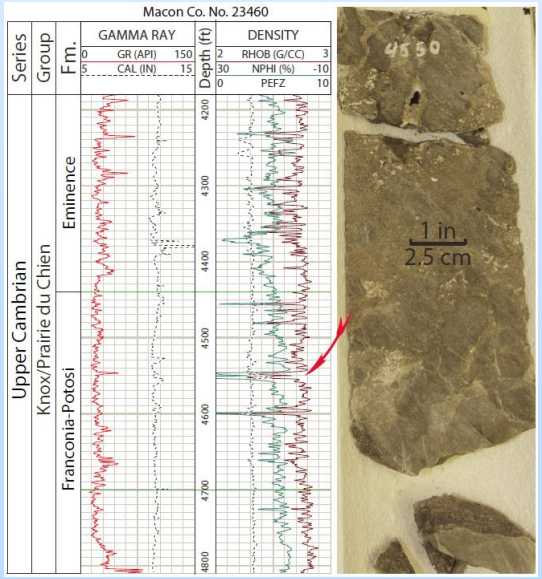
Potosi Dolomite (Knox Group)

Previous/Regional Knowledge

- Thick bedded, fine to coarsely crystalline dolomite unit
- Chert and partially/completely mineralized cavities common
- Vugular, brecciated, fractured and/or cavernous intervals

Vuggy porosity with the cavities lined with drusy quartz in the Potosi Dolomite; ADM Verification Well #1, Macon Co. IL.

- Regionally extensive, several zones with high porosity & permeability
- Trace in logs: Knox-St.Peter Project, IBDP, CarbonSAFE
- Lost circulation zone throughout Basin: IBDP (and Wabash)
- No Potosi core in Wabash #1, limited logs (e.g. no FMI)

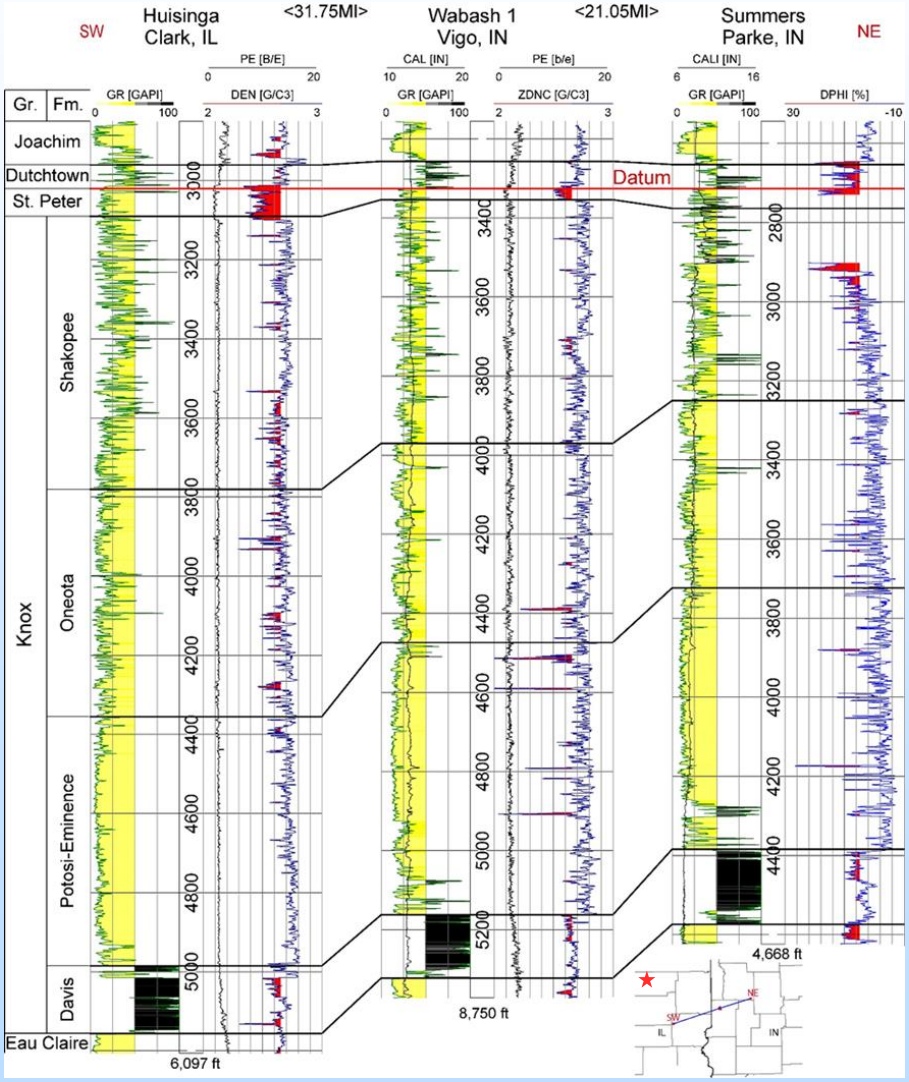


Potosi Dolomite

Previous/Regional Knowledge

Tuscola, IL chemical waste disposal wells (~50mi WNW):

- From an injectivity/ falloff test, the estimates of Potosi permeabilities were greater than 9,000 md
- Since 1970, injected 18 billion Gal of liquid into the Potosi through Cabot-Tuscola #2 well
- Equivalent to injecting more than 50 million metric tons of CO_2
- Still injecting equivalent to 60,000 tonnes per month of CO_2



Southwest-northeast correlation of the units in the Knox Group from east-central Illinois to west-central Indiana (Datum top of the St. Peter Sandstone). Note: The available Cabot #2 well log is incomplete for the Potosi Dolomite, but the approximate well location in Tuscola, IL is shown in the index map as a red star.

