Mark Kelley - Battelle

MRCI Task 2 Addressing Key Technical Challenges

Budget Period 1 Summary

Partners and Stakeholders Meeting
September 28th, 2022
Columbus, OH

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Midwest Regional Carbon Initiative

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY | BATTELLE | ILLINOIS

Contributors

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- Ohio Geologic Survey – Jim McDonald
- Pennsylvania Geologic Survey – Kris Carter, Michele Cooney
- Rutgers – John Schmelz, Ken Miller
- Univ. Western Michigan – Bill Harrison
- Univ. Iowa – Ryan Clark
- West Va. Geologic Survey – Jessica Moore, Sue Pool

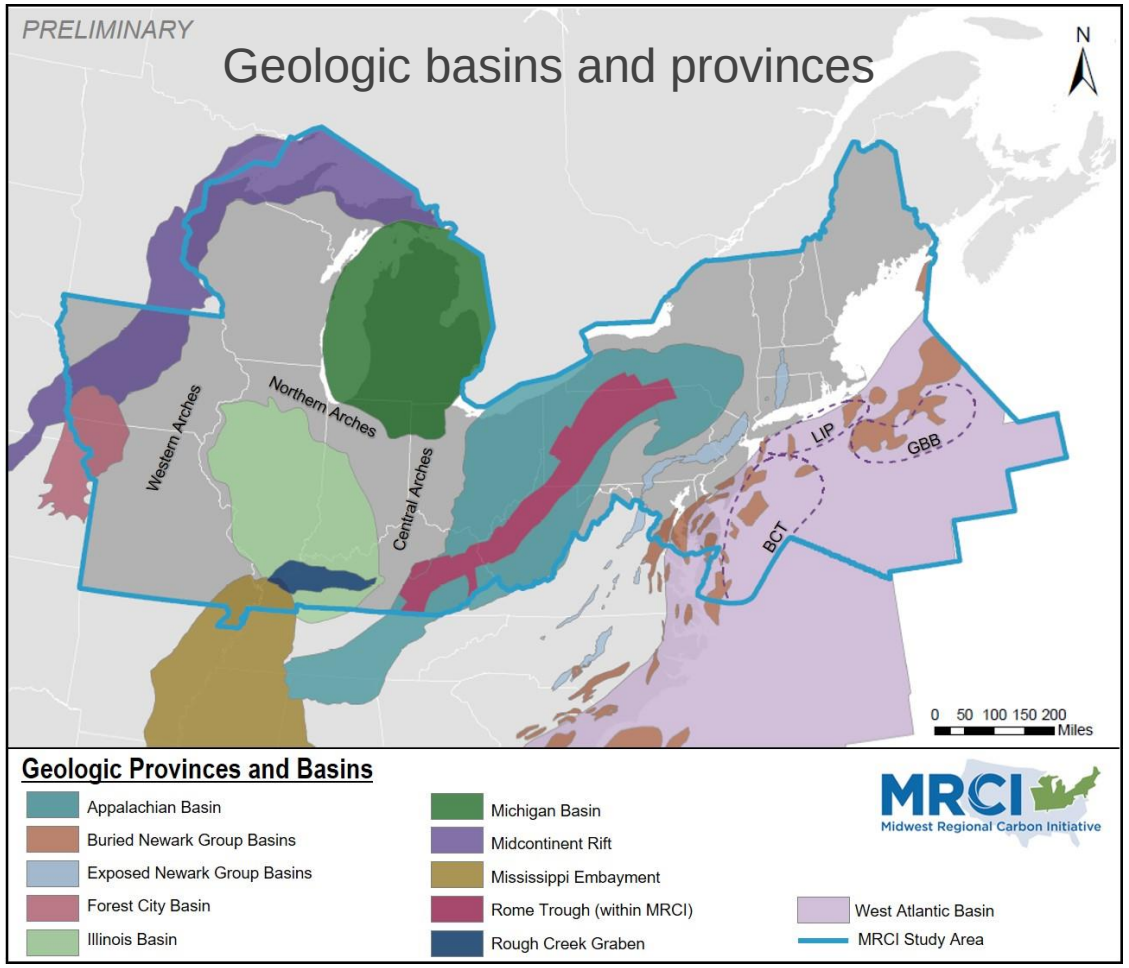
Task 2 – Scope and Objectives

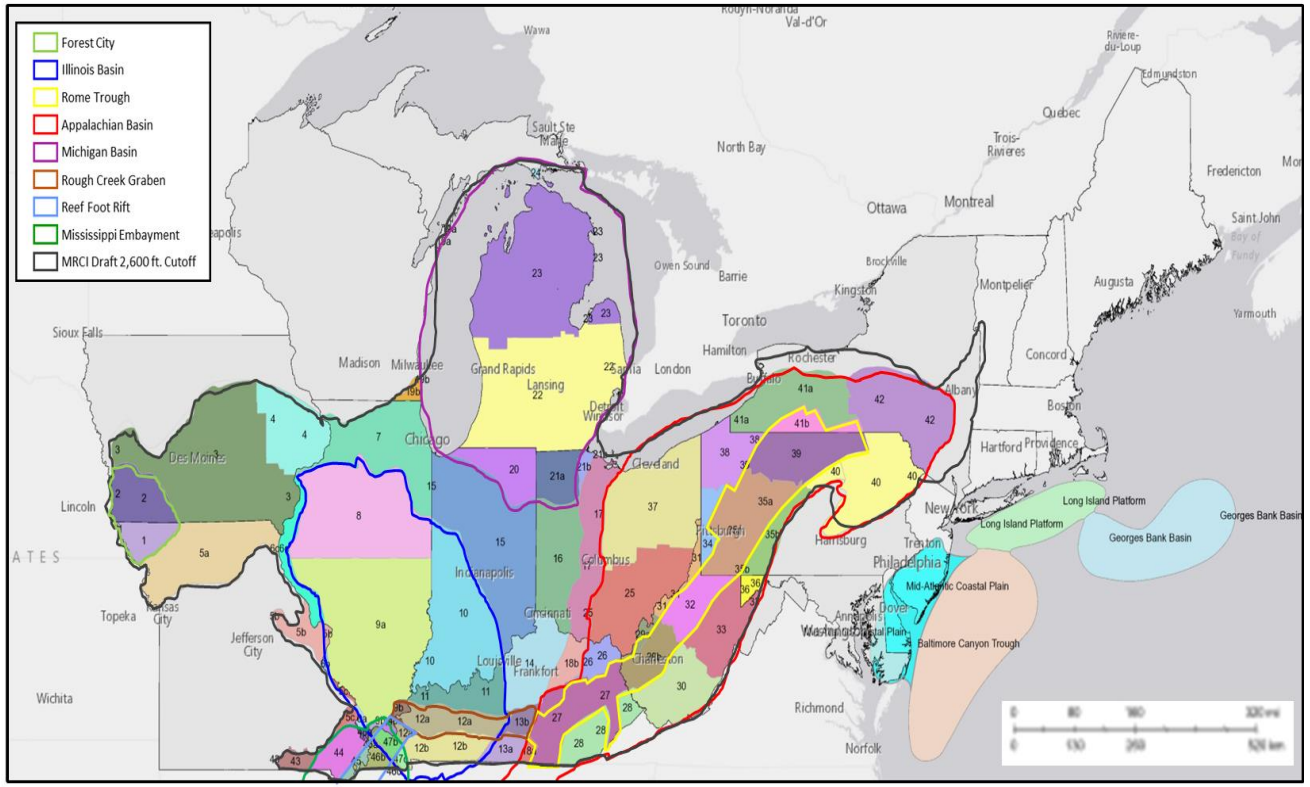
GOAL: Identify and address key technical challenges with establishment of CCUS in the region.

- Characterize Regional/Subregional Geologic Framework and Expand CO_2 Stacked Storage Characterization
- Characterize Basement Structure/Faulting/Stress and compile other information to assess Induced Seismicity potential
- Assess commercial-scale CO_2 storage feasibility of selected CS Systems and demonstrate process
- Demonstrate method for assessing commercial-scale CO_2 storage risks and apply to example scenarios
- Facilitate Industrial Partnership and Regional Technical Collaboration

Geologic Framework - Defining Carbon Storage Systems

Objective #1





Geologic basins and provinces were subdivided into sub-regions on the basis of stratigraphy.

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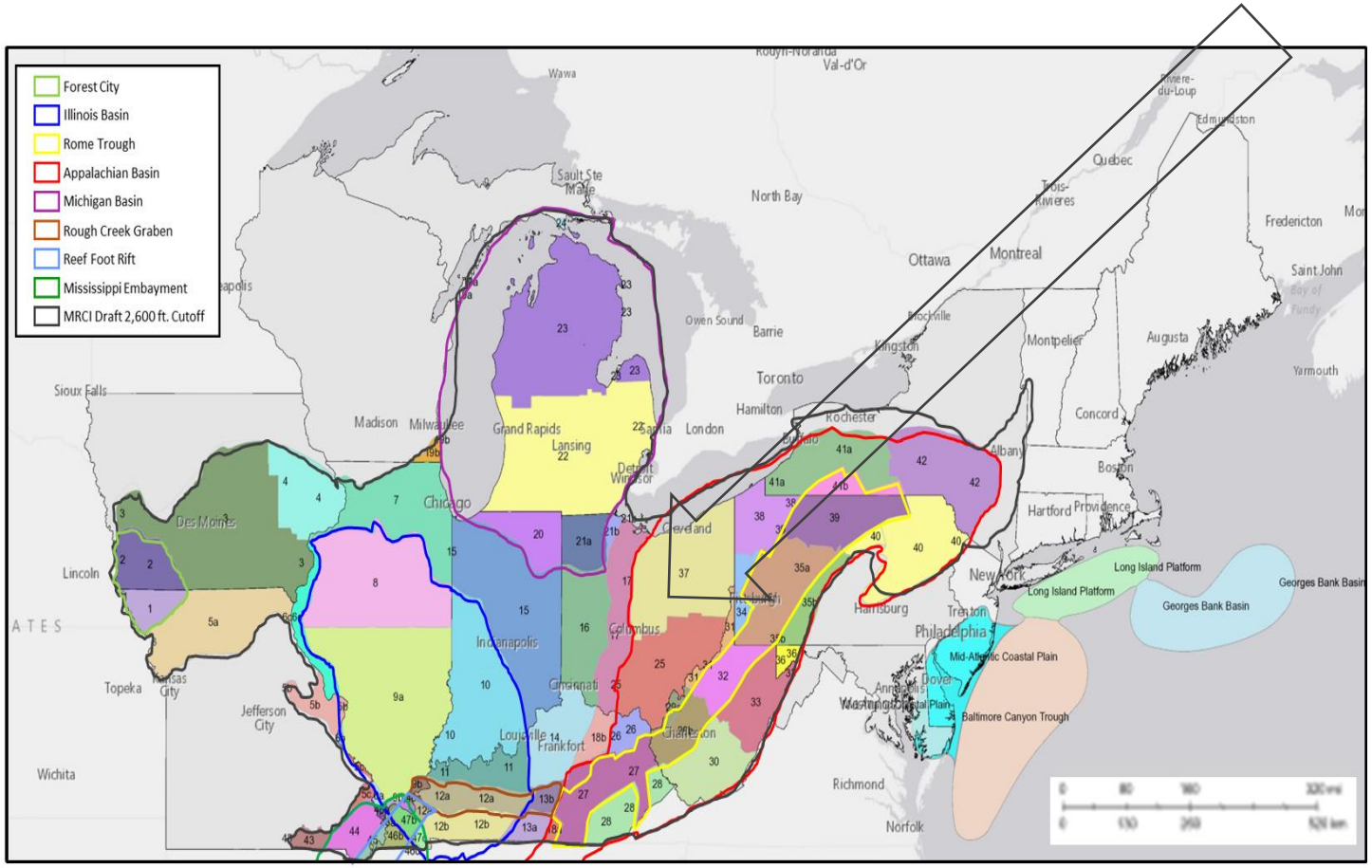
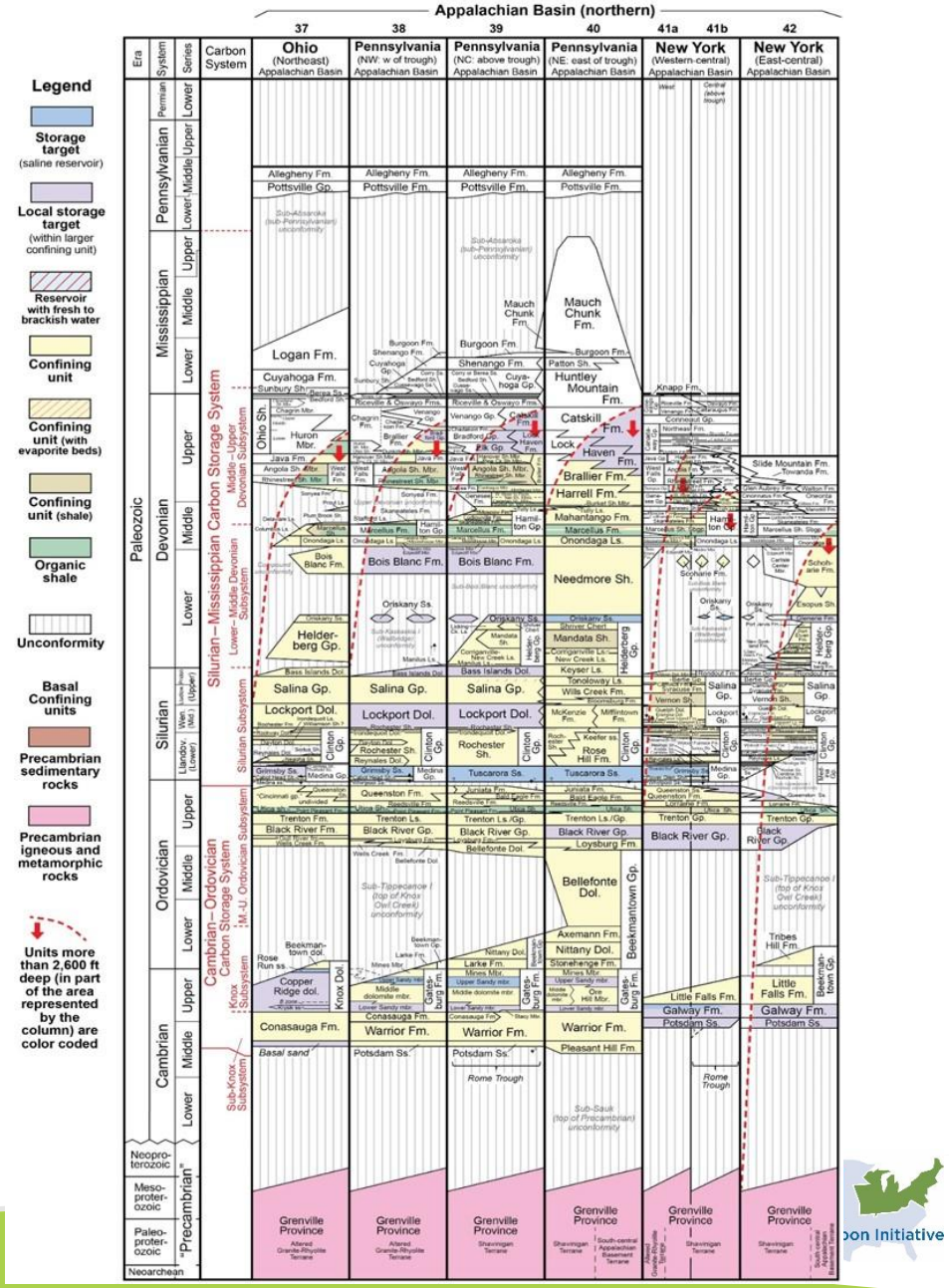
Defining Carbon Storage Systems

