CO_2 Storage Resource and Reservoir Feasibility Assessment for Deep Saline Cambrian-Ordovician Formations in Eastern Ohio

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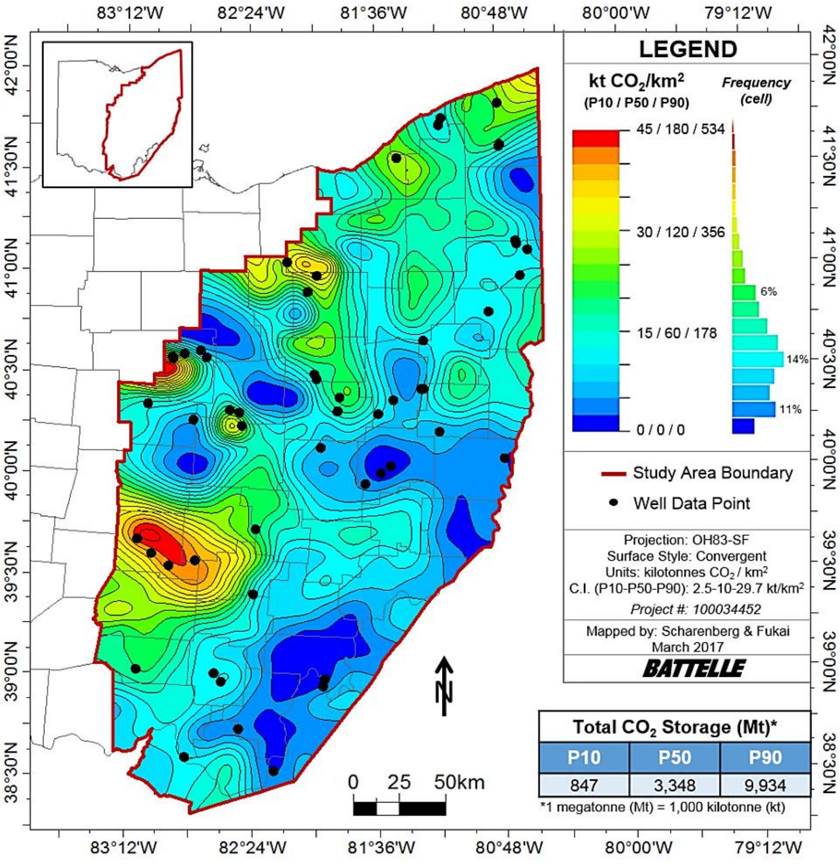

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Carbon Management Technology Conference

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Ohio | Development Services Agency

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Project Overview

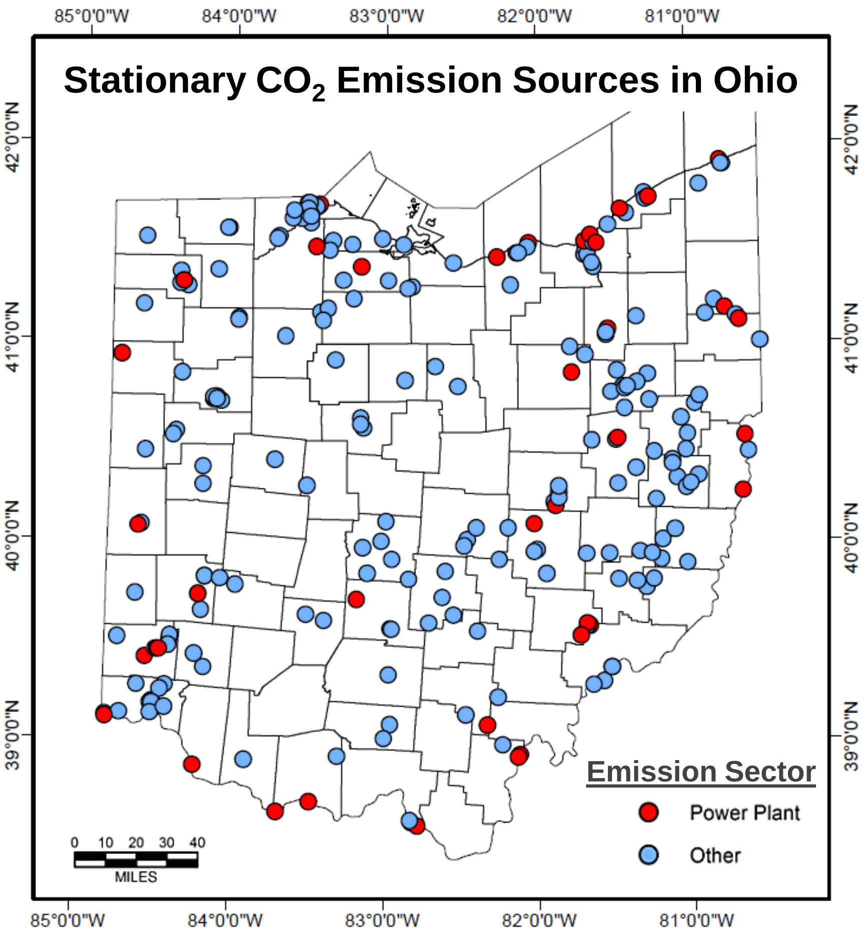
Problem

- Ohio responsible for ~25% of total CO_2 emissions reported in the United States[1]
- Geologic resources available in-state for CO_2 storage & climate change mitigation not well defined

