

CO₂ Storage in Saline Reservoirs – MRCI Perspective

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1

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1

Storage Uncertainties and Cost Considerations

- Significant uncertainty exists in CO₂ storage resources and resulting deployment cost ranges
- Low hanging fruit options are limited and highly localized
- Scale-up to larger projects and regional multi-site hubs will require advanced design and configurations:
 - Lateral and multilateral wells (similar to shale gas); multi-well pads
 - Larger wellfields (10s to hundreds of wells) – advanced modeling, area permits
 - Controlled stimulation to achieve injectivity
 - Stacked storage, complex permitting
- Enhanced regional exploration and analysis programs, focus on carbonates
- Uncertainty also driven by 3D seismic and pore-space procurement over large plume areas
- In addition to EPA requirements, need for business certainty drives up cost
- DOE and other cost models need more validation and advanced design options

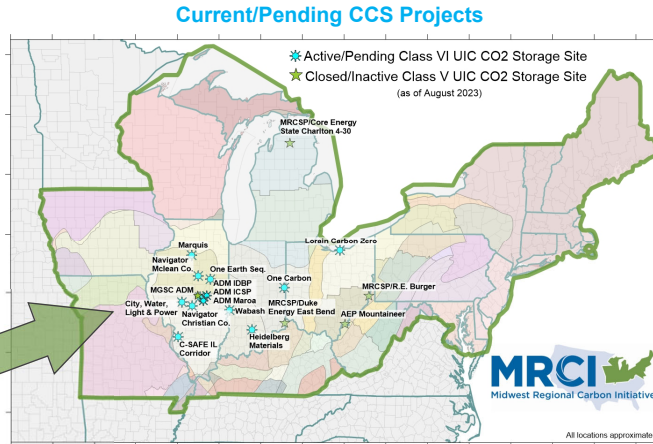
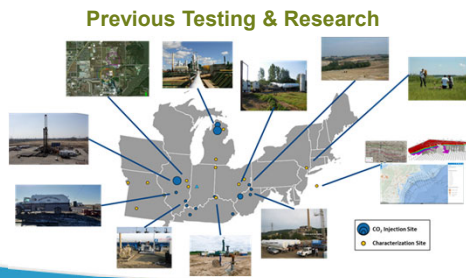
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Previous Testing and Research in the MRCI: A foundation for CCS Development

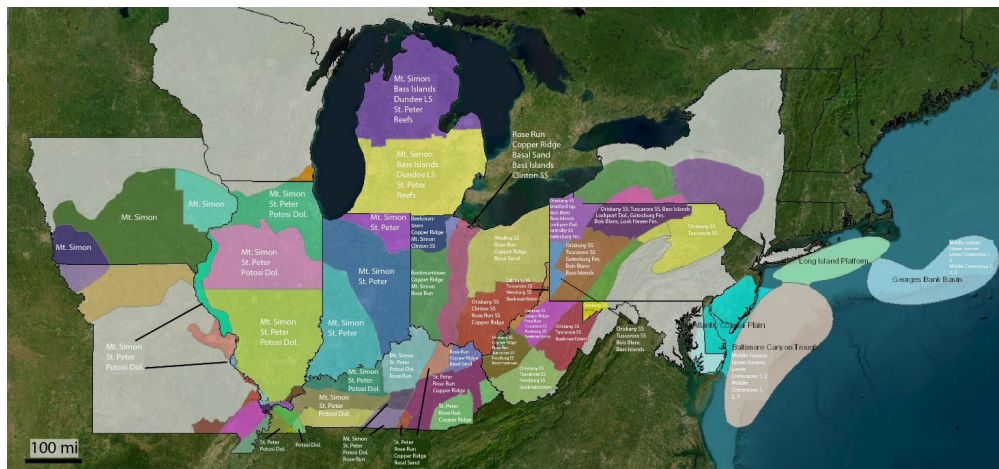
- CCS projects span major sedimentary basins in the MRCI.
- 30+ site characterization wells, piggyback drilling efforts, geological studies completed.