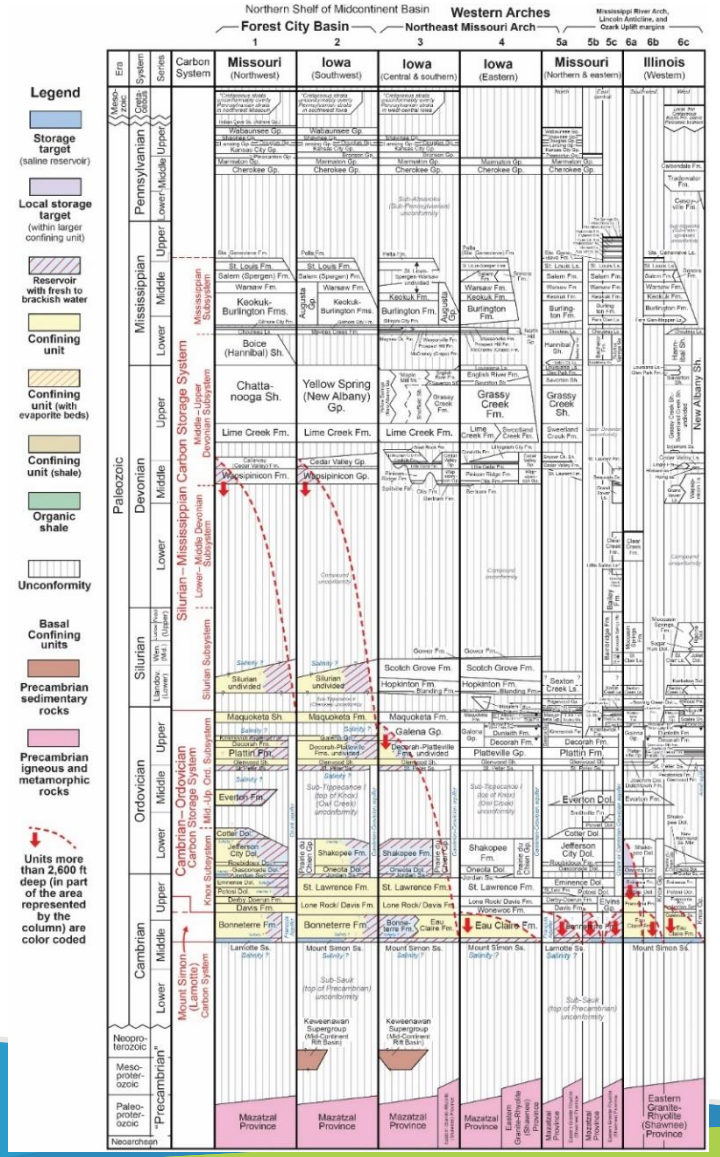


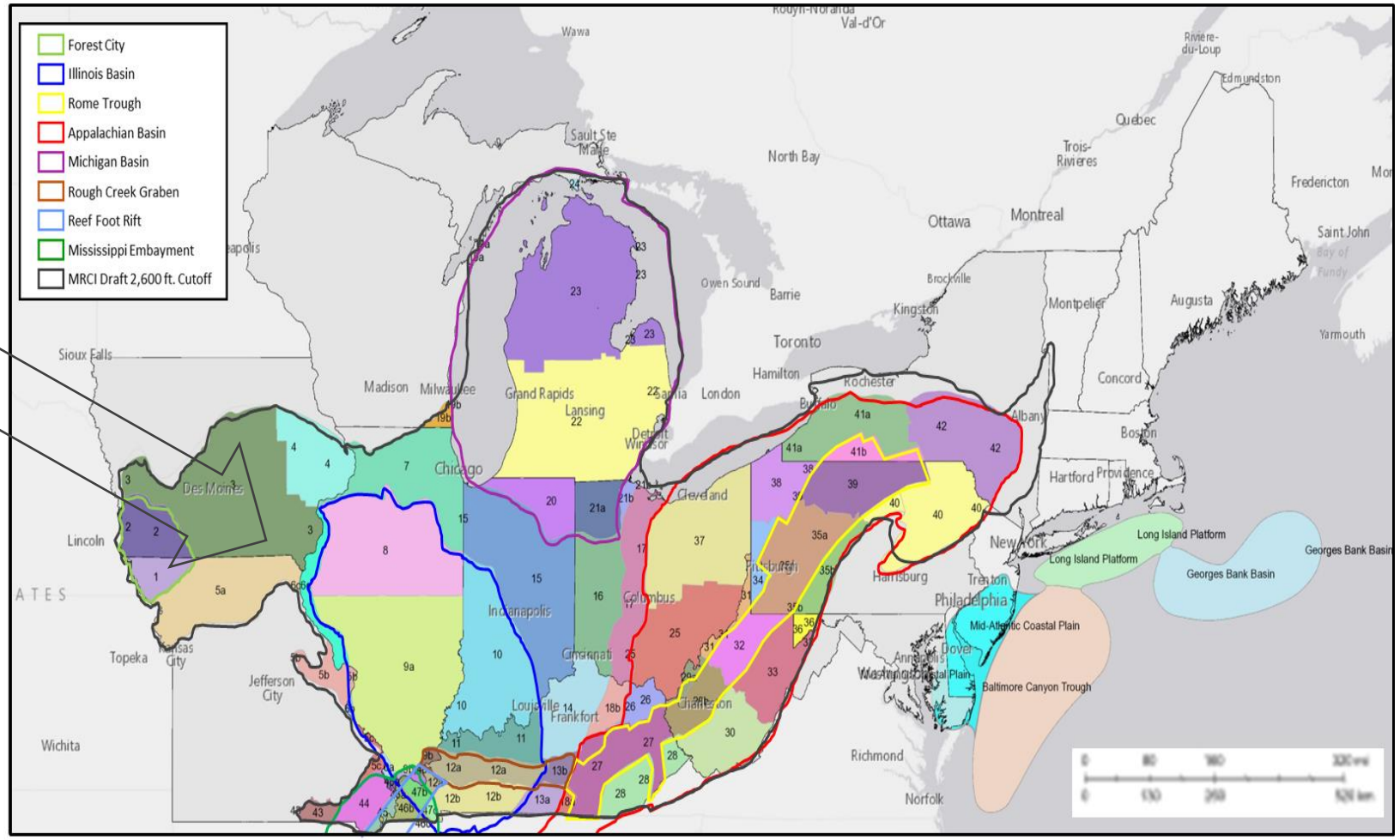
Stratigraphy of Northern Appalachian Basin



Defining Carbon Storage Systems

Stratigraphy of Forest City Basin/Western Arches





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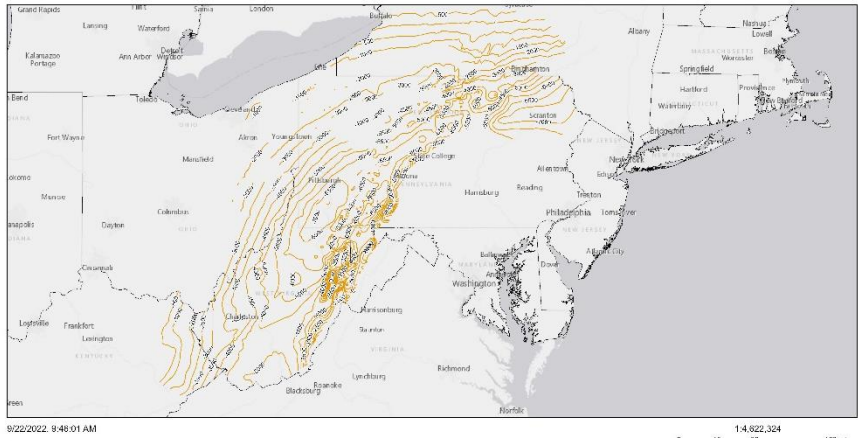
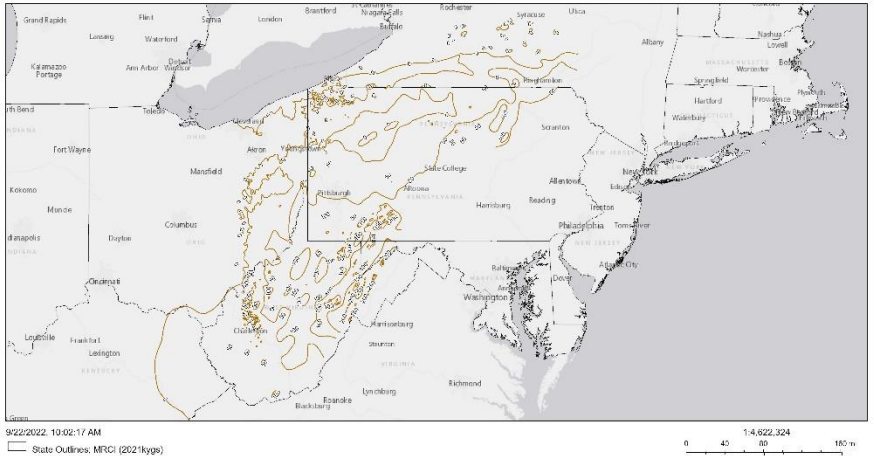
Developing a Geologic Maps Database

Existing maps for key geologic units were vetted and compiled into an interactive ArcGIS map database containing over 500 maps from previous carbon partnerships and state geologic surveys, for example:

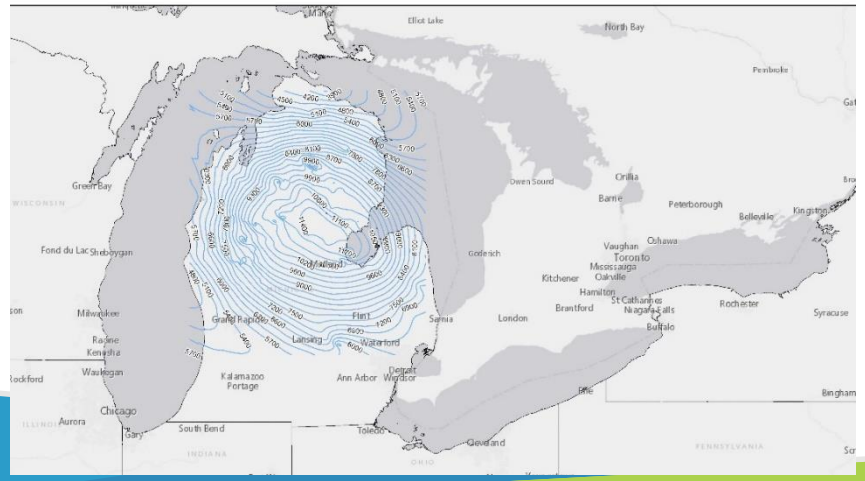
Oriskany Structure Top



Oriskany Thickness



St. Peter Sandstone Overburden Thickness



St. Peter Sandstone Isopach

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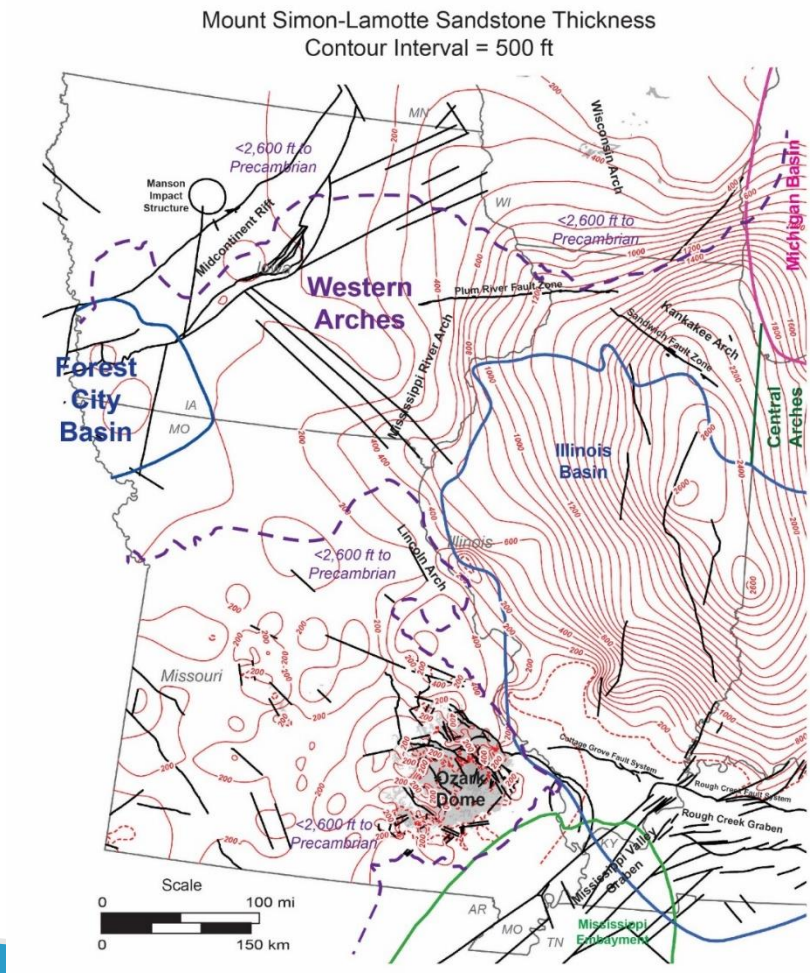
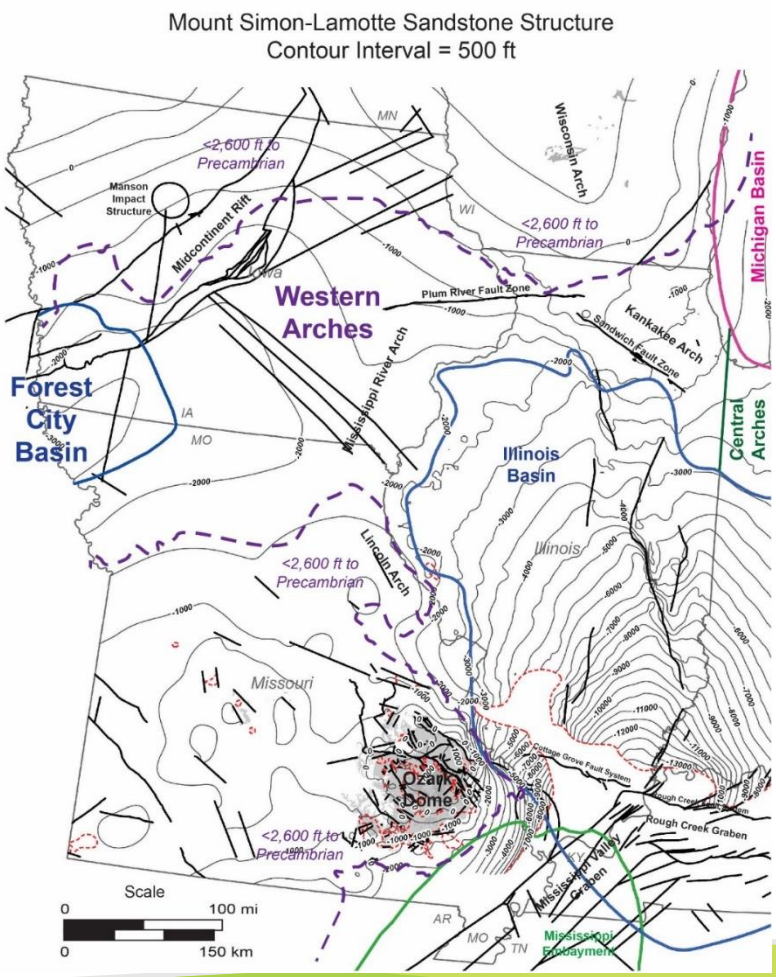
Developing a Geologic Maps Database (cont'd)

New structure and thickness map were developed for areas/formations such as the Forest City Basin and Western Arches area that had not previously been mapped .





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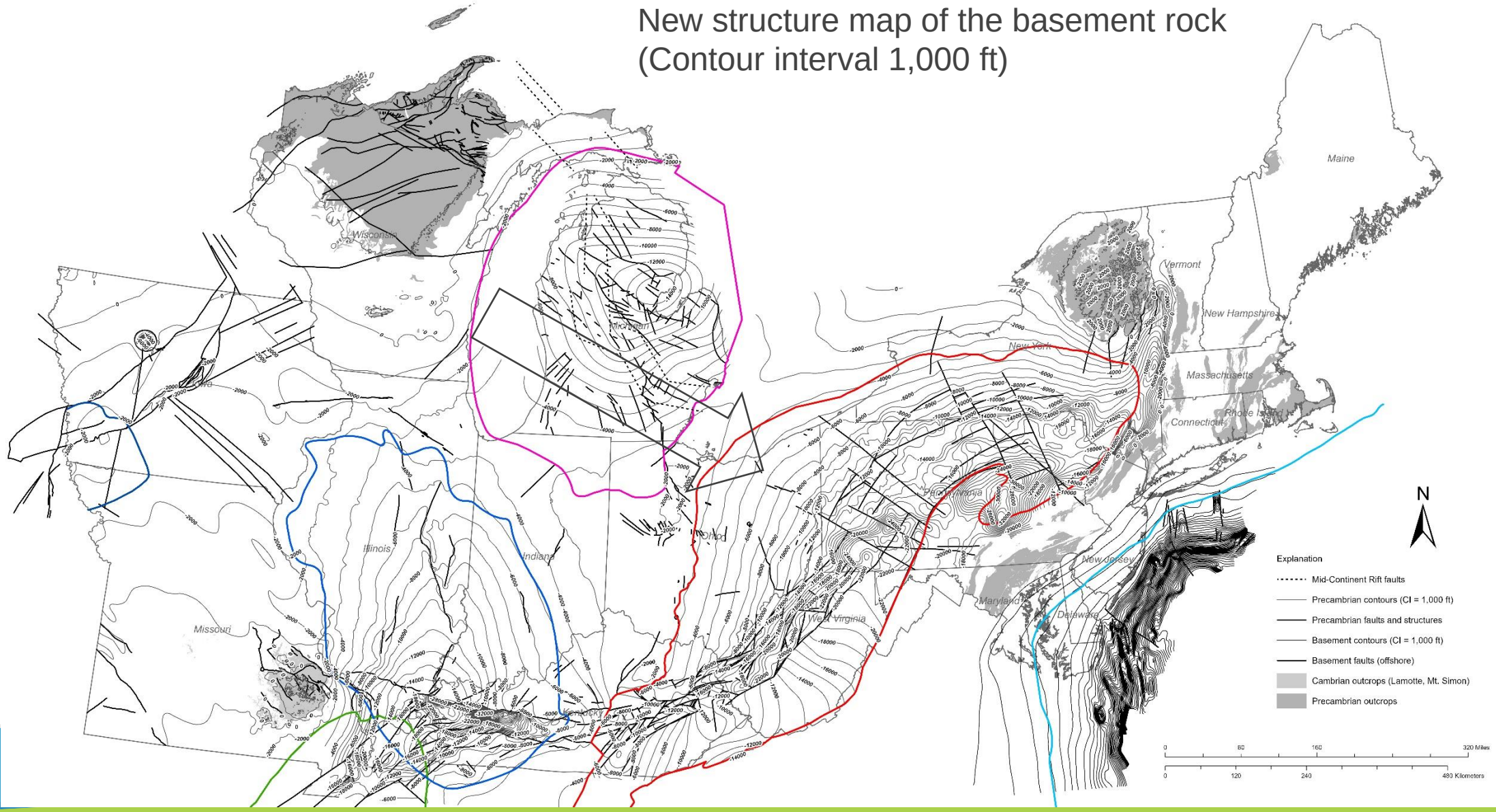
Basement Rock Characterization – Structure and faults

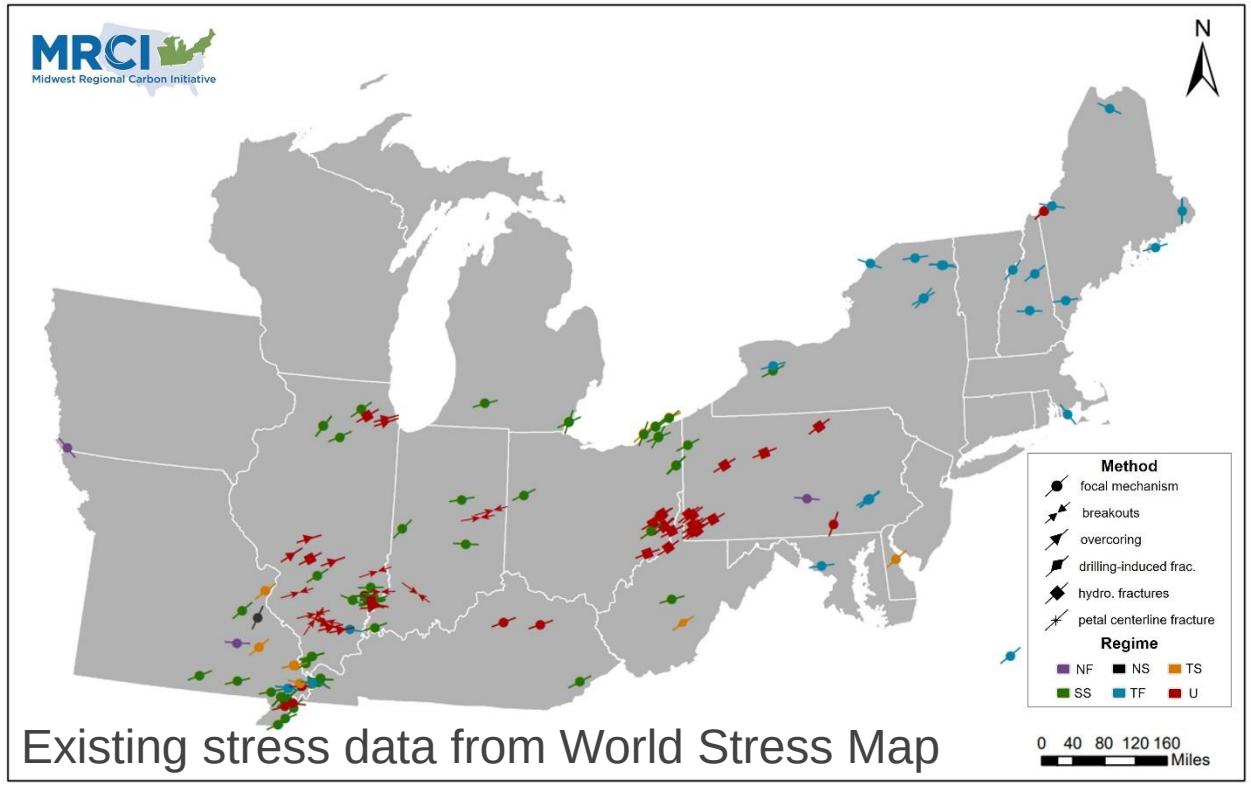
Objective #2

New structure map of the basement rock
(Contour interval 1,000 ft)