Objective

Characterize deep saline formations & overlying caprocks to help define geologic storage framework for OH

1. Based on 2015 emissions reported to EPA GHGRP (2016)



Map showing the locations of stationary CO_2 emission sources in Ohio (EPA GHGRP, 2016; Battelle, 2017). Total reported 2015 emissions: 113 megatonnes CO_2

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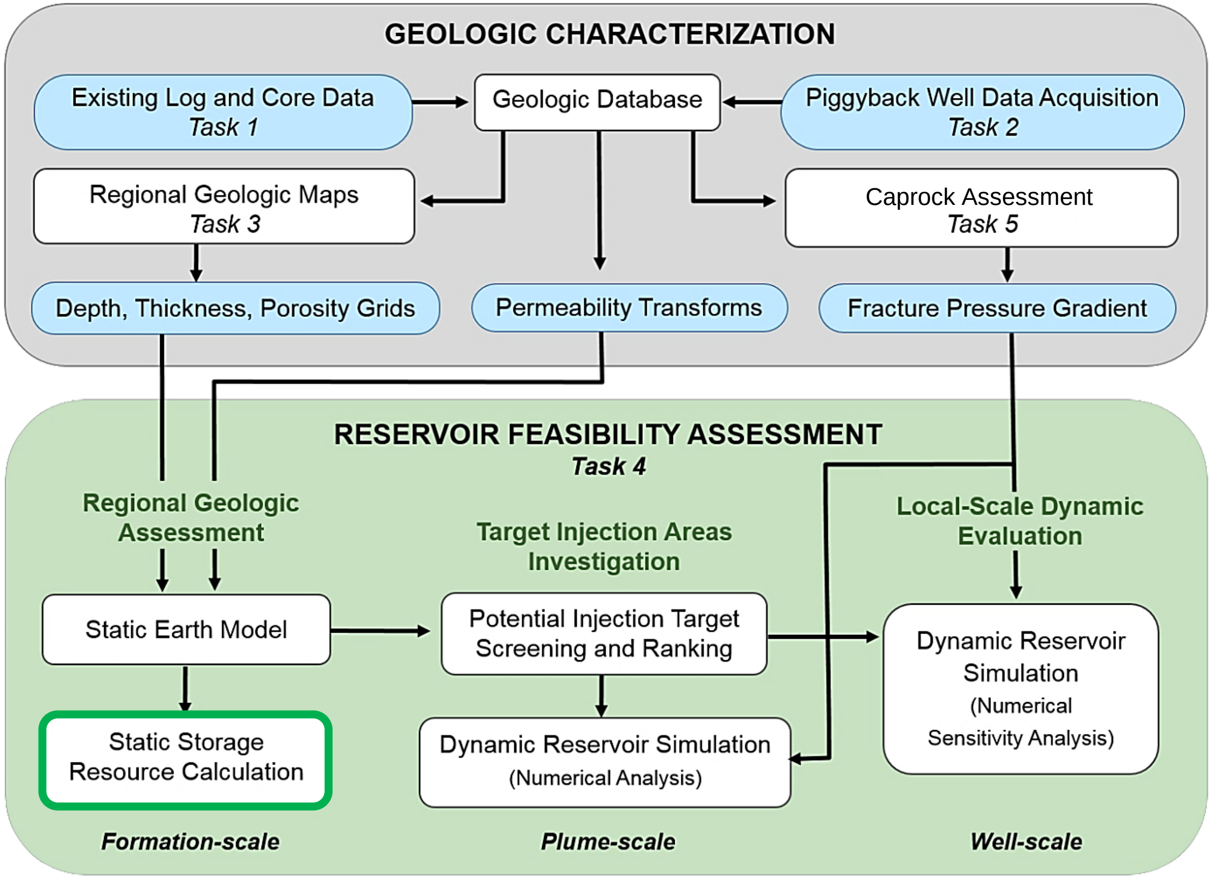
Project Overview: Organization & Approach