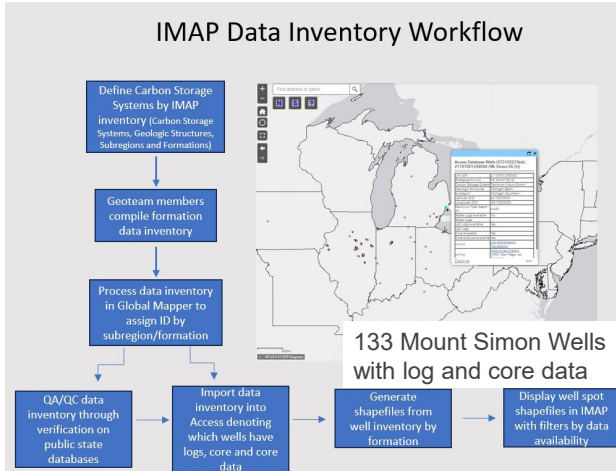
Many non-public projects not shown above

CO₂ Storage Reservoirs in the MRCI Region

This map identifies the 28 key storage formations within each of the 48 onshore sub-regions and the 4 off-shore sub-regions.



Data Inventory Workflow MRCI GeoTeam Collaboration



Formation	Count of Wells	Wells with Logs	Wells with Core Analysis
Basal Sand	186	184	3
Bass Islands	1,891	1,889	1
Beekmantown Dol.	36	32	1
Bois Blanc	1,481	1,481	
Bradford Gp.	4	4	
Clinton SS	1,983	1,982	1
Copper Ridge Dol.	2,306	2,233	18
Dundee LS	284	284	11
Elk Gp.	6	6	
Gatesburg Fm.	100	100	
Grimsby SS	5,179	5,179	
Lock Haven Fm.	22	22	
Lockport Dol.	4,389	4,389	
Lower Cretaceous 1	44	40	5
Lower Cretaceous 2	44	39	7
Medina SS	3,633	3,633	1
Middle Cretaceous 1	44	40	
Middle Cretaceous 2	44	40	3
Middle Cretaceous 3	44	40	1
Middle Jurassic	44	31	
Mt. Simon SS	1,360	1,116	143
Oriskany SS	8,105	6,868	6
Potosi Dol.	1,004	851	3
Rose Run SS	2,431	2,347	18
Salina Gp.	271	271	3
St. Peter SS	8,282	3,500	222
Tuscarora SS	249	201	2
Upper Jurassic	44	40	12
Total	43,510	36,842	461

Across the MRCI region - identified that are potential storage targets with log, 28 formations and core data.

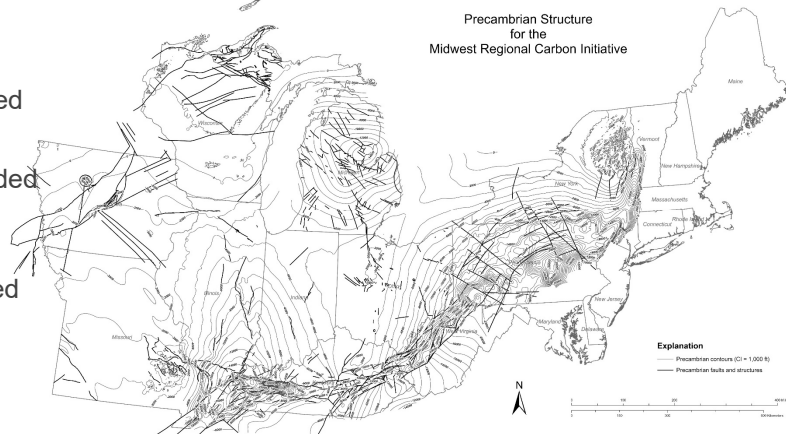
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5

Precambrian Structure, Faults and Stress – Seismicity!