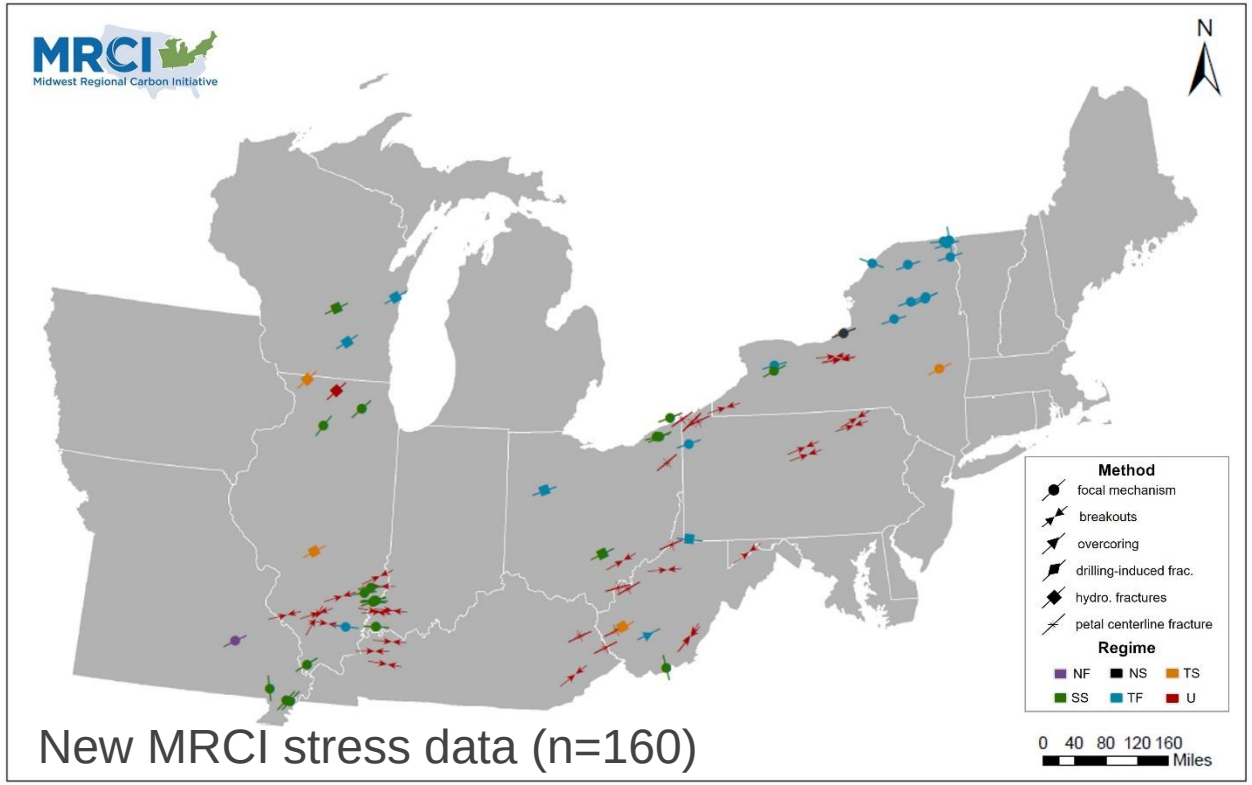


Basement Rock Characterization – Stress Data

Information to assess induced seismicity and other geomechanical risks

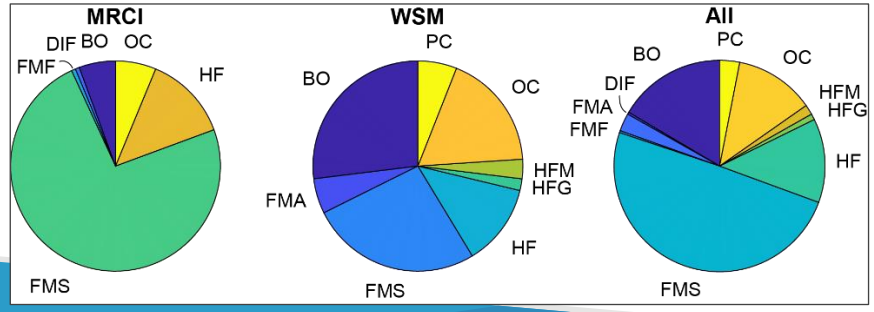


Existing stress data from World Stress Map



New MRCI stress data (n=160)

Source of stress data



BO, borehole breakout; DIF, drilling-induced tensile fracturing; FMA, average/composite focal mechanism; FMF, focal mechanism inversion; FMS, single-earthquake focal mechanism, HF, hydrofracturing; HFG, gradient-based hydrofracturing measurement; HFM, maximum-depth hydrofracturing measurement; OC, over coring; HF, hydrofracturing; and PC, mean petal-line fracture.

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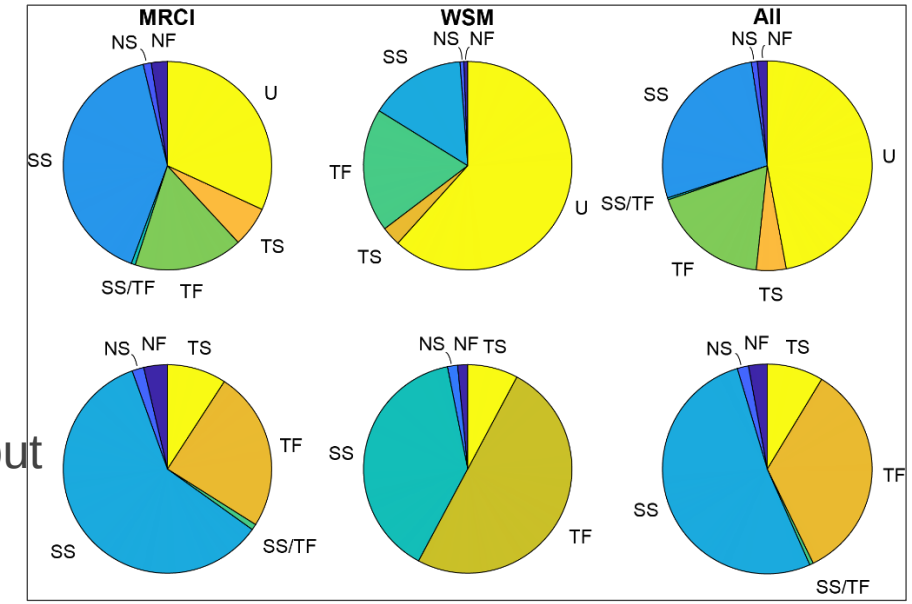
Basement Rock Characterization – Stress Data (cont'd)

Types of stress regime in MRCI Region

With "U"s

Without "U"s

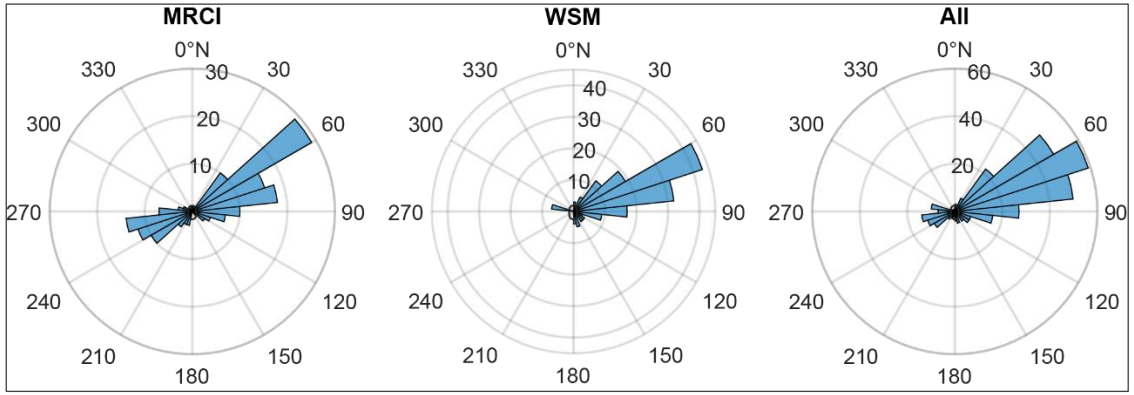


Distributions of stress regime in the MRCI data compilation for new data (left column), WSM (World Stress Map) (middle column), and the combination of the two (right column).

TF – thrust faulting; TS – oblique thrust faulting; SS – strike-slip faulting; NS – oblique normal faulting; NF – normal faulting; U – undetermined

	MRCI		WSM		All	
REGIME	Count	Percent	Count	Percent	Count	Percent
NF	4	2.5	1	0.6	5	1.5
NS	2	1.3	1	0.6	3	0.9
SS	65	40.6	25	15.0	90	27.5
SS/TF	1	0.6			1	0.3
TF	27	16.9	32	19.2	59	18.0
TS	10	6.3	5	3.0	15	4.6
U	51	31.9	103	61.7	154	47.1

Stress Orientation in MRCI Region



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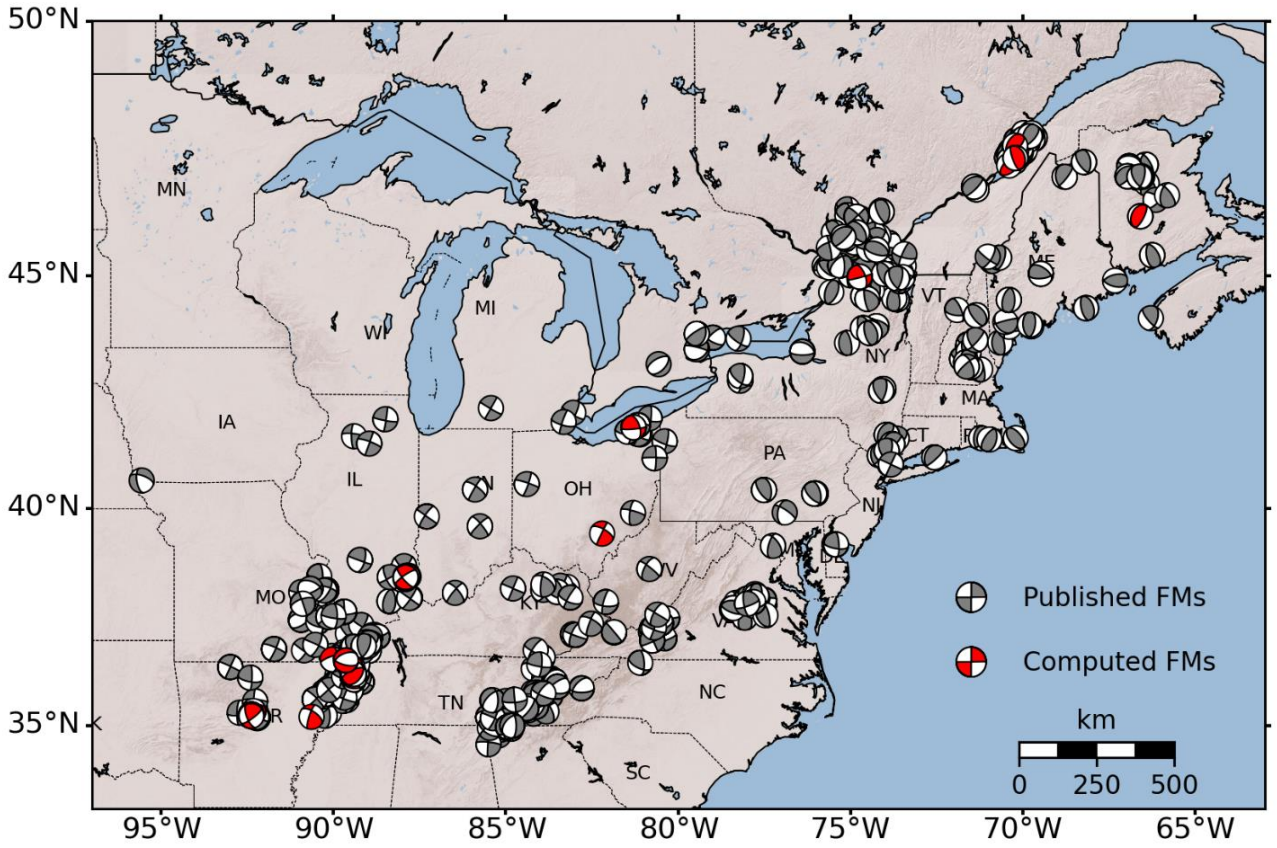
Additional Stress Data Derived from Focal Mechanism Calculations