Potosi Dolomite

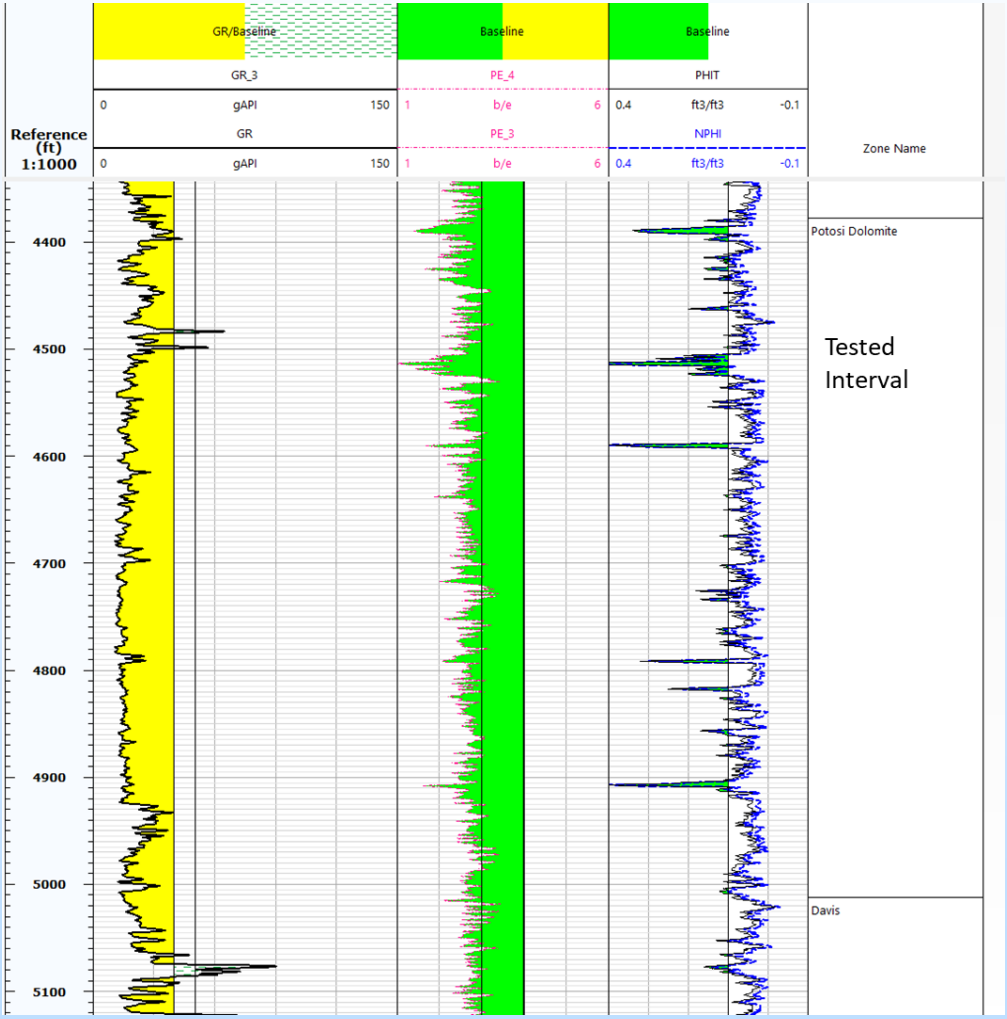
Wabash #1: Petrophysical Analysis

Potosi Dolomite in the Wabash #1 well:

- Six porous & permeable intervals in the Potosi
- Range from less than 5 ft to ~20 ft in thickness
- Neutron-density porosity in the 20-ft test interval is estimated to be over 30%

Potential Potosi reservoir zone:

- 784 ft thick at 4,378 ft MD
- Total of 149.5 ft is greater than 10% porosity.



Geophysical log of the Potosi Dolomite in, Wabash #1 Well, Vigo County, Indiana. The green highlighted areas on the right-most porosity column are zones with greater than 10% porosity.

Maquoketa Group

Wabash #1: Core Studies

Maquoketa Group in the Wabash #1 well (regional seal):

- Dominantly interbedded shale + argillaceous layers in upper zone
- Increasing limestone and argillaceous limestone in middle to lower
- 314 ft thick at 2,386 ft MD in Wabash #1
- Core 2,435-2495 ft: fairly consistent, thinly-laminated calcareous shale lithology

Sealing capacity/integrity to CO_2:

MICP data:

- Formation pressure: 1,080 psi; assume a CA range between 20° and 40°
- Data indicate the Maquoketa can hold a $scCO_2$ column height of 2,020 ft

Geological characterization and geomechanical testing:

- FMI log + core show little to no natural fractures within the Maquoketa Group interval
- Triaxial test results, Maquoketa:
  - has high Young's modulus (suggesting very stiff rock and not easily deformable)
  - has high cohesive and uniaxial compressive strength
    (suggesting it will require very high injection pressures [above the fracture gradient of the reservoir] to induce a failure in the formation)

Photo: R. Bauer

The test results indicate the Maquoketa is an effective caprock to $scCO_2$ migration and exhibits geomechanical characteristics of a good seal.

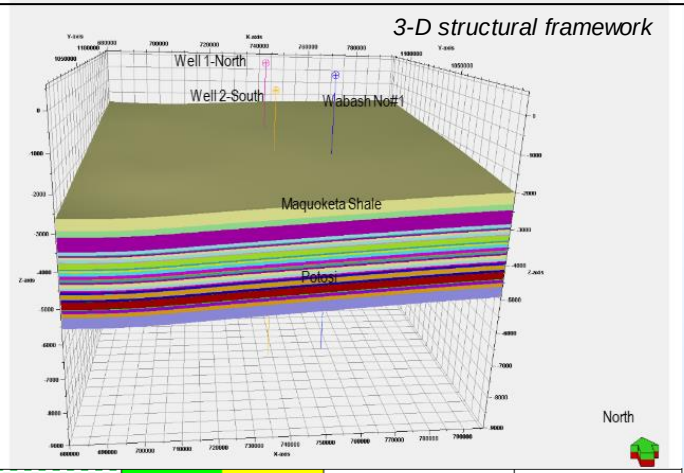
	Petrophysical properties	Static elastic properties			
Seal	ρ (g/cc)	υ	UCS (MPa)	C_0 (Mpa)	φ (°)
Maquoketa	2.61-2.71	0.23-0.3	180	51.8	30

Static Model Development

Potosi Static model: 22 x 22 mi, 241 layers

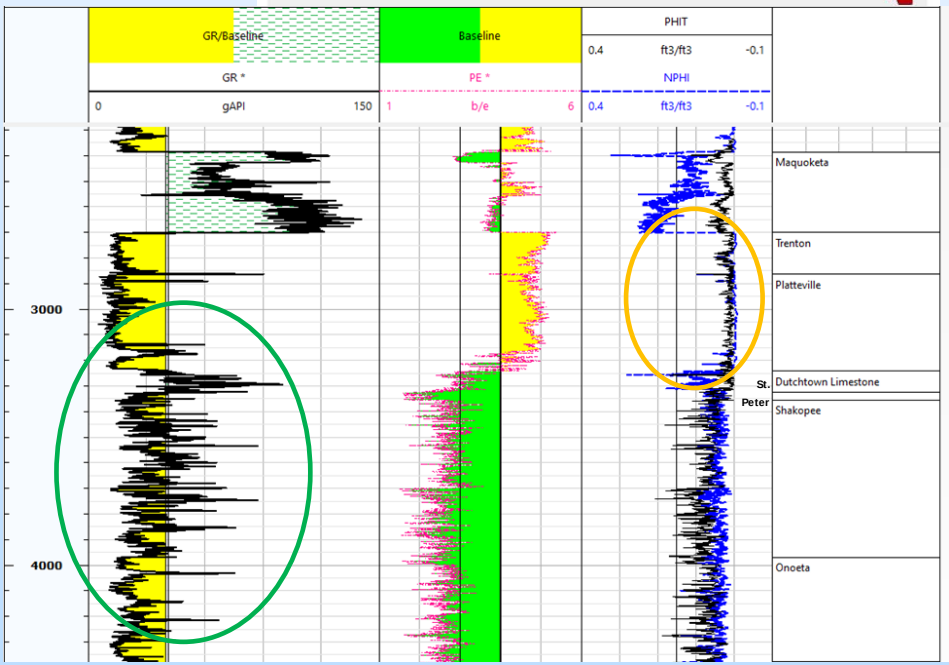
7 confining units above Potosi and below Maquoketa:

- Dense carbonates with interbedded shales
- 1,678 ft cumulative thickness between Potosi and Maquoketa



Confining Zone	Formation Thickness (feet)	Depth (feet)	Avg. Porosity (%)	Avg. Permeability (mD)	Shale Thickness (feet)
Maquoketa Group	314	2,386	3.0	0.0001-0.00001	312
Trenton Limestone	163	2,700	1.3	0.00000273	3.5
Platteville Group	379	2,863	1.2	0.00000475	16
Dutchtown Limestone	84	3,242	2.8	0.0000840	70.5
St. Peter Sandstone	28	3,326	4.0	0.0039	3.5
Shakopee Dolomite (upper)	346	3,354	2.8	0.022360406	101
Shakopee Dolomite (lower)	270	3,700	9.1	0.098032	71
Oneota Dolomite	408	3,970	7.1	2.585488	15

Data from: Well test data, geophysical well logs, and calculations (Lucia 1995; 2007) that link rock fabrics to petrophysical properties.