- Regional Precambrian structure surface compiled
- Regional faulting at the Precambrian surface was included
- Precambrian sedimentary and igneous rift fill locations were added to the map
- In the coastal plain and Atlantic offshore, Triassic rift basins added
- A Precambrian crystalline (metamorphic-igneous) province and terrane map for the surface



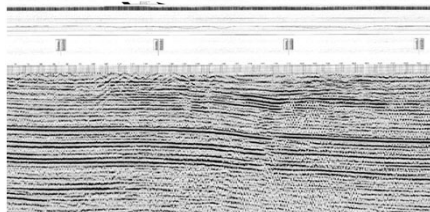
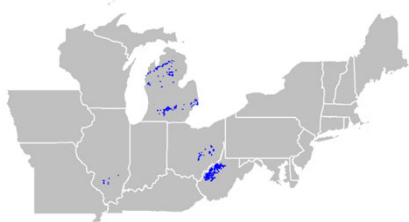
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Rescuing Legacy Seismic Datasets

Legacy seismic data organized, summarized, and digitized to support CCS:

- 986 seismic surveys - 1,892 linear miles of 2D seismic data
- 43 square miles of 3D seismic data
- 61 boxes - CD's, DVD's, tape cartridges, floppy disks, reels, mylars, paper
- 8 O&G operators with data from Illinois, Michigan, Ohio, West Virginia

Seismic surveys cataloged for location, acquisition parameters, data type, format.



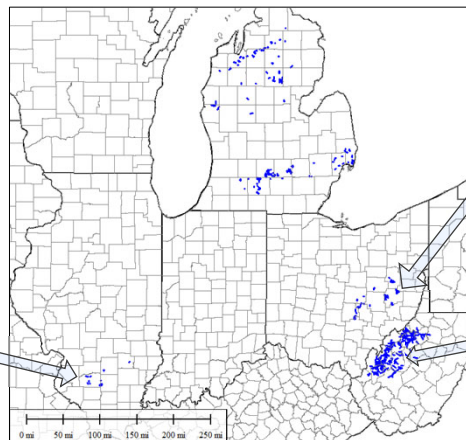
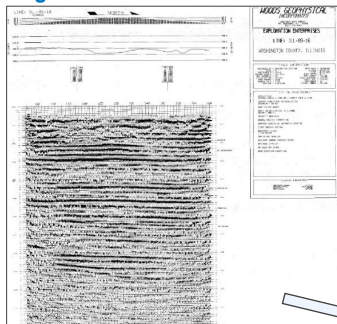
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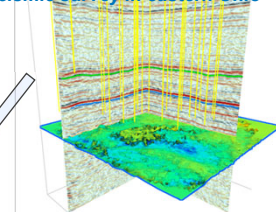
7