- focal mechanisms (FMs) from published work (gray beachballs) and new FMs computed in this study (red beachballs) in and around the MRCI states



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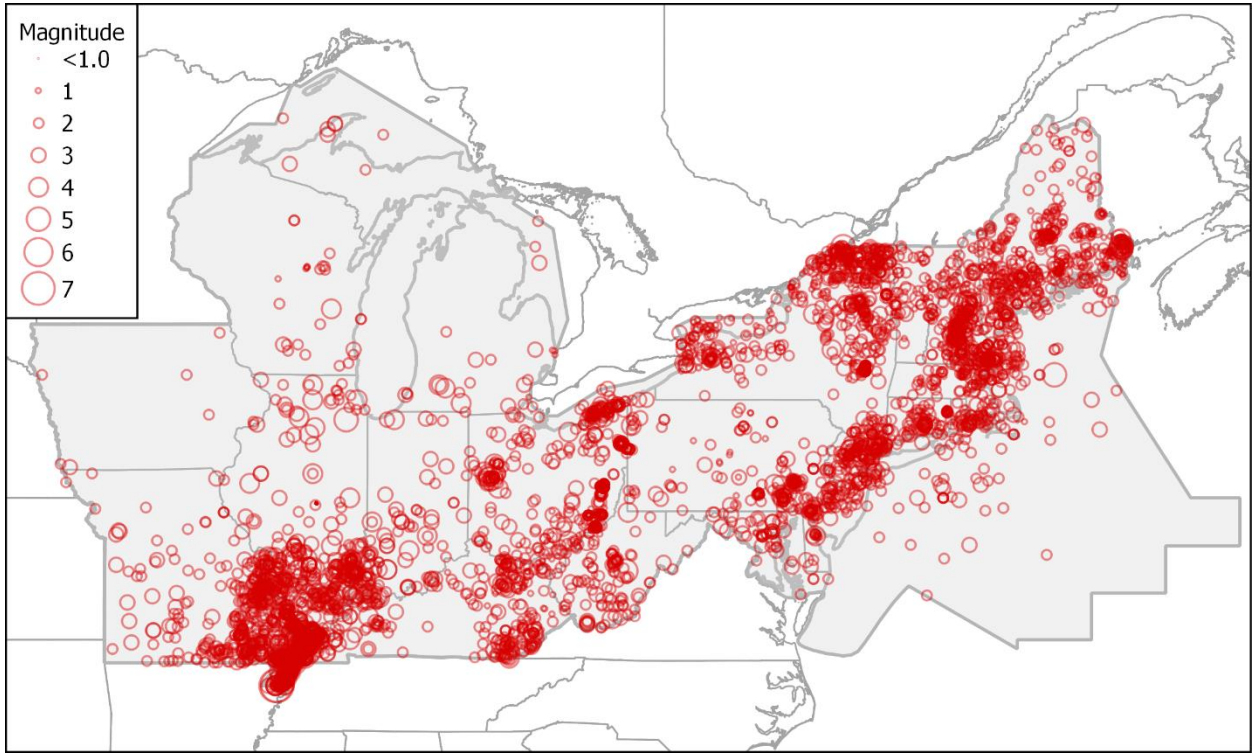
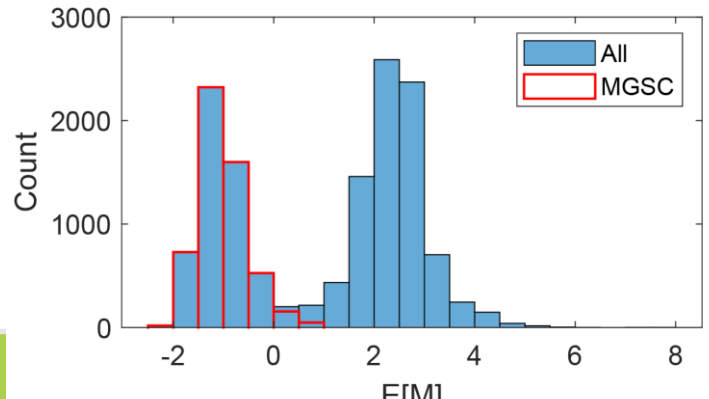
MRCI Earthquake Catalog

- A historical seismicity catalog containing a list of earthquakes that occurred in the MRCI study area from 1568 through 2020 was compiled from various sources of earthquake data.

Data source	Start year	End year	Na	Nm	N
ANF	2010	2015	6,615	71	61
CEA14	2012	2012	8	8	8
CEA18	2013	2015	74	74	73
CERI	2009	2020	7,166	1,900	1,846
GSC-NEDB	2009	2020	5,580	475	46
KEA18	2010	2018	13	13	13
KGS	2015	2020	222	155	93
LCI	1568	2019	13,048	4,658	3,645
MGSC	2011	2018	5,397	5,397	5,397
NESN	2009	2020	1,634	853	620
ODNR-ONET	2011	2020	907	907	886
ODNR-OSEIS	2009	2020	269	227	83
OIINK	2011	2015	277	129	105
PASEIS	2013	2020	61	61	33
SEA14	2011	2013	140	140	140
SEA15	2014	2014	69	69	69
SLU	2009	2020	80	24	0
SPREE	2012	2013	14	4	4
USGS-ANSS	2009	2020	9,410	2,775	441
USGS-NEIC	2009	2020	2,681	862	72
WES	2009	2014	664	342	1





Williams-Stroud, S., Bauer, R., Leetaru, H., Oye, V., Stanek, F., Greenberg, S. and Langet, N., 2020. Analysis of microseismicity and reactivated fault size to assess the potential for felt events by CO_2 injection in the Illinois Basin. Bulletin of the Seismological Society of America, 110(5), pp.2188-2204.

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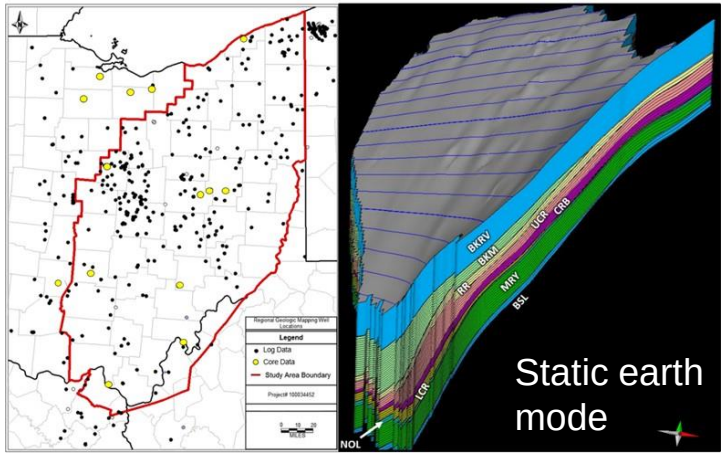
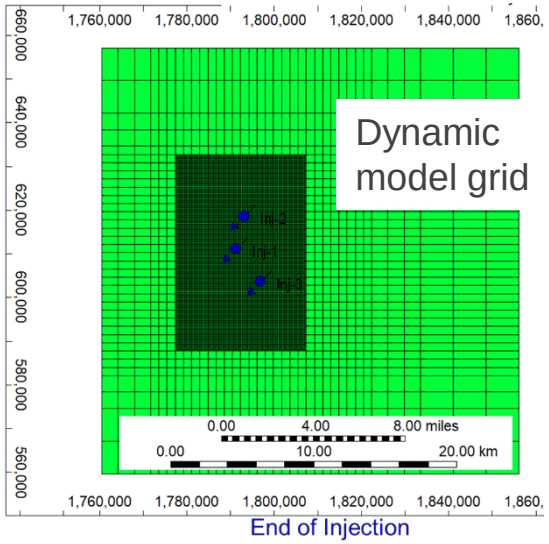
Storage Feasibility Analysis

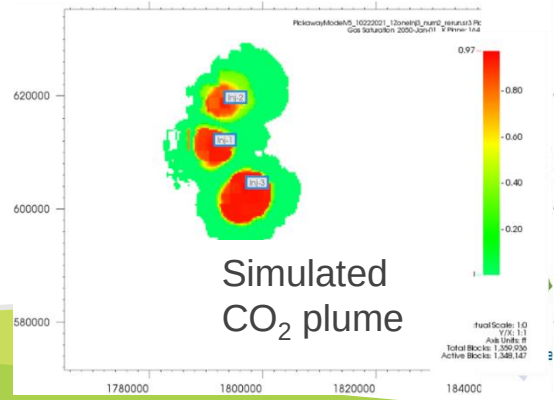
Objective #3

- Objective was to evaluate the feasibility of commercial-scale (≥1 MMT for 30 years) CO_2 storage in different CS systems in the MRCI region and to illustrate a process for assessing storage feasibility
- Method – 3D static and dynamic numerical models were constructed for selected CS systems/formations to simulate commercial-scale CO_2 injection to determine
  - Number of injection wells/spacing
  - CO_2 plume and pressure area
- Modeling software included Petrel for static earth models and CMG-GEM for dynamic reservoir models
- Models were constructed for 3 CS systems/formations
- 2 additional CS systems/formations were evaluated using previous modeling by ISGS

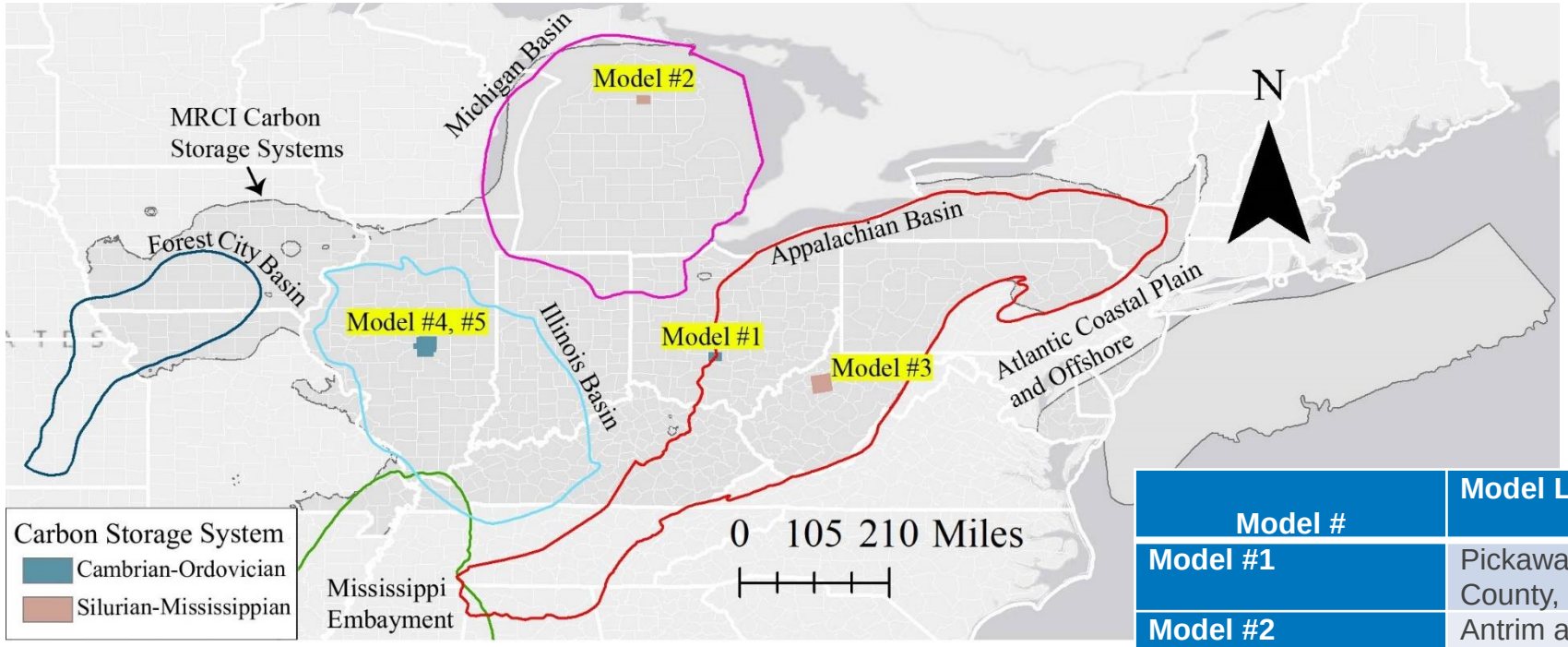




End of Injection



Model Sites for Storage Feasibility Analysis

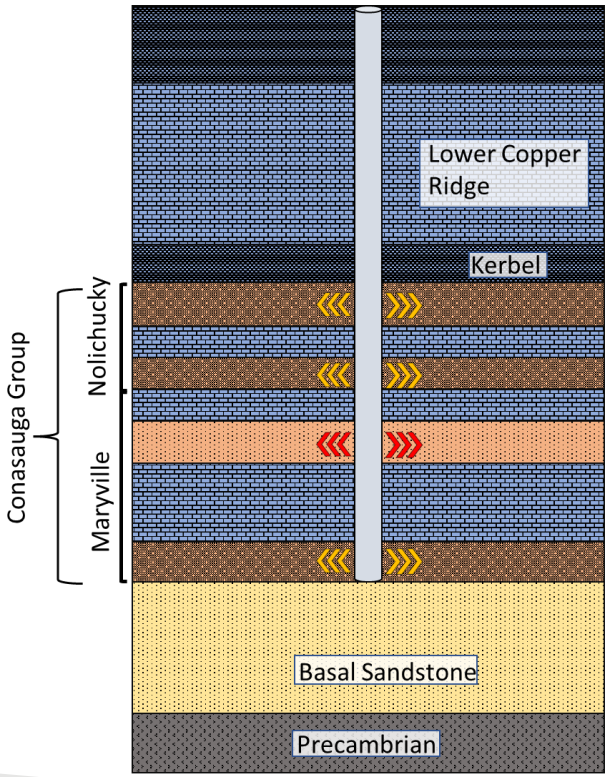


Model #	Model Location	Carbon Storage System	Formations of Interest
Model #1	Pickaway County, Ohio	Cambrian-Ordovician	Maryville
Model #2	Antrim and Otsego Counties, Michigan	Silurian-Mississippian	Bass Islands Dolomite, Bois Blanc
Model #3	Tri-State Area (Gilmer, Ritchie, Doddridge Counties, WVa)	Silurian-Mississippian	Oriskany Sandstone
Model #4 (Will et al., 2014)	Macon County, Illinois	Cambrian-Ordovician	St. Peter Sandstone
Model #5 (Smith and Adushita, 2014)	Macon County, Illinois	Cambrian-Ordovician	Potosi