Project divided into five main tasks

Focus: Static Storage Resource Assessment

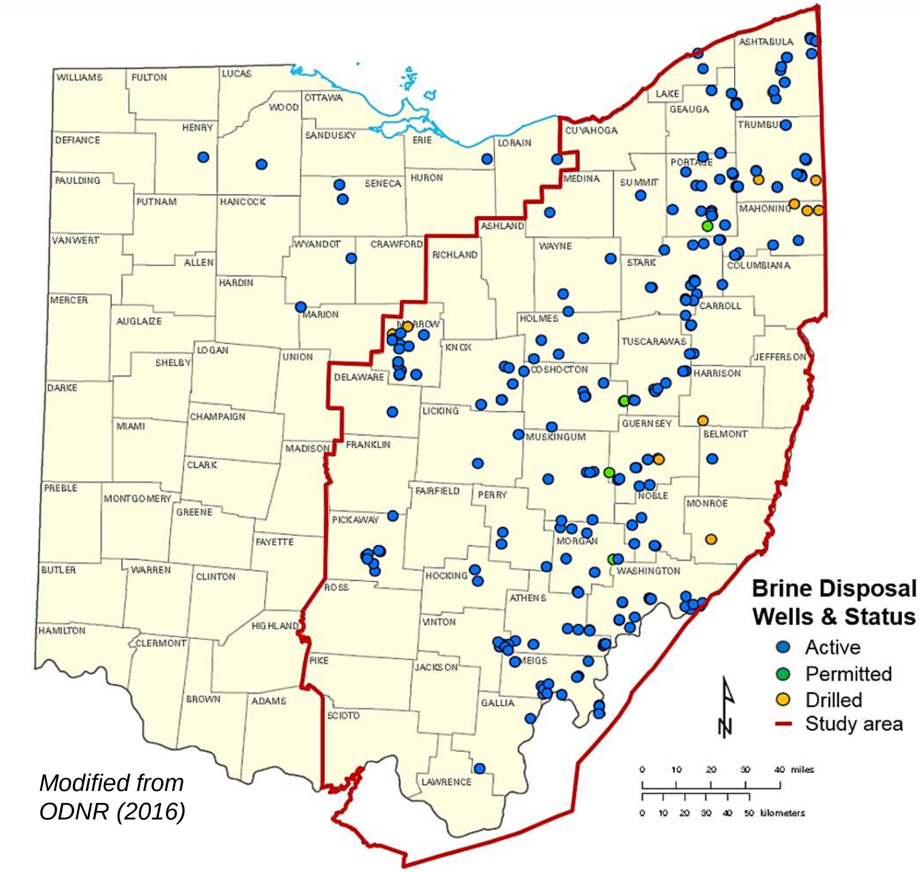
Formation-scale evaluation

Component of Reservoir Feasibility Analysis

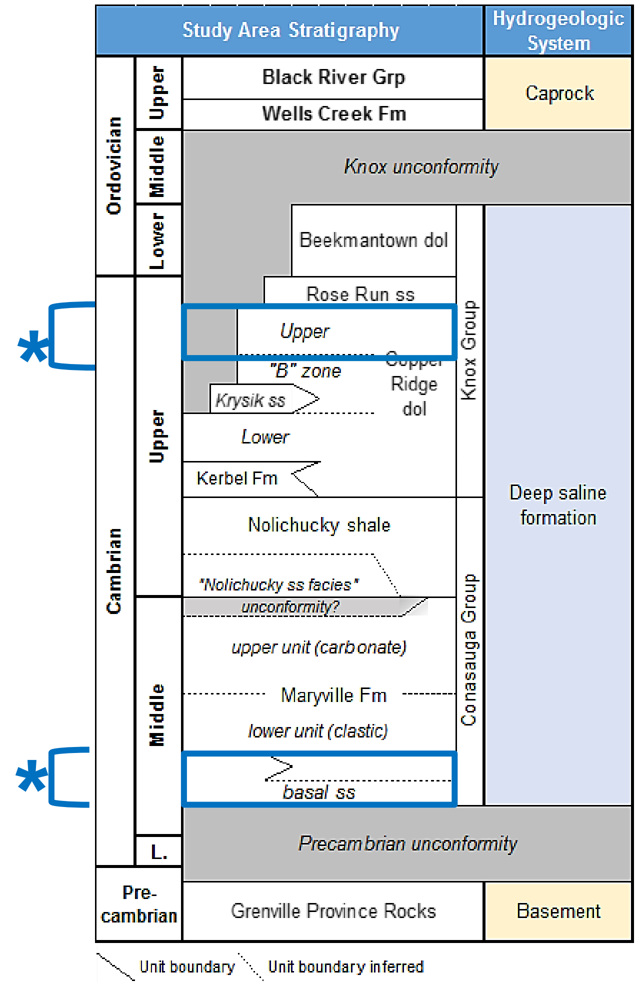


Schematic showing overall project approach and task organization, with an emphasis on components of the Reservoir Feasibility Assessment (Battelle, 2017).

Study Area & Formations of Interest



Study Area: 23,643 mi^2 (61,236 km^2) area in eastern Ohio comprising corridor of brine disposal wells



Saline formations (reservoirs): brine-saturated sandstones and dolomites

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