Leveraging Legacy 2D and 3D Seismic Datasets

2D seismic line in southern Illinois scanned from mylar to digital format



Mount Simon horizon on a 3D seismic survey in eastern Ohio



Legacy seismic lines (blue) in relation to the model area in West Virginia



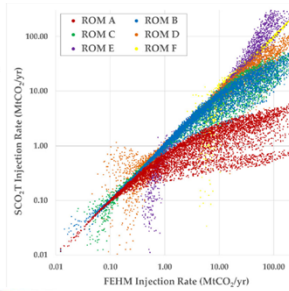
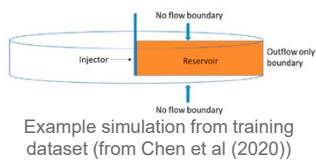
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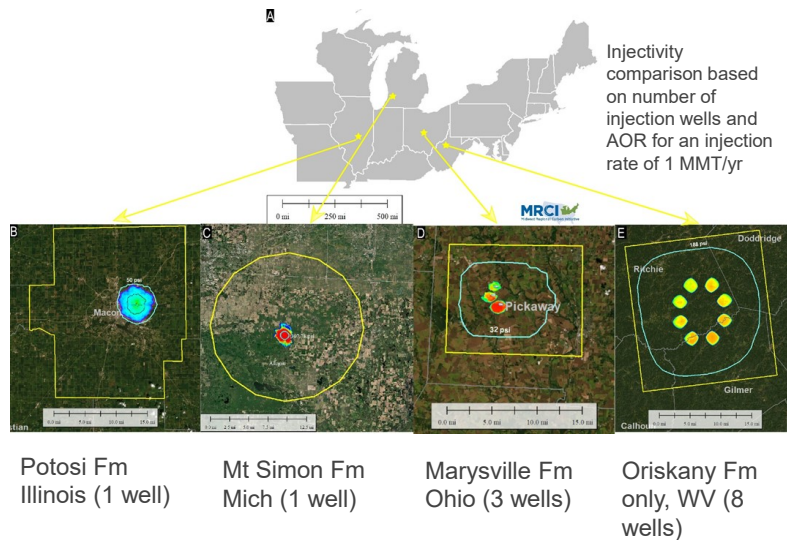
Regional CO₂ Injectivity Assessment - Lack of Data is a Major Issue

- Evaluated the feasibility of commercial-scale CO₂ injection (≥ 1 MMT for 30 yrs) in 5 storage systems region using 3D models to simulate CO₂ injection
- Expanded the feasibility to additional formations using:
 - Reduced order injectivity model (ROM) trained to synthetic data from a 3-D models; and
 - Site-scale 3-D numerical flow models.

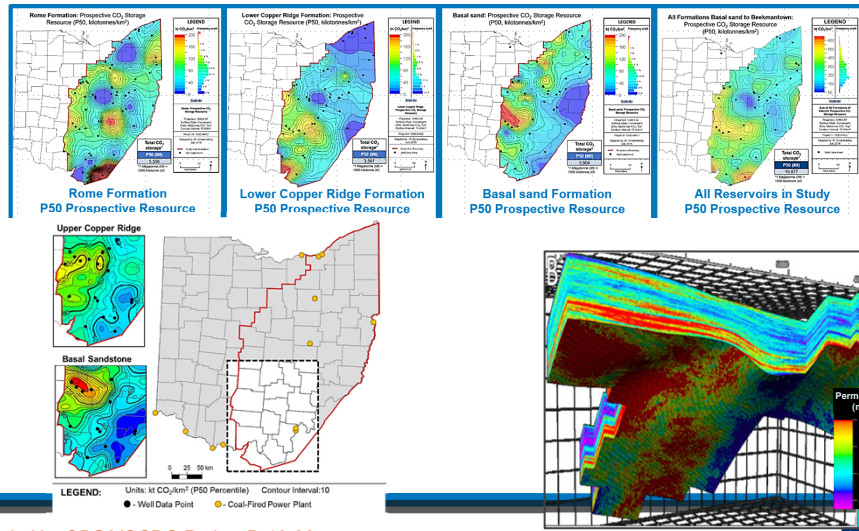



CO₂ Injectivity from Site-Scale Models

- Feasibility of select formations showing number of injection wells and Area of Review (CO₂ plume and pressure) required to accommodate the target injection rate.
- Best sites with sufficient data are in the Illinois Basin and Michigan Basin
- Deeper basins require more wells and exploration



Prospective Stacked CO₂ Storage Resource Assessment – Need for Geologic Characterization