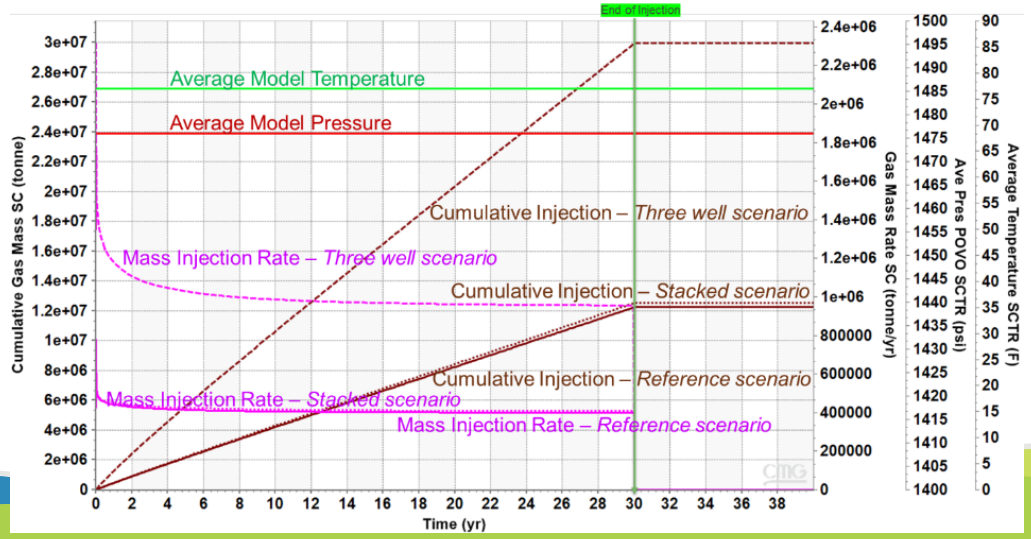
Model #1 – Cambrian Ordovician CS System, Pickaway County Ohio

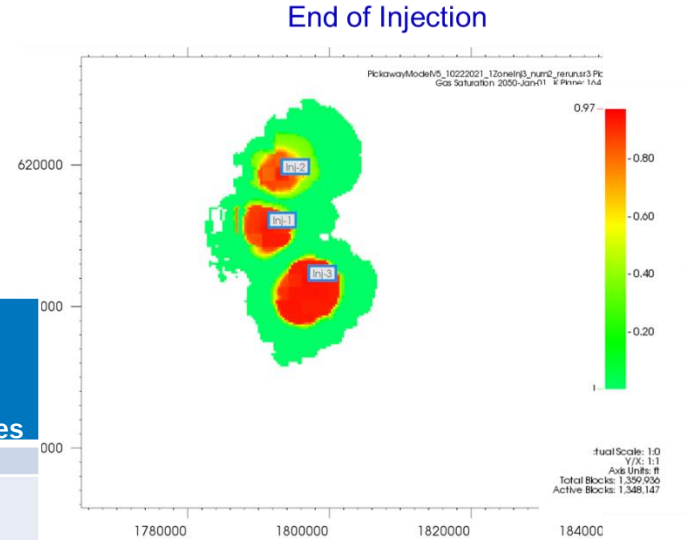
Results indicate that the Maryville Formation in Pickaway County offers a *potentially viable* commercial-scale target for CO_2 sequestration if three or more injection wells are used.

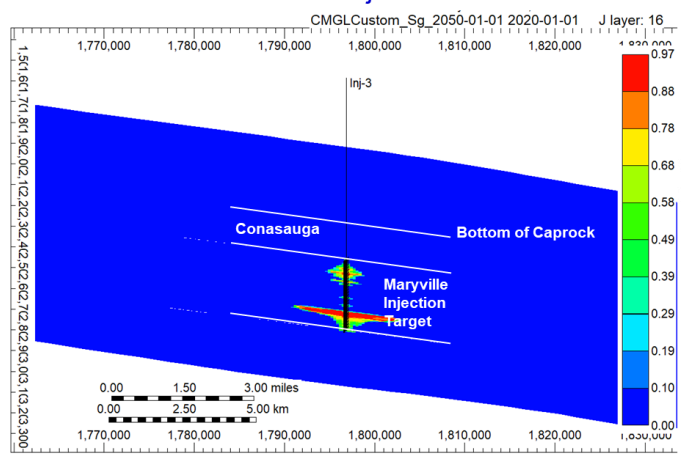
Stacked scenario did not significantly increase injectivity.



Scenario Name	Target Injection Zone(s)	Target Injection Model Layers	Number of Injection Wells	Cumulative CO_2 injected, MMT	Maximum plume radius at end of injection, miles
Reference	Maryville	103-179	1	*12.24*	*1.1*
Stacked	Upper Conasauga, Conasauga sandy facies, Maryville sandy facies, Maryville basal transition	73-85, 95-102, 113-131, 160-179	1	*12.53*	*1.5*
Three well	Maryville	103-179	3	*30*	*3.5*







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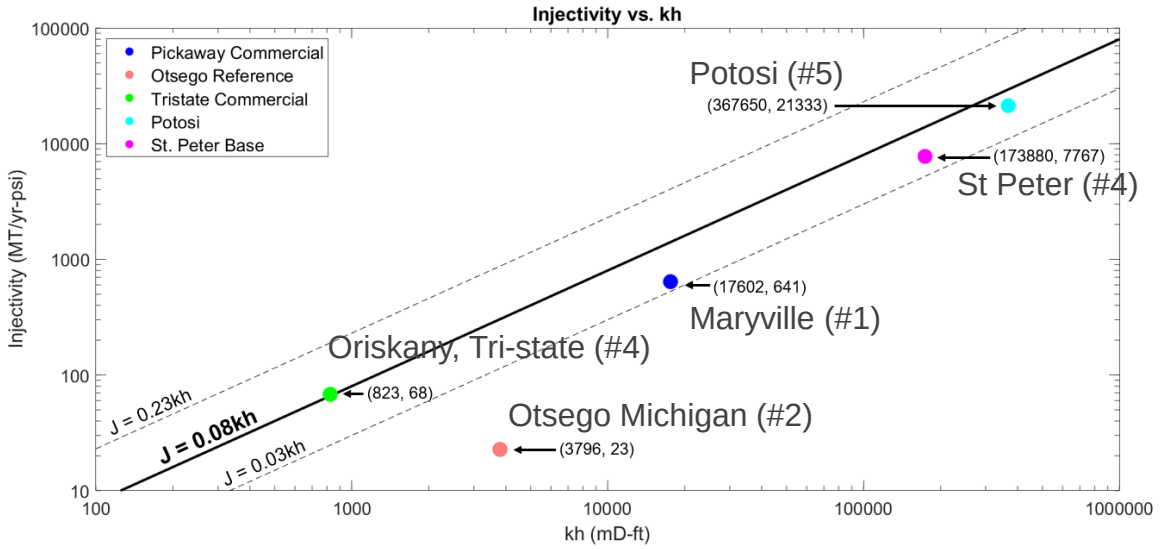
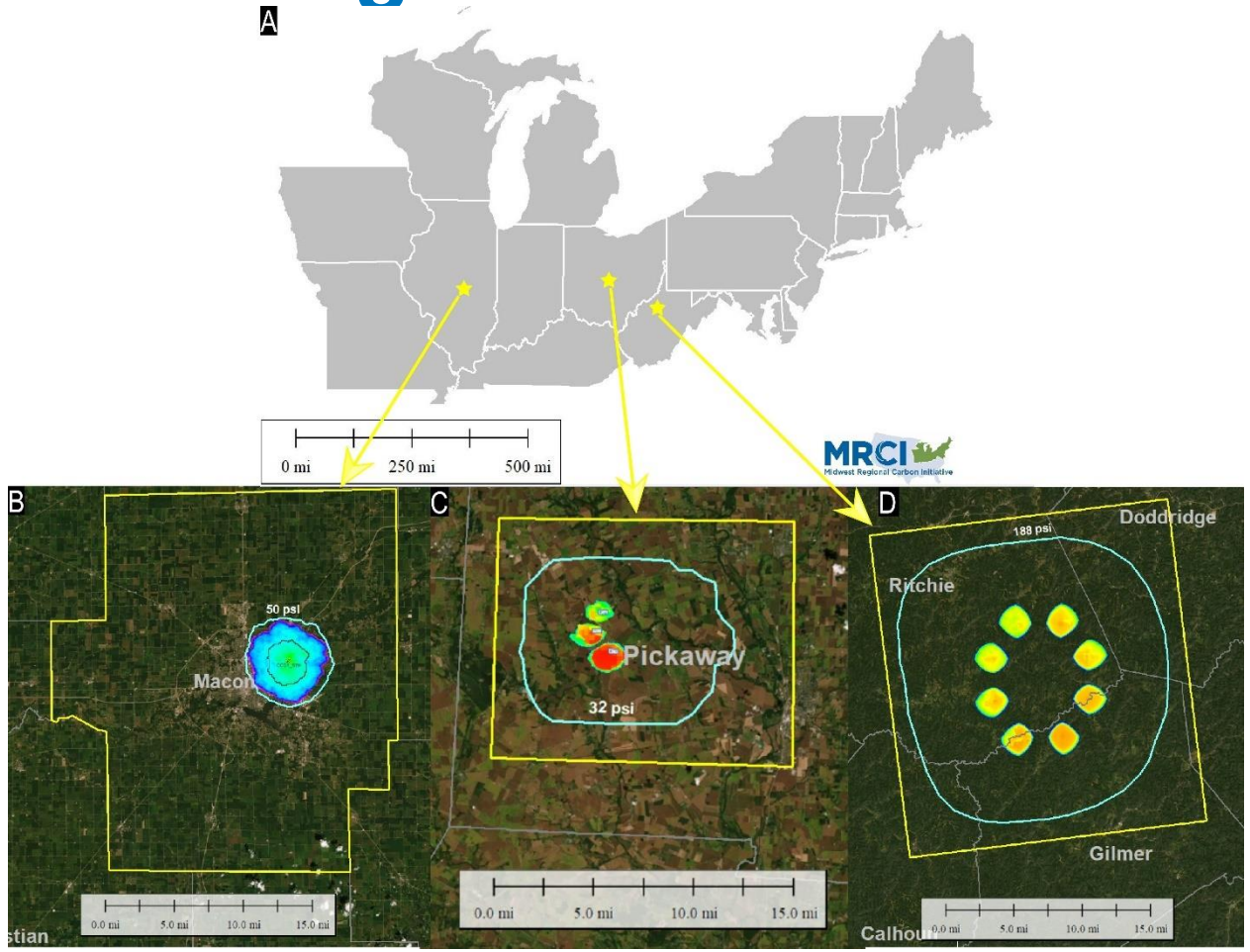
Comparison of Injectivity Modeling Results



Comparison of Calculated Injectivity Index for 5 model sites. Note that Otsego Reference scenario only includes the Bass Island Fm., which by itself did not achieve commercial-scale injection.