Partial geophysical log, Wabash #1 Well, Vigo County, Indiana.

Dynamic Modeling

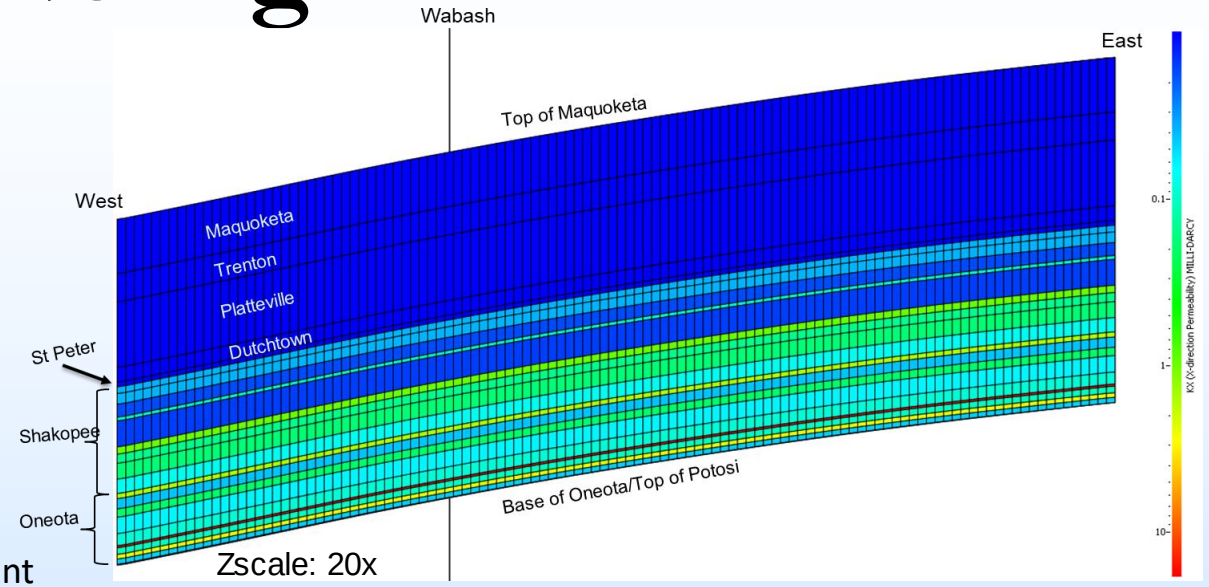
Nexus Simulation model:

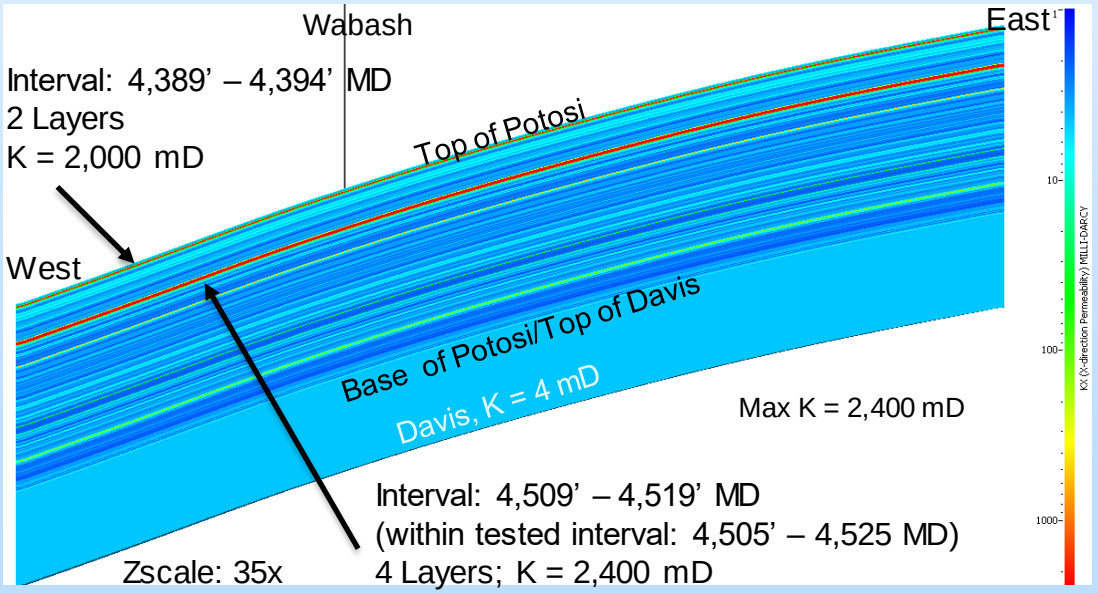
- 22 x 22 miles; based on geologic model
- Constant property within layers
  (vertical heterogeneity)
- Potosi contains vuggy intervals with high perm.

Model Size, Grid Cells:

- 1000’ x 1000’ / 333’ x 333’ local refinement
- 241 layers
  - 217 within the Potosi (~3 ft thick)
  - 23 in confining units; 1 below
- Total blocks: 7.6 million; infinite acting aquifer boundary

Parameter	Value
Initial Pressure	1,954 psia at 4,500' MD
Resevoir Temperature	108F at 4,500' MD
Salinity	34,250 ppm
Frac Gradient	0.71 psi/ft





Dynamic Modeling

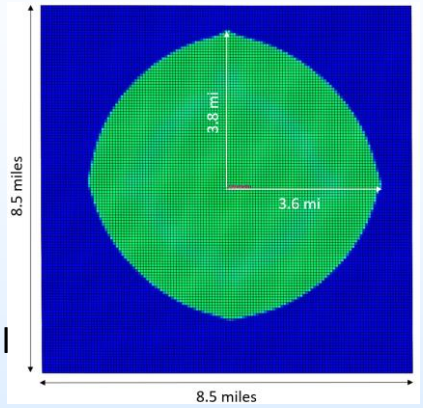
Wabash #1 Example

30-year injection period
- Entire Potosi perforated
- CO_2 injection rate of 1.67 Mta
- 50 mil. tonnes CO_2 injected
- Injection constraint
  - Pmax = 0.9 * 0.71 psi/ft
  - Applied at top of perf interval

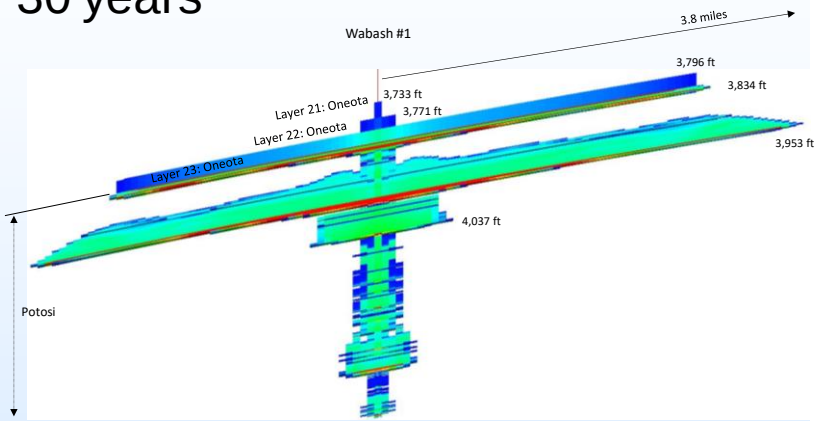
50-year post-injection period
Max plume radius: 3.8 miles