12

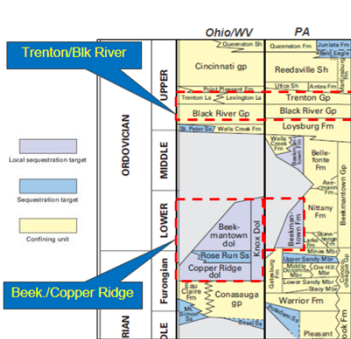
Co-Funded by ODSA/OCDO Project D-13-22



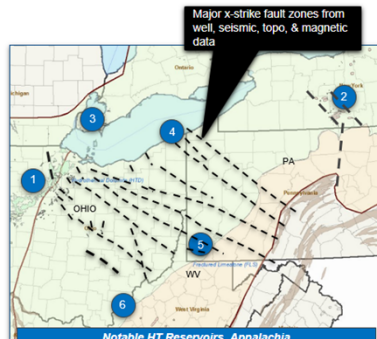
12

Exploring CO₂ Storage in Carbonates

Hydrothermal Dolomite for CO₂ Storage in Appalachian Basin

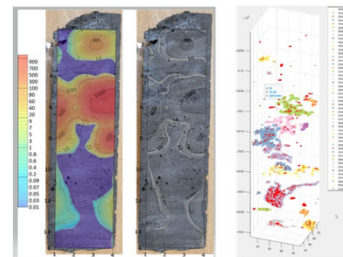


- Pre-Crustal zones of weakness and three subsequent orogenies
- Resulted in development of a vast, long-lasting system of wrench/strike-slip faults
- A thick section of Ordovician carbonates were exposed to deep, hot brines via the extensive wrench system



- Notable HT Reservoirs, Appalachia**
1. Lima-Indiana: World's first giant oil field
 2. Prolific HT gas fields of S. NY
 3. Rochester oil field, Ontario
 4. Saybrook HT oil/gas, OH
 5. Scotts Run: biggest "shale gas" well.
 6. Copper Ridge Fm vuggy zones
- Trenton/Beekmantown River Fm

Mapping Vugular Porosity in Carbonates via Rock Core CT Scans



13



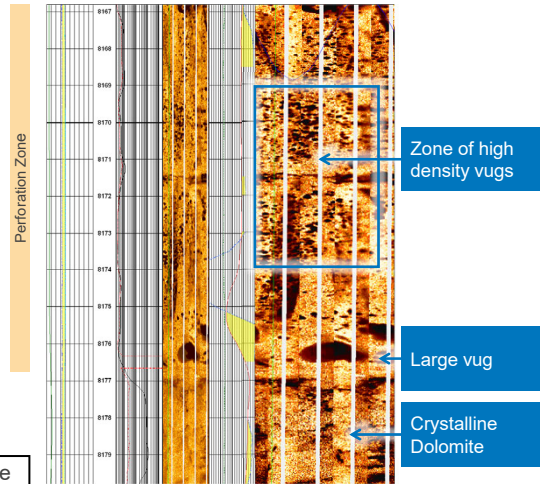
13

Characterizing Vuggy Dolomite

AEP1 image log in Copper Ridge Dolomite showing vuggy zones. Regional exploration effort for these zones underway



Appalachian Basin vuggy dolomite core – from a 2 km distant well

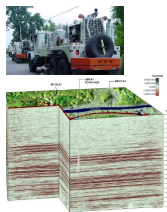


14

AEP Mountaineer program – full life-cycle CCS spanning 15 years with Battelle as CO₂ storage service provider

Feasibility – Exploration Well

- Seismic survey conducted and AEP-1 test well was drilled in 2002
- Included extensive data collection and community outreach
- DOE and industry funded



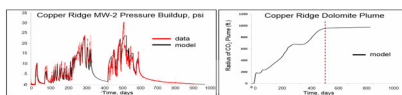
Pilot Construction & Commissioning

- Network of five wells, two injection and three monitoring, constructed (drilling and completion) in 2008-2009
- Integrated with the capture system on site
- Pressure maintenance and monitoring system was installed



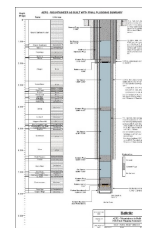
Injection and Operations Monitoring

- ~37,000 tonnes of CO₂ was injected and stored over 18 months from 2009 to 2011
- Included monitoring of reservoir pressure, groundwater chemistry, CO₂ injectate, and soil gas