Comparison of modeled CO_2 plume(s) and areas with increased pressure for 4 model sites (Otsego Michigan Model Site #2 not shown)

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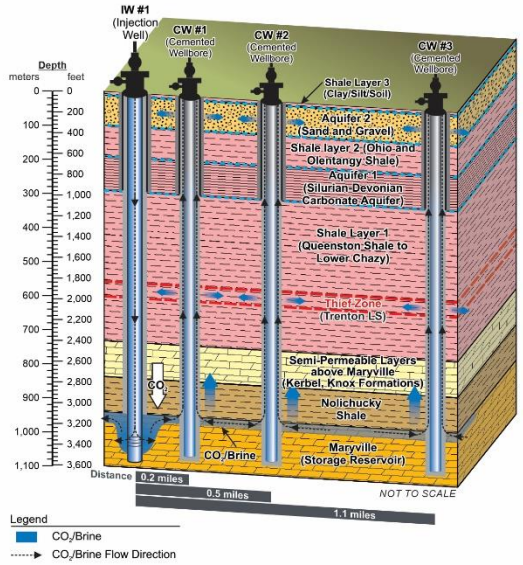
Assessing Containment Risks for Different CS Systems

Objective #4

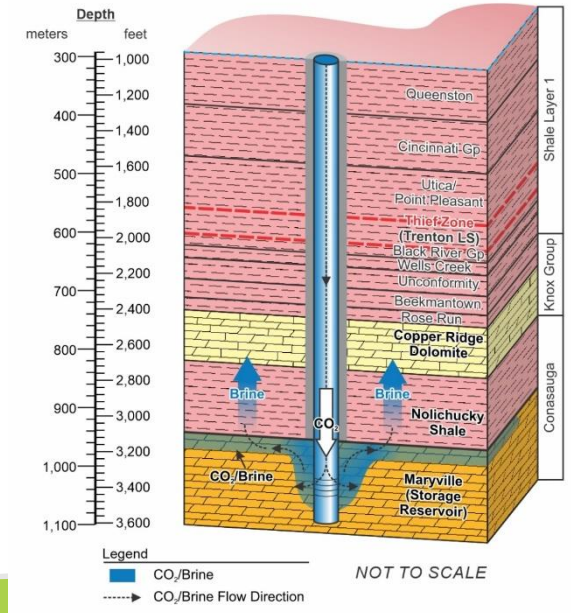
- Objective – evaluate feasibility of DOE NRAP Reduced Order Models (ROMs) for assessing containment risks at CO_2 storage sites

- Methodology – evaluate two primary leakage pathways:
  - Leakage along cemented wellbore (NRAP-OPEN-IAM)
  - Leakage across unfractured caprock (NRAP OPEN-IAM Seal Horizon component)

Note: The Seal Horizon mode did not produce valid results, so the 3D GEM model(s) were used to evaluate the caprock leakage pathway.



Conceptual diagram for leakage along cemented wells



Conceptual diagram for leakage across caprock

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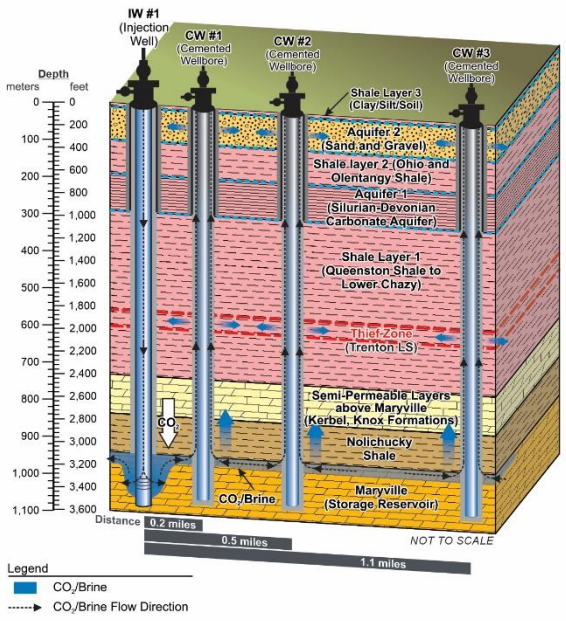
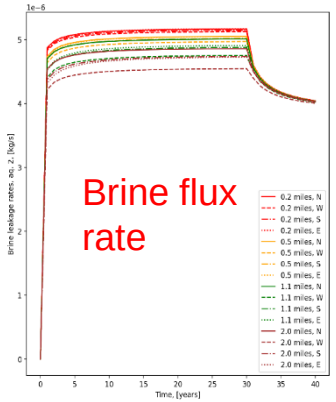
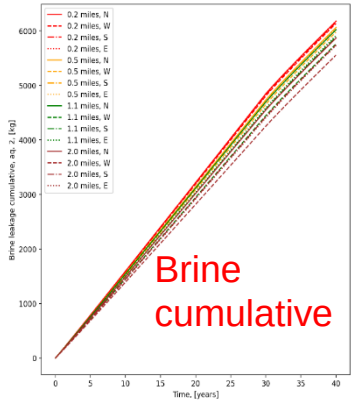
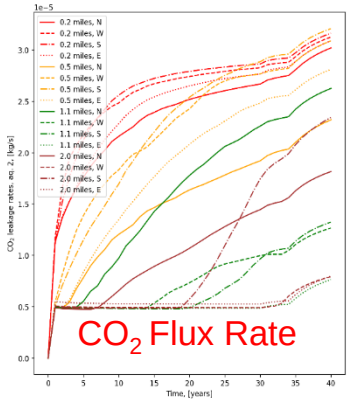
Modeling Cemented Wellbore Leakage Pathway

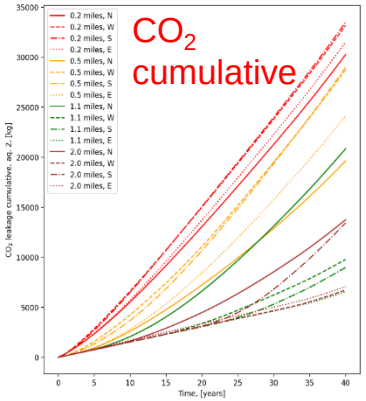
Example Cemented Wellbore leakage results for the Pickaway County Site





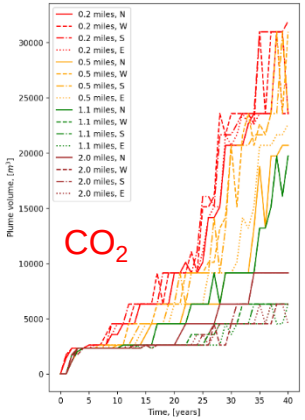


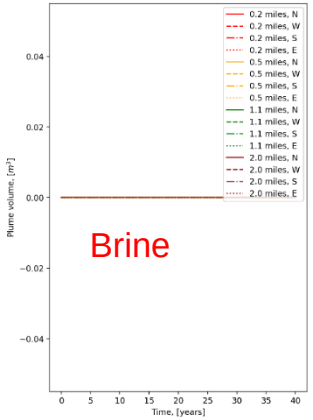




Rate (left) of brine (top) and CO_2 (bottom) leakage and cumulative mass leaked (right) into shallow Aquifer via hypothetical cemented wells at various distances from the injection well.

Volume of Aquifer Impacted





Volume of CO_2 plume (left) and brine plume (right) above threshold concentrations in shallow Aquifer via cemented wellbore leakage (brine does not exceed threshold).

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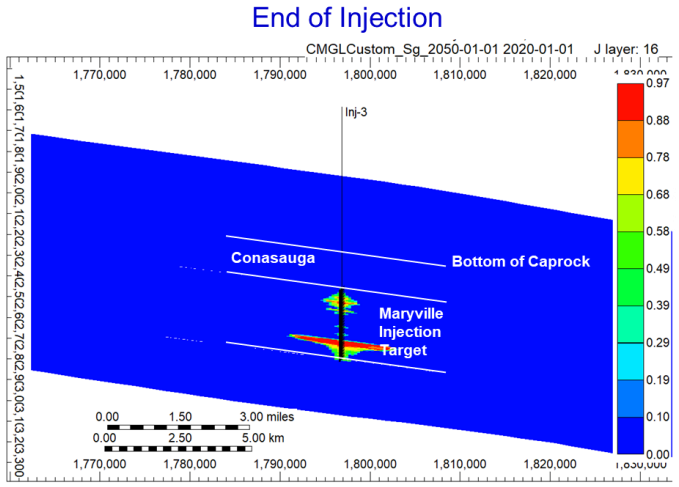
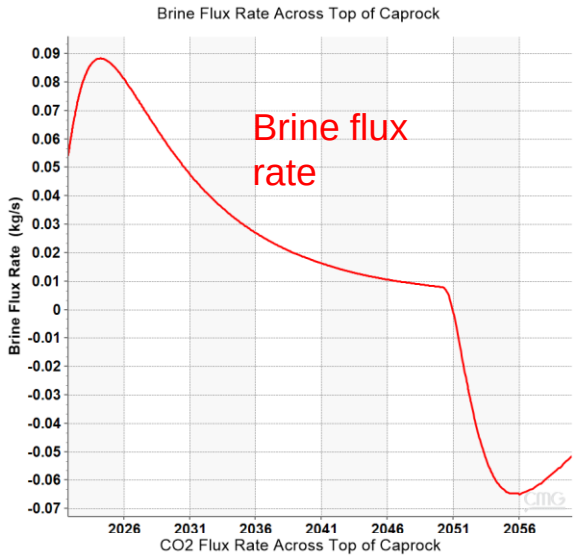
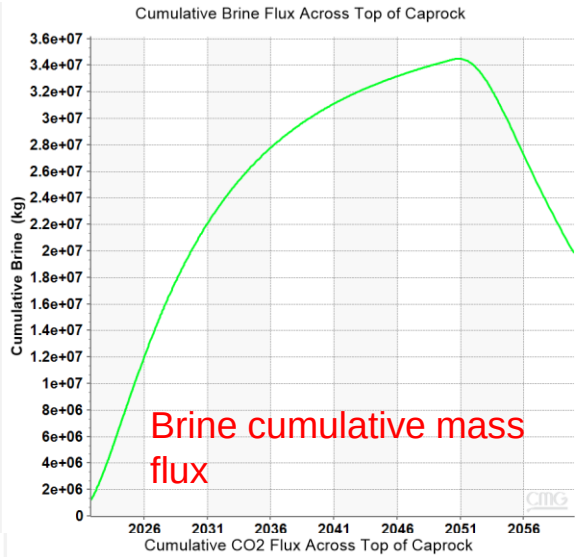
Modeling Caprock Leakage Pathway

Example Caprock leakage results for the Pickaway County Site

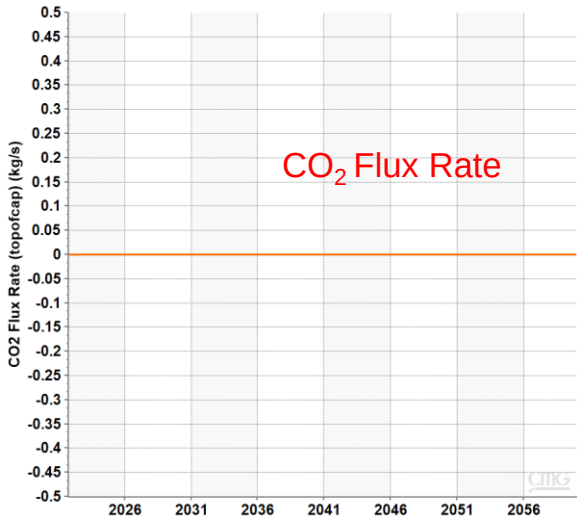


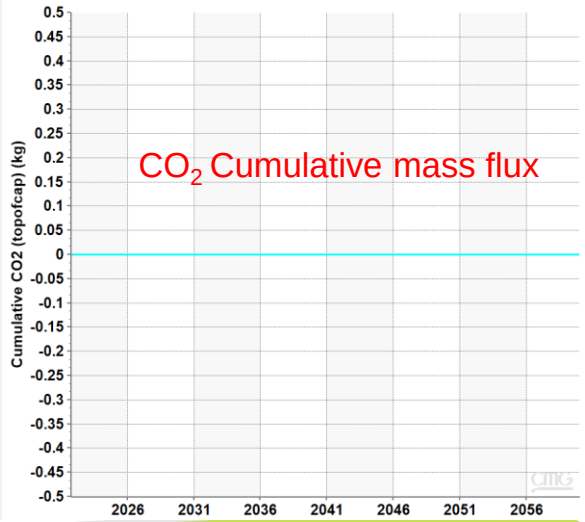
CO_2 plume at end of injection period showing top of CO_2 does not reach base of caprock





Brine mass flux rate (left) and cumulative brine mass (right) across top of caprock.





CO_2 mass flux rate (left) and cumulative CO_2 mass (right) across top of caprock.