Plume does not move in the lateral direction, after injection stops
- Plume moves vertically and saturation changes with time
- Vertical migration into Oneota Dolomite
- > 1,270 ft below base of Maquoketa seal

30 years

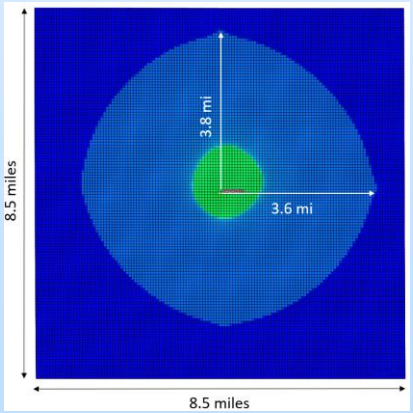


Layer 67 (Potosi, top of tested interval)



S-N cross-section through well
Cells with Sg ≥ 1%
Zscale = 20x

80 years



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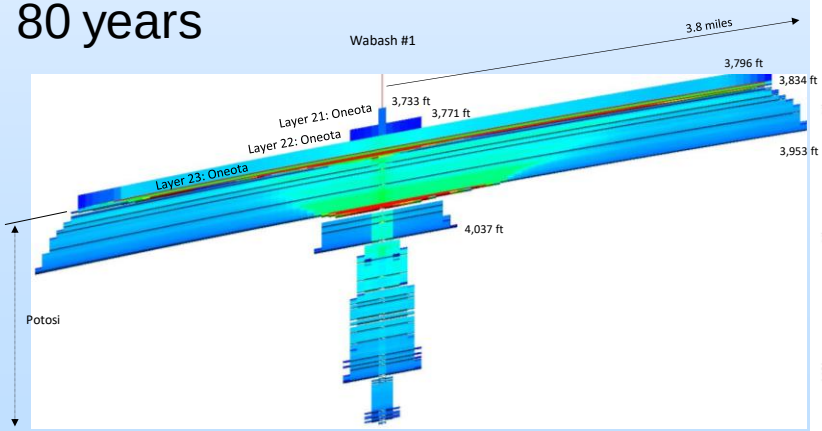

S-N cross-section through well
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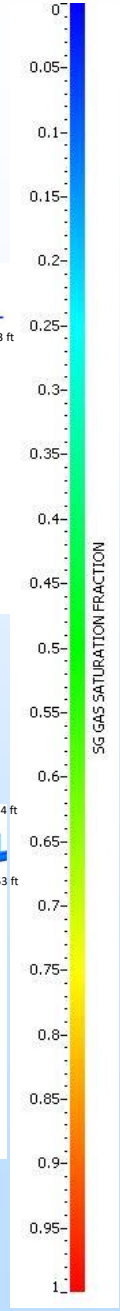


Plume Radius vs. Time

Dynamic Modeling

Well pressures

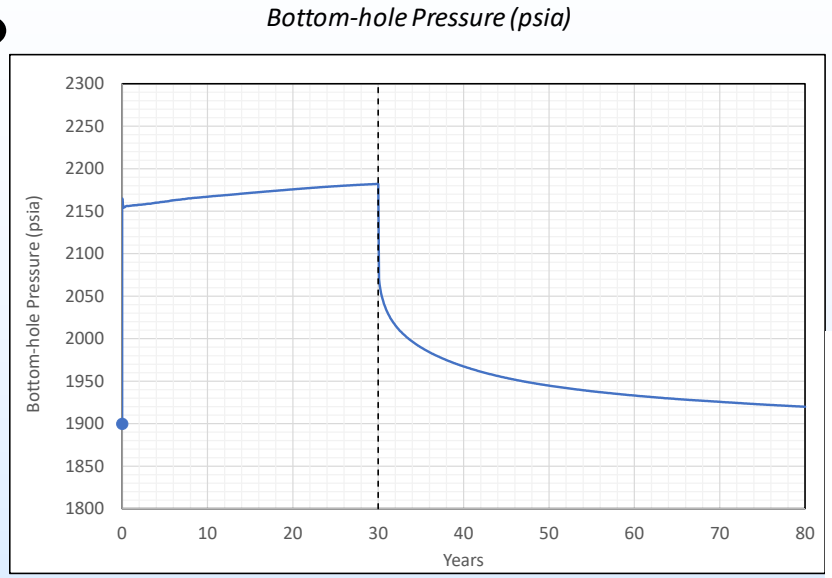
- 30-year injection period (1.67 Mta)
- 50-year post-injection period

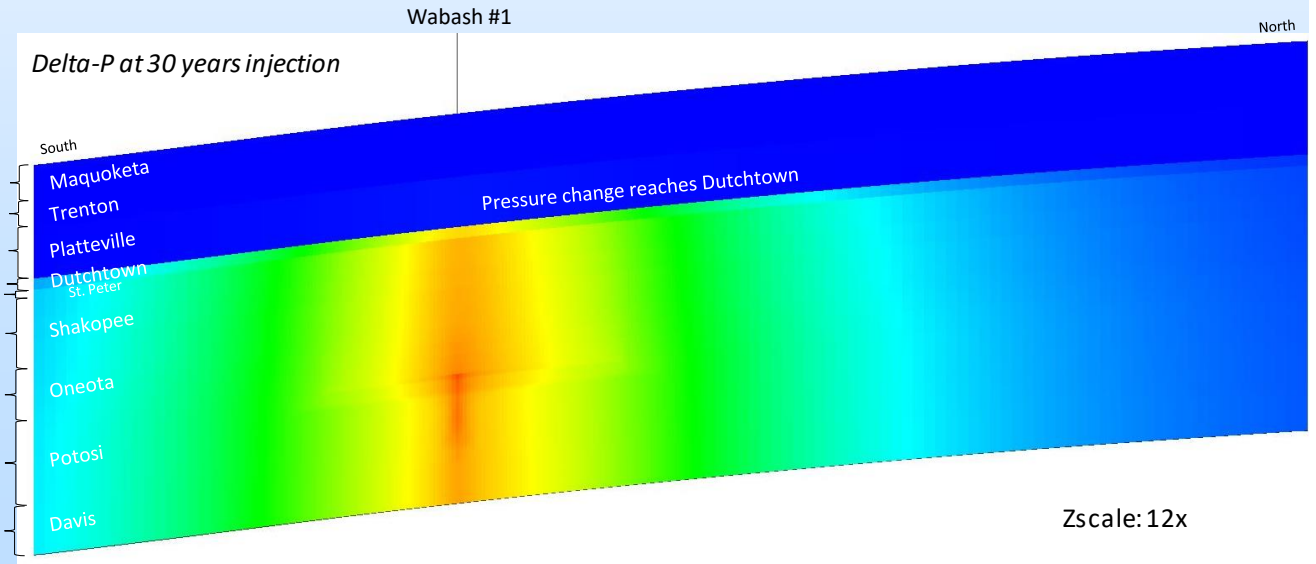
- Maximum BHP constraint:
  2,804 psia at 3,829 ft, ss

- BHP increases by 282 psi at 30 years
- Well BHP (2,182 psia) is significantly below maximum BHP constraint