Post-Injection and Site Closure

- Post-injection – pressure, groundwater monitoring, plume modeling
- Well plugging and site closure within 5 years by working with regulators and meeting all permit requirements
- Scale-up design for 235 MWe facility completed

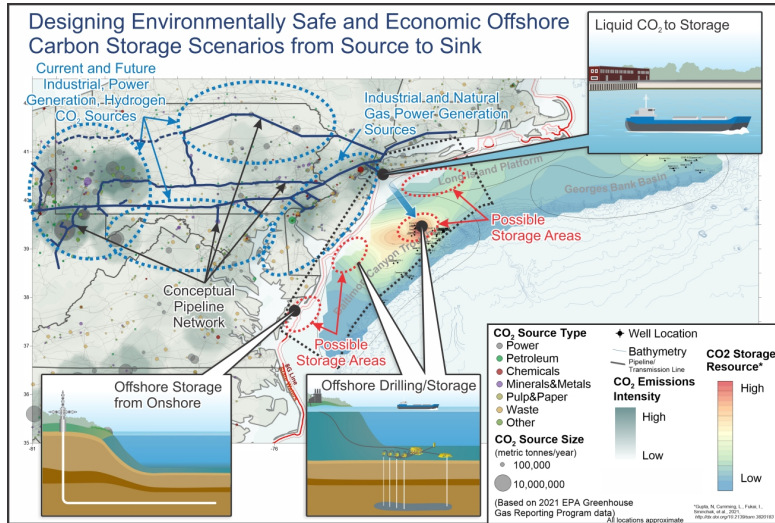


15

15

Mid-Atlantic Offshore Carbon Storage Hub Development

- Goal - link current & future CO₂ sources from the East Coast & Northern Appalachian Basin with suitable CO₂ storage options with an environmentally safe focus.
- The project is designed to provide benefits for energy, equity, reduce emissions, and provide quality jobs for critical industry along the U.S. East Coast, where many existing CO₂ sources have no options for CO₂ storage.



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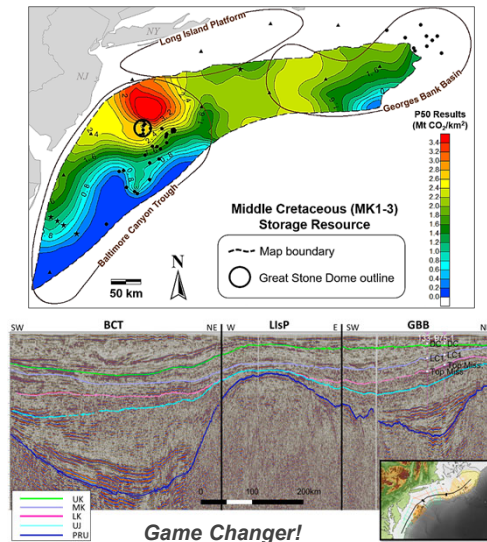
16

Mid-Atlantic Offshore Carbon Storage Hub Development - Supporting Communities and Industry for

- Very large storage resource in Mid-Atlantic Outer Continental Shelf: **150-1136 Gt.**
- **Opportunities:** large storage capacity, shallow water along OCS, large area, favorable porosity/permeability, limited development in subsurface.
- **Challenges:** limits on offshore exploration, lack of infrastructure, environmental/stakeholder issues, source-sink routing.
- **Development Plan:** exploration plan, pipeline feasibility for CO₂ sources, offshore drilling, well field, monitoring, logistics, cost-benefit risk analysis, energy transition, community benefits, environmental protection.