MRCI Midwest Regional Carbon Initiative

Collaboration with NRAP

Battelle collaborated with NRAP software developers:

- Veronika Vasylkivska of NETL
- Ernest Lindner of NETL
- Bailian Chen and Michelle Bourret of LANL
- Diana Bacon of PNNL

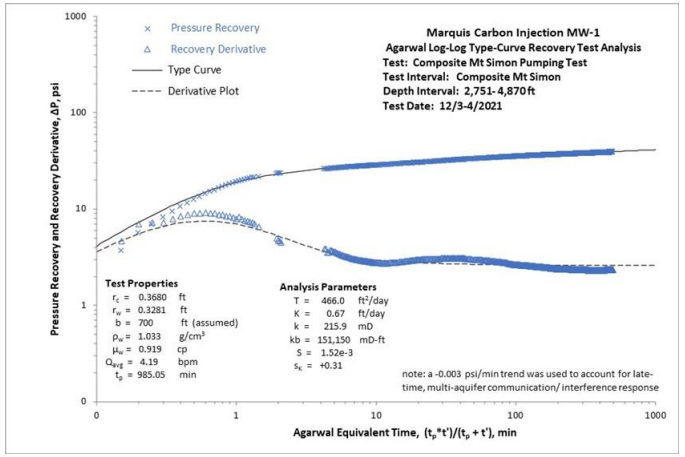
Various NRAP tools were evaluated, including:

- Open-IAM Software for Cemented Wellbore leakage
- Seal Horizon component for caprock leakage
- Custom Cemented Wellbore component
- Generic Aquifer component
- Seal Flux and Seal FracX Software (leakage through fractured caprock)
- Python scripts developed for various NRAP component models for each modeling sites

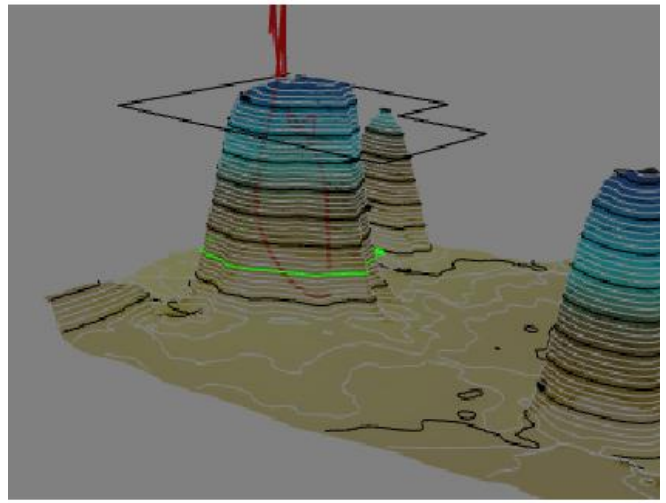
Facilitating Industrial Partnership and Technical Collaboration

Objective #5

- Geo-characterization data from test well for proposed Class VI UIC well in NW Illinois was shared by Marquis (Ethanol Producer in NW Illinois)
  - Geophysical log data
  - Hydraulic Injection fall-off tests
  - Geomechanical tests
  - Core data
  - Fluid geochemistry
  - 3D Seismic
  - Etc
- Data provide important “data point” for Mt Simon/Eau Claire storage complex



- Data from new geophysical logs acquired in Chester 16 reef during CO_2-EOR were shared by Core Energy (CO_2-EOR Producer in N. Michigan)
  - data will help refine understanding of porosity distribution and CO_2 behavior in the Northern Michigan reefs reefs which represent a significant CO_2 storage resource



Task 2 Presentations and Publications

Information Dissemination

Carpenter, N.S., Schmidt, J.P., Kelley, M.E., Greb, S.F., Wang, Z.W., 2022. Developing a Baseline Seismicity Catalog in the North-Central and Northeastern U.S. to Assist with CCUS Deployment, *in* 2022 GSA Joint Northcentral – Southeastern Section, April 7-8, 2022, Cincinnati, OH: Geological Society of America Northcentral – Southeastern Section Annual Meeting, vol. 54, no. 4, p. 23. (Presentation)

Conner, A., Kelley, M. , Ravi-Ganesh, P., Haagsma, A., Gupta, N. , Greenburg, S., Leetaru, H. , Greb, S., Moore, J., Carter, K., Harrison, W., Developing a Regional Framework to Define and Assess CO_2 Storage Systems in the Midwestern to Northeastern United States, Mar. 2022, AAPG CCUS 2022 Conference Houston, Texas (Poster)

Conner, A., Kelley, M., Ravi-Ganesh, P., Haagsma, A., Gupta, N., Greenberg, S., Leetaru, H., Greb, S., Moore, J., Carter, K., Harrison, W., Assessing Multi-State CO_2 Storage Systems in the Midwestern to Northeastern United States - Southeastern Section, April 7-8, 2022, Cincinnati, OH: Geological Society of America Northcentral – Southeastern Section Annual Meeting, vol. 54, no. 4, p. 23. (Presentation)

Conner, A., Kelley, M., Haagsma, A., Ravi-Ganesh, P., Gupta, N. , Greenberg, S., Leetaru, H. , Greb, S., Moore, J., Carter, K., Harrison, W., Assessment of Storage Systems in the Midwest-Northeastern United States for Large-Scale CCUS Projects - 16th International Conference on Greenhouse Gas Control Technologies GHGT-16. 23-27th October 2022, Lyon, France (Poster)

Hulett, Samuel, and McDonald, James, 2022, CO2 solubility in the Silurian “Clinton/Medina” Sandstone – Multi-element modeling and implications for carbon storage, *in* 2022 GSA Joint Northcentral – Southeastern Section, April 7-8, 2022, Cincinnati, OH: Geological Society of America Northcentral – Southeastern Section Annual Meeting, vol. 54, no. 4, p. 23. (Presentation)

McDonald, James, Waid, C.B.T., Solis, M.P., Hulett, S.R.W., and Danielsen, E.M., 2022, Regional characterization of the Utica Shale/Point Pleasant Formation for enhanced oil recovery, *in* 2022 GSA Joint Northcentral – Southeastern Section, April 7-8, 2022, Cincinnati, OH: Geological Society of America Northcentral – Southeastern Section Annual Meeting, vol. 54, no. 4, p. 16. (Presentation)

Skopec, S., Haagsma, A., Ravi Ganesh, P., Kelley, M., Conner, A., Mawalkar, S., Screening Assessment of the Oriskany Sandstone in Northern West Virginia for Hosting a Commercial-Scale CO_2 Injection Site, Aug. 2022, AAPG/SEG IMAGE Conference, Houston, TX.

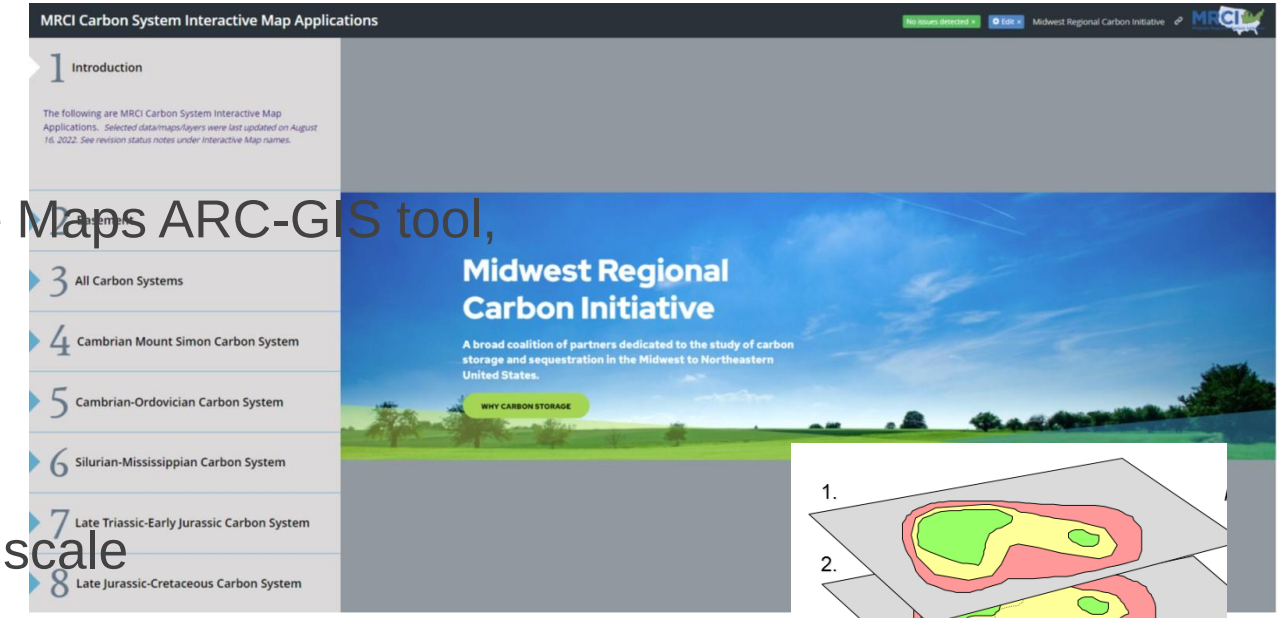
Skopec, S., Mawalkar, S., Vasylkivska, V., Ravi Ganesh, P., Haagsma, A., Kelley, M., Risk Assessment of Carbon Storage at Potential Midwest Regional Carbon Initiative (MRCI) Sites Using NRAP Open-IAM Component Models, Aug. 2022, AAPG/SEG IMAGE Conference, Houston, TX.

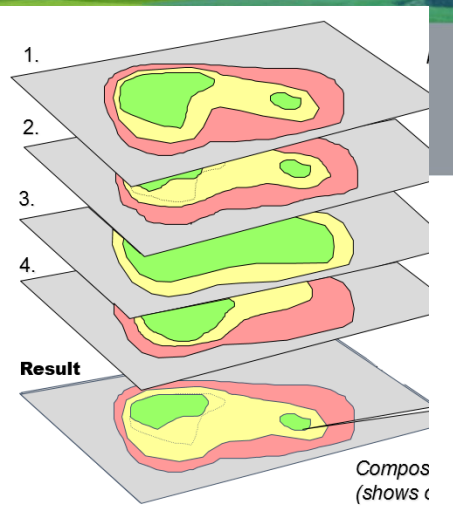
Haagsma, A., Skopec, S., Conner, A., Ravi Ganesh, P., Kelley, M., Developing 3D Static Earth Models to Represent CO_2 Storage Systems in the Midwestern United States, Apr. 2022, GSA 2022 Joint North-Central & Southeastern Section Meeting (Presentation)

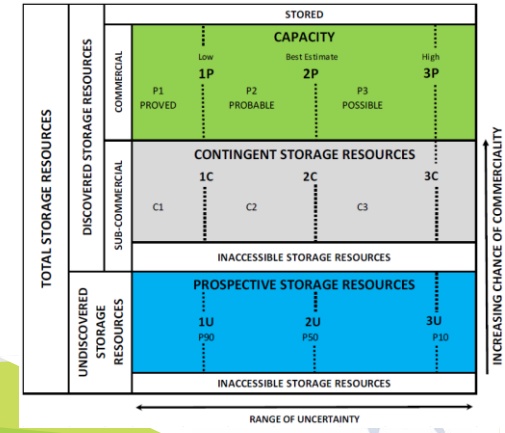
Wong, I., Carpenter, S., Kelley, M., Bubeck, A., Schmidt, P., Wu, Q. Wang, Z., Greb, S., Sparks, T. and N. Lewandowski (2022). Towards large-scale characterization of induced seismicity potential and its impacts for CCUS in the central and eastern U.S. 16th International Conference on Greenhouse Gas Control Technologies **GHGT-16.** 23-27th October 2022, Lyon, France

Future Work in BP-2

- Continue to develop/expand the MRCI Interactive Maps ARC-GIS tool, e.g.:
  - Compile/add rock property data
  - Develop new regional maps where possible
- Evaluate induced seismicity potential on regional scale
- Evaluate commercial-scale storage feasibility for additional CS systems and evaluate “hub-scale” storage feasibility
- Continue to collaborate with NRAP software developers to facilitate applicability of NRAP models to broader range of site conditions
- Evaluate NRAP software for other leakage pathway risks (fractured caprock)
- Apply SRMS methodology across the region
- Evaluate CO_2 storage needs/resources to support DAC and Hydrogen production in the MRCI region.







Closing Remark

- The charter of the MRCI program is to support/expedite the development of the CCS/CCUS industry in the 20-state study area.
- We are achieving this objective by compiling essential geologic information needed by CCS/CCUS project developers into maps, databases, modeling analyses, and other information resources.
- If you are a project developer, please feel free to contact us to better understand how these studies apply to your project specifically.


MRCI
Midwest Regional Carbon Initiative