Injection never reaches pressures high enough to fracture reservoir

Pressure change reaches Dutchtown Limestone





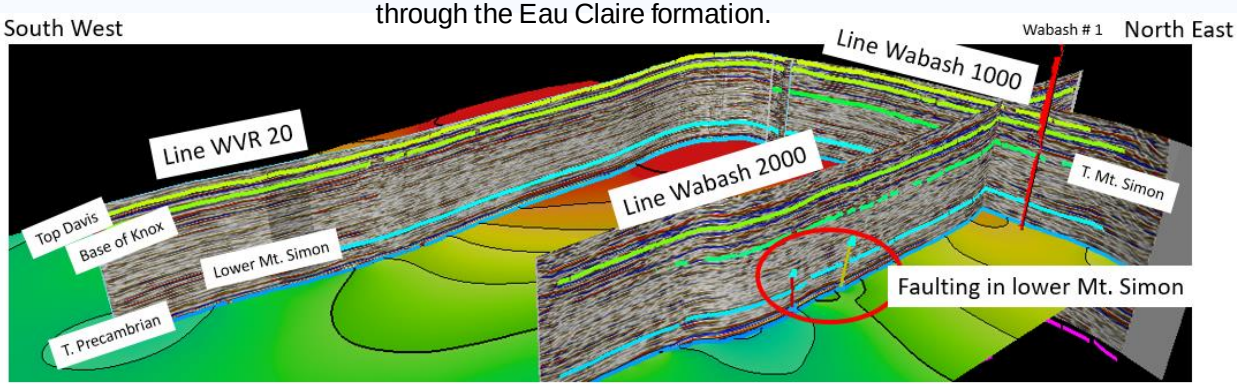
Change in pressure (P - Pinitial) at 30 years along a South to North cross-section through the center of the model, for the 30-year injection case.

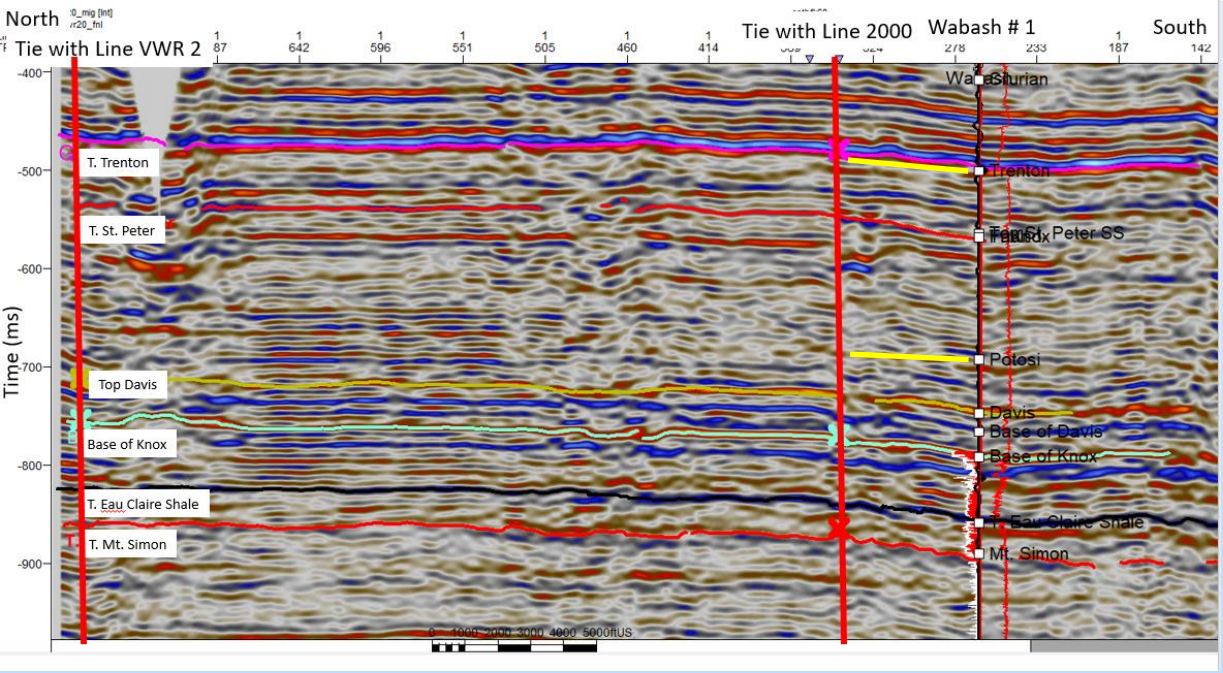
Geological Characterization

Seismic Interpretation

- Some faulting in the Precambrian and lower Mt. Simon Sandstone
- Faults do not appear to be present in upper Mt. Simon and Eau Claire Fm.

Three-dimensional view of the Precambrian through the Eau Claire formation.





- No faulting observed through Potosi-Maquoketa interval

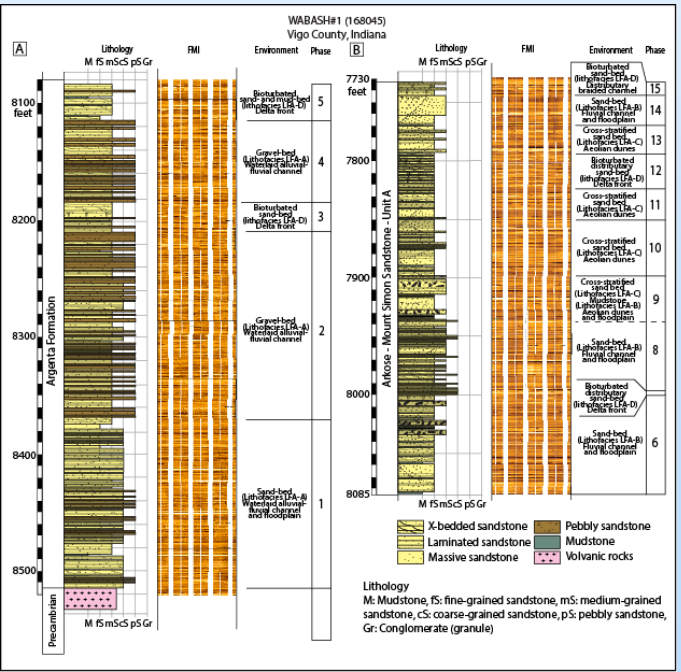
Line 1000 (N-S) showing correlation of the Wabash #1 with the seismic reflection data.