Focus of new project



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17

Storage Resources- 150-1100 Gigatonnes

Reservoir gross thickness up to 7700 ft
Net thickness 100-700 ft

Identified **three potential storage targets** and four regional caprocks

Age	Seal or Reservoir	Formation Name*	Depth (ft.)	Thickness (ft.)
Upper Cretaceous	Seal	Dawson Canyon	996 - 6,831	556 - 3,128
	Reservoir	Logan Canyon	2,208 - 9,561	174 - 2,227
Lower Cretaceous	Seal	Naakapi	3,022 - 10,557	49 - 1,481
	Reservoir	Mesauga	3,583 - 10,639	553 - 4,542
Upper Jurassic	Seal	Mic Mac	4,116 - 13,591	331 - 13,591
	Reservoir	Mohawk	4,924 - 15,082	5,274 - 7,742
	Base/Seal	Mohican/Tropozo	> 9738	-

Regional averages for total storage zone (SS, ≥10 mD)

Storage Zone	Area (km ²)	Thickness (m)	Effective Porosity (%)	Permeability (mD)*	CO ₂ Density (kg/m ³)
MK1-3	92,928	181	23	71	815
LK1	117,493	154	26	65	809
UJ1	134,578	211	21	45	796

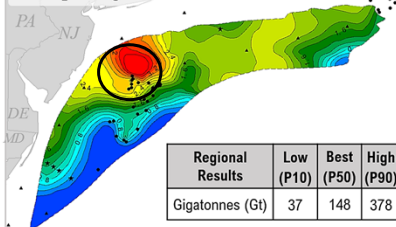
*geometric mean

Regional averages for net storage zone (SS, ≥100 mD)

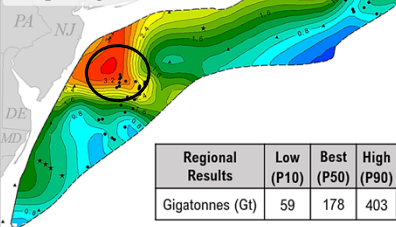
Storage Zone	Area (km ²)	Thickness (m)	Effective Porosity (%)	Permeability (mD)*
MK1-3	79,918	55	27	314
LK1	117,102	40	29	339
UJ1	88,372	32	25	264

*geometric mean

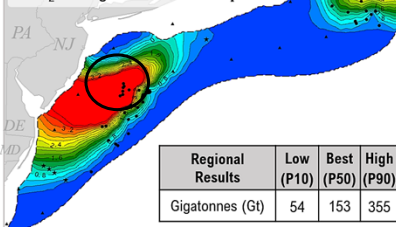
Middle Cretaceous (MK1-3)
CO₂ Storage Resource



Lower Cretaceous (LK1)
CO₂ Storage Resource



Upper Jurassic (UJ1)
CO₂ Storage Resource



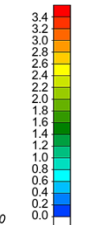
LEGEND

- Well
- ▲ Pseudo-well w/average porosity
- ★ Pseudo-well w/seismic porosity
- Calculation boundary



Map Projection: NAD83/UTM zone 19N, GRS 1980

P50 Results (Mt CO₂/km²)

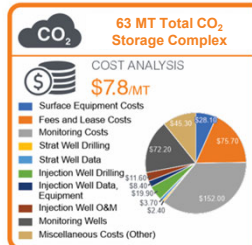
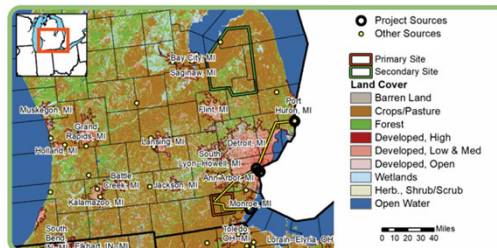


SE Michigan CarbonSAFE Storage Complex Feasibility

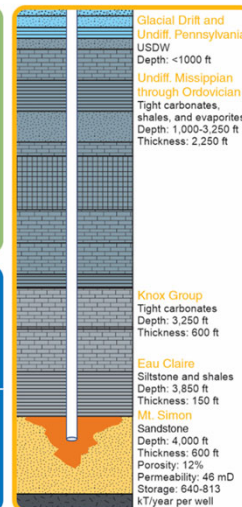
Develop a CO₂ storage hub for natural gas-based power generation sources & other emitters in SE Michigan.