Geological Characterization

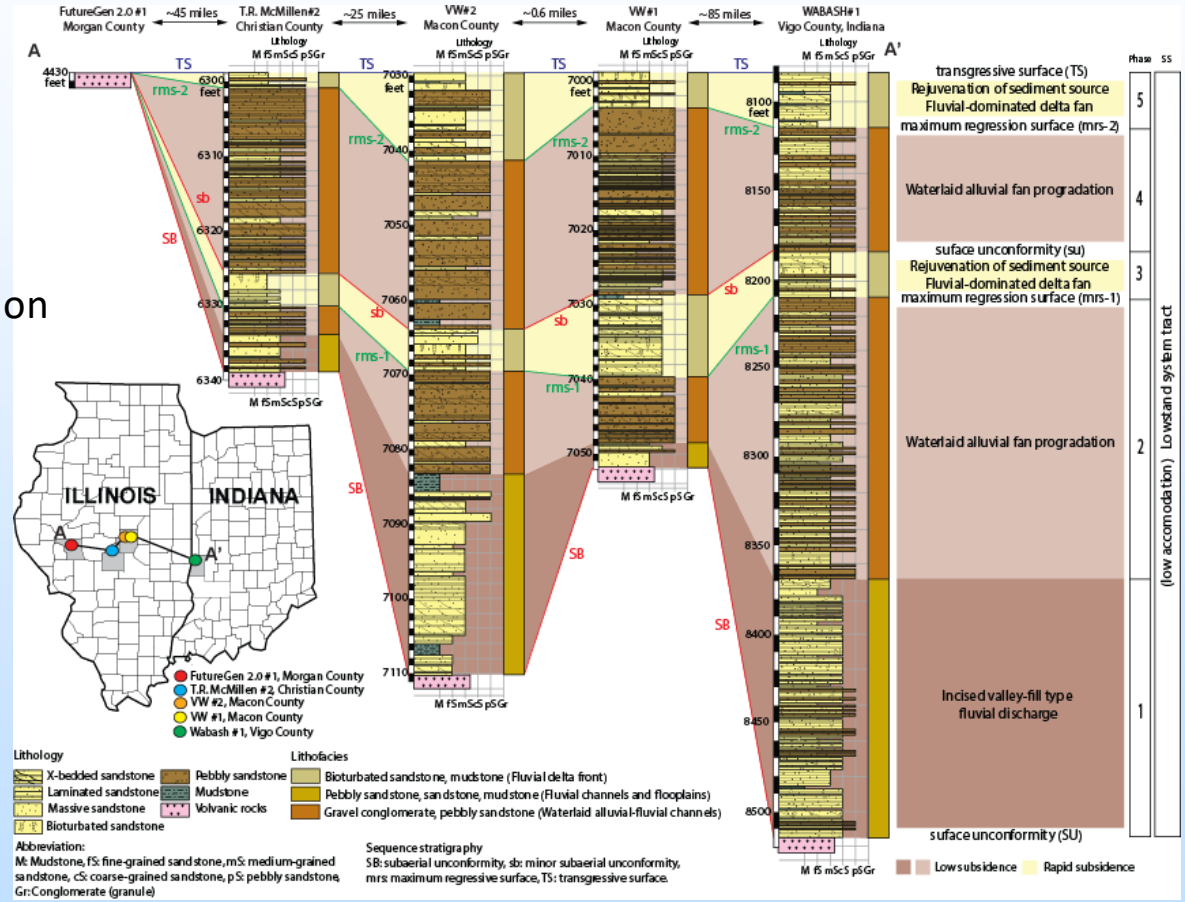
Sedimentology of Argenta / Mt. Simon Sandstone

Wabash #1 Mt. Simon core, CT scans, thin sections, high-resolution FMI log

- Detailed descriptions
- Lithostratigraphic columns
- Depositional sequences & correlation



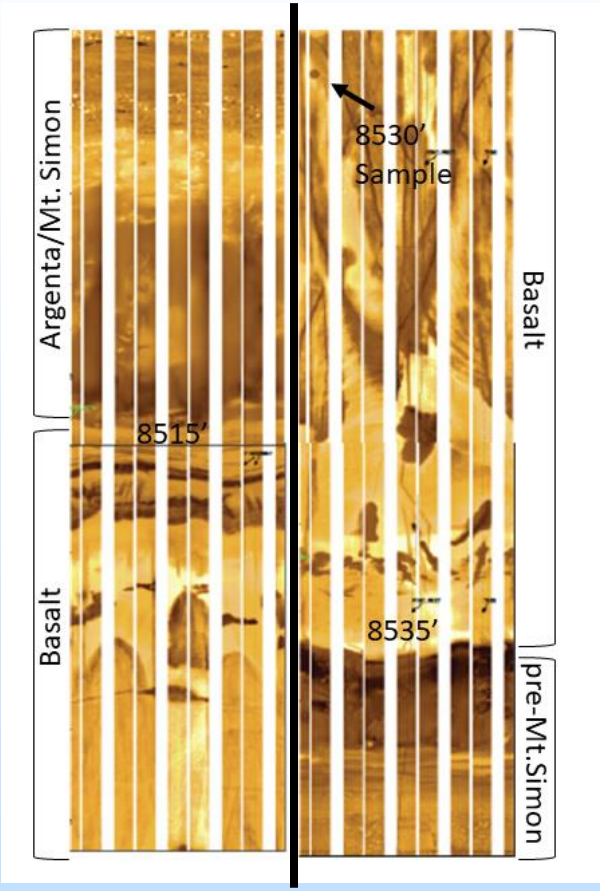
Lithostratigraphic column, FMI log and interpretations.



Tectono-stratigraphic correlation between Wabash #1, IBDP VW #1 and 2, TR. McMillen #1 and FutureGen #1 boreholes.

Geological Characterization

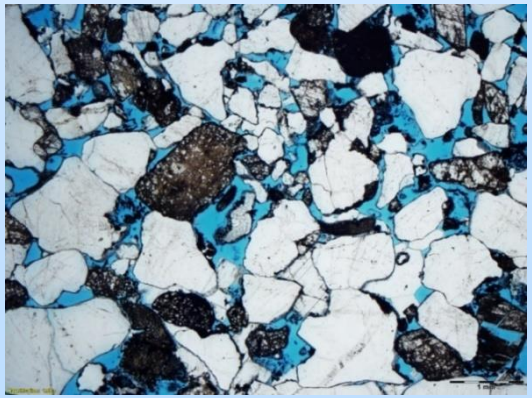
Sedimentology of Argenta / Mt. Simon Sandstone



Fullbore formation micro-imager log photos showing the top contact of the basalt with the Mt. Simon or Argenta sandstone at 8,515 ft and the basal contact with sediments at 8,535 ft.

- The basalt penetrated in the Wabash #1 well (8,515-8,535 ft) is interpreted as a flood overlying lacustrine deposits
- Early Cambrian in age
- Sediments below basalt: DZ proximal source, more like lower Mt. Simon
- 8,690 ft: best reservoir properties from sandstone samples
- Potential reservoir rocks below well TD 8,739 ft (?)

Rotary sidewall core plug from 8690 ft MD



Thin Section. 8690 ft MD

Current Status

Project Milestones

Task	ID	Milestone	Planned Completion	Completion	Verification Method
1.0/1.1	A	Project Kickoff Meeting	04/01/19	03/21/19	Attend Meeting, Presentation File
1.0/1.2	B	Revised Project Management Plan	03/29/19	03/27/19	File provided to DOE
1.0/1.4	C	Finalized Communication Plan	06/02/19	03/27/19	File provided to DOE
2.0/2.1	D	Risk Assessment Summary	2/28/22		Summary in quarterly reports
3.0/3.1	**E**	**NRAP Assessment Report**	**9/30/21**		File provided to DOE
5.0/5.1	**F**	**Business Environment Study**	**9/30/21**		File provided to DOE
6.0/6.2	G	Obtain Stratigraphic Well Drilling Permit	10/31/19	11/12/19	Summary in quarterly reports
7.0/7.1	H	Pre-Drilling Site Assessment	07/31/19	11/27/19	File provided to DOE
7.0/7.3	I	Regional 2D Seismic Survey	10/31/19	08/21/19	Summary in quarterly reports
7.0/7.4	J	Deliver Integrated Data for Modeling	12/31/21		Data provided
8.0/8.2	K	Stratigraphic Test Well Completed	5/31/20	02/07/20	Summary in quarterly reports
9.0/9.4	L	Report on Modeling	1/31/22		Summary in quarterly reports
10.0/10.1	M	CO2 Source Assessment	11/30/21		File provided to DOE
11.0/11.1	N	Detailed Characterization Plan	03/31/22		File provided to DOE

Near/Completed work

NRAP Toolkit Assessment:

Modeling:

- STOMP reservoir simulation for Potosi Dolomite

Well Risk: NRAP-Open-IAM ROM:

- Consider hypothetical uncemented wells or damaged cemented wells
- Overall risk profile for well leakage is low. For cemented well (annulus):
  - no significant brine leakage; negligible CO_2 leakage to aquifers and atmosphere (0.035 Mt).
  - impact plumes for pH and dissolved CO_2 the radii do not exceed 0.3 mi from the leak source.

Subsurface Stress: SOSAT ROM:

- Tested new version–including better constraint of horizontal stress magnitude.
- Estimates a low risk of shear failure resulting from CO_2 injection.

Business Environment Study: Wabash Valley Resources

- Utilizing 45Q allows for a realized economic value in *pre-tax dollars*
- State of Indiana support
  IN Law 291 for pore space and pipeline access and acquisition
- Project funded by a combination of private equity investments and government loan guarantees
- Project appears to have commercial viability

In Progress

In Progress work/reports:

- Well Drilling/Testing Report
- Geologic Data Catalog
- Geology: Potosi Dolomite, Mt. Simon SS
- Modeling Report
- UIC Permitting Plan
- Risk Analysis

- Source/Transport

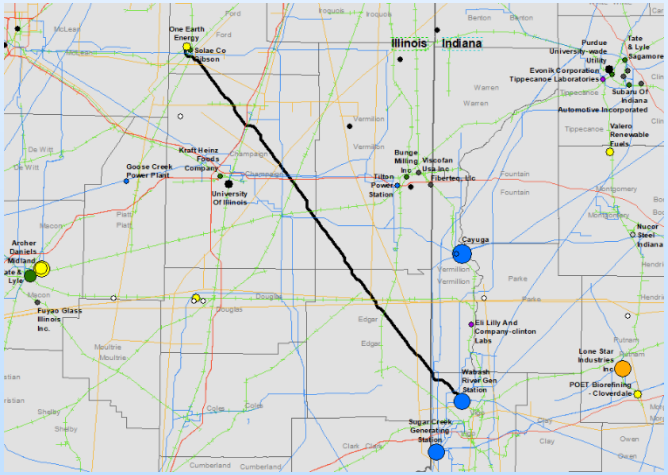
  Assess equipment/infrastructure needs, costs.

  SimCCS: Simulate conceptual pipeline network:

  – WVR (Potosi) – One Earth Energy (Mt. Simon)

  – Add additional sources

  Synergy with CarbonSAFE - IL Storage Corridor



Conceptual 83-mile pipeline between endmember sources in Vigo County, IN and Ford County, IL (from ArcGIS)

Project Summary

Key Findings

- Wabash #1 providing greater insight into regional distribution of the Mt. Simon Sandstone
- Potosi Dolomite appears to have excellent storage reservoir potential
- Containment:
    - Maquoketa Group regional seal
    - Multiple confining units between reservoir and seal
    - No faulting or significant fracturing observed through Potosi-Maquoketa interval
- Modeling shows Potosi can accept required CO_2 amount; no adverse pressure buildup
- Potosi-Maquoketa storage complex has economic potential

Challenges Remaining

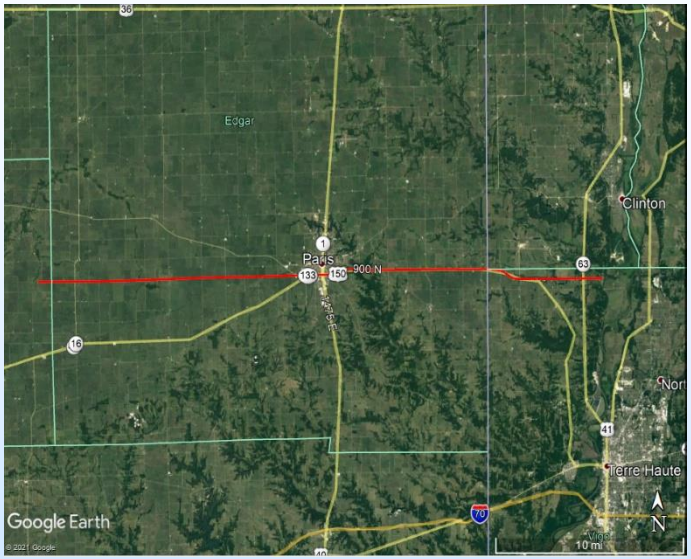
- How to model Potosi, continuity of porous and permeable zones, monitoring
- Cambrian sandstone at Wabash #1 TD: potential reservoir below these; further research

Project Summary

Next Steps

Wabash CarbonSAFE (through 3/31/2022):

- 30 mile 2D seismic (acquisition synergy with ISC)
    - Further assess Potosi-Maquoketa storage complex
    - Deep-seated geological structures
- Finalize analyses and complete reporting in progress
- Complete site characterization plan and final reporting



Final Data and Reports: EDX and MRCI Regional Initiative

End of CarbonSAFE: Phase II

WVR continuing as DOE Coal FIRST project *(FE0031994)*:

Flexible fuel gasification-based carbon-negative power and carbon-free hydrogen co-production

- Completing Project FEED designs for carbon capture process and sequestration infrastructure
- Complete FEED designs for hydrogen power generation facilities and consider hydrogen offtake markets
- Integrate biomass feed stock and complete lifecycle analysis to potentially achieve a negative carbon intensity of the hydrogen product

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Thank You!

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Thank You!

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

Benefits Statement, Wabash CarbonSAFE (02/01/2019)

This project will determine the feasibility of developing a commercial-scale CCS project capable of storing over 50 million tonnes of anthropogenic CO_2 in the U.S. Midwest. Wabash CarbonSAFE will demonstrate the transfer of technology to apply CCS to ammonia production thereby broadening the portfolio of industries that may benefit from integrating CCS into their operations. The project will address the development gap in upscaling CCS to commercial-scale as there are still are relatively few large carbon storage projects globally using deep saline reservoirs. Our work will address improving storage capacity estimates to attain an industry standard of ±30% or better for investment decisions. The data from this study will be used within the NRAP Toolkits to move toward validating technologies to ensure storage permanence and to improve reservoir storage efficiency. The project will determine the potential for transporting and utilizing CO_2 for EOR in oil fields of the Illinois Basin. The knowledge gained will contribute to greater development of regional CCS assets, best practice manuals about CCS technology, and issues that will be of broad use to other sites and future commercialization efforts.