Mt. Simon Sandstone storage

Start Oct. 2023



- COMMUNITY BENEFITS
- Clean Air
 - Jobs
 - Education and Training
 - Community Investments and Improvements
- LOW RISK
- No Seismicity or Induced Seismicity
 - Few Well Penetrations
 - Few Geohazards
 - Experienced Project Team



Reducing Risk, Advancing Technology, and Supporting Growth

Appalachian Regional Clean Hydrogen Hub (ARCH2)

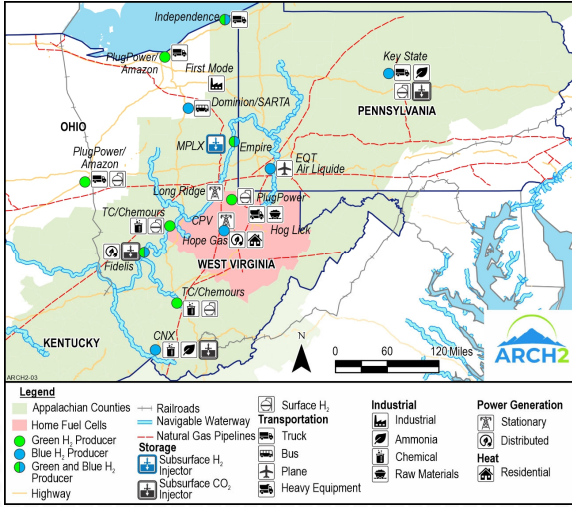
Appalachian Hydrogen and Carbon Capture Conference
November 30, 2023





20

ARCH2 Overview



Legend

- Appalachian Counties
- Home Fuel Cells
- Green H₂ Producer
- Blue H₂ Producer
- Green and Blue H₂ Producer
- Highway
- Railroads
- Navigable Waterway
- Natural Gas Pipelines
- Storage
- Subsurface H₂ Injector
- Subsurface CO₂ Injector
- Surface H₂ Transportation
- Truck
- Bus
- Plane
- Heavy Equipment
- Industrial
- Ammonia
- Chemical
- Raw Materials
- Power Generation
- Stationary
- Distributed
- Heat
- Residential

PROGRAM MANAGEMENT AND TECHNICAL SUPPORT

BATTELLE **GTI ENERGY** **AST** **TRC** **NATIONAL TECHNOLOGY LABORATORY**

PROJECT DEVELOPERS

Air Liquide **Chemours** **CNX** **Dominion Energy** **EMPIRE**

EQT **FIDELIS** **HOG LICK** **Hope Gas** **IH**

KeyState **FIRST MODE** **MPLX** **TC Energy** **PLUG**

ARCH2 ECOSYSTEM

Executive Board: **BATTELLE** **GTI ENERGY** **AST** **EQT**

Advisory Board: [Logos of various regional organizations]

Educational Alliance: **WVSU** **Mountwest** **West Virginia University** **KENT STATE UNIVERSITY** **THE OHIO STATE UNIVERSITY** **MASSILLON**


Transit Authorities: **SARTA** **POTOMAC VALLEY** **TRILLIUM H. POWER** **MTA**

Connective Infrastructure: **NATIONAL FUEL** **ENBRIDGE** **APPALACHIAN POWER** **TRILLIUM H. POWER** **DT Midstream**

Community/Business Groups: **AFL-CIO** **CLEAN AIR TASK FORCE** **JobsOhio** **IN-MARKET**

Note: Proposed project locations based on preliminary siting are subject to change during the detailed planning phase (phase 1).

Re-energizing Appalachia
Economically • Socially • Environmentally



21

Midwest Regional Carbon Initiative (MRCI) - Regional Initiative to Accelerate CCUS Deployment in Midwestern and Northeastern USA DE-FE0031836



25



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It can be done

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26