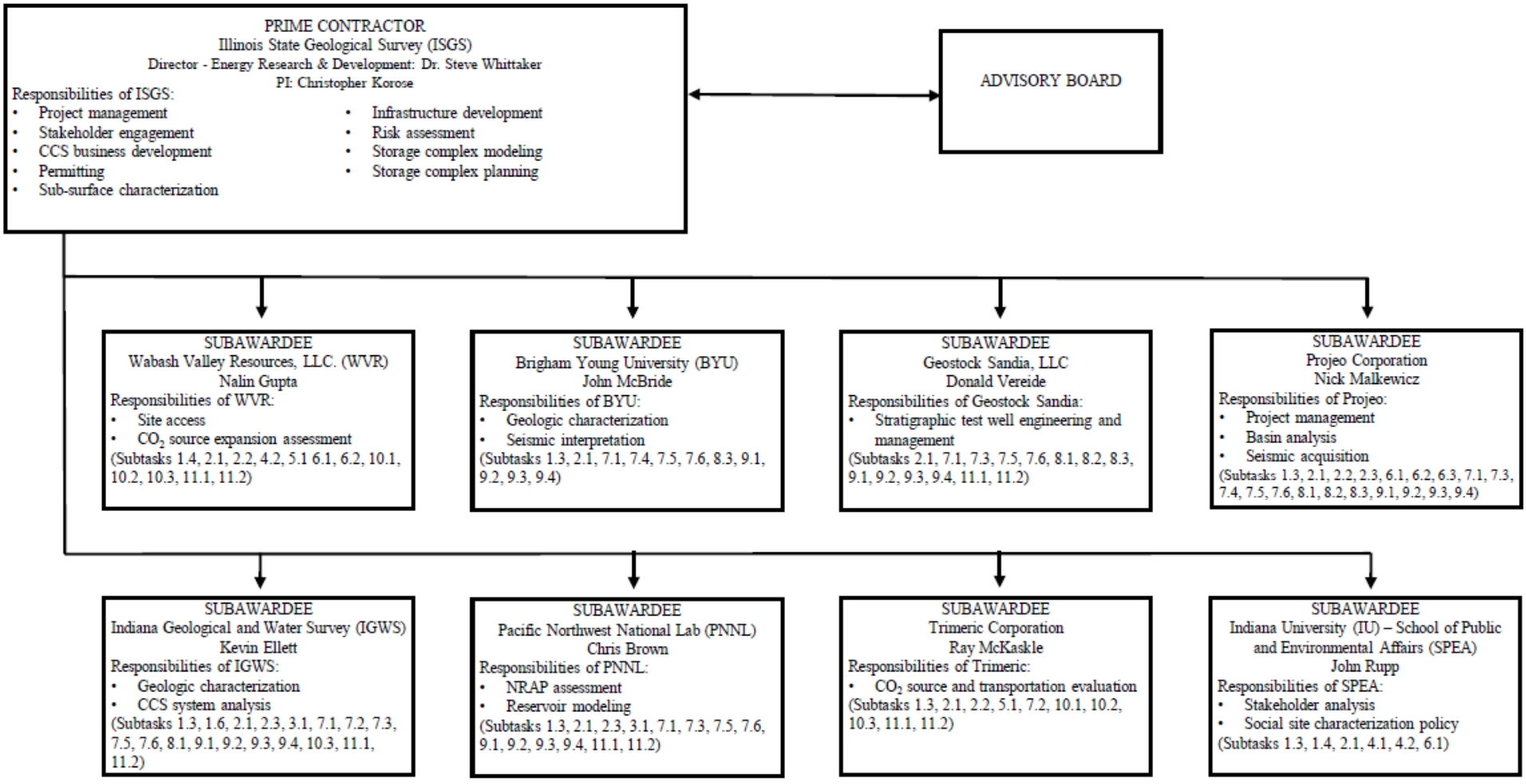
Project Overview

Project Objectives and Program Goals

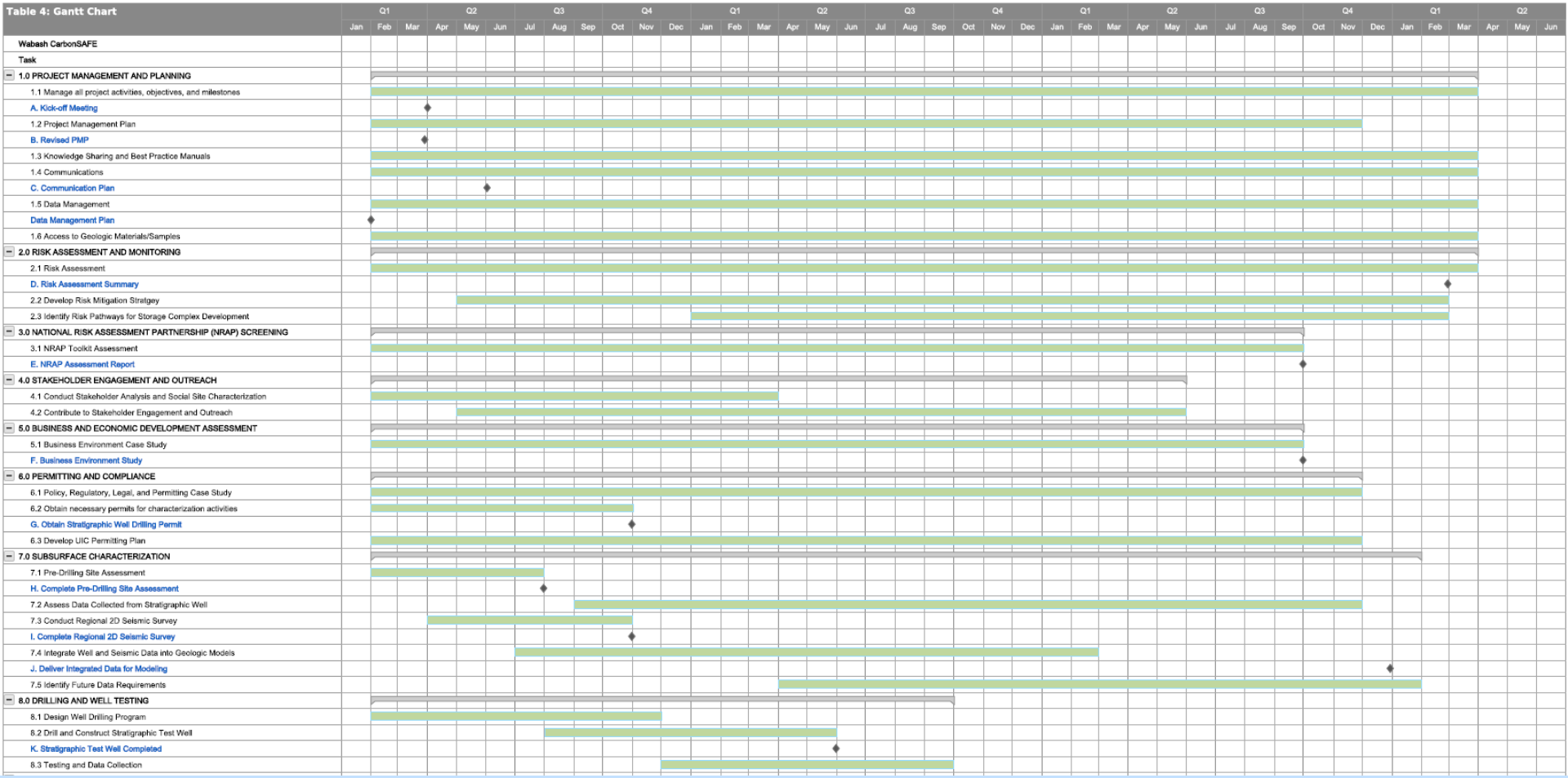
- Establish the feasibility of developing a commercial-scale geological storage complex near Terre Haute IN, that could store up to 50 million tonnes of industrially-sourced CO_2.
  - Address gap in knowledge around developing large-scale geological storage complexes
  1) Validate technologies to ensure 99% storage
  2) Validation of NRAP toolkits using field site data
  3) Improve storage capacity estimations for industry investment decision
  4) Contribute to best practice manuals to inform future commercialization efforts

- Address technical and non-technical questions around developing commercial-scale storage complexes.
  - Assess Public Outreach needs
  - Analyze Regulatory Issues
  - Characterize the Subsurface Storage Complex
  - Construct Storage Complex Model
  - Site Development Plan

Organization Chart



Gantt Chart (Page 1 of 2)



Gantt Chart (Page 2 of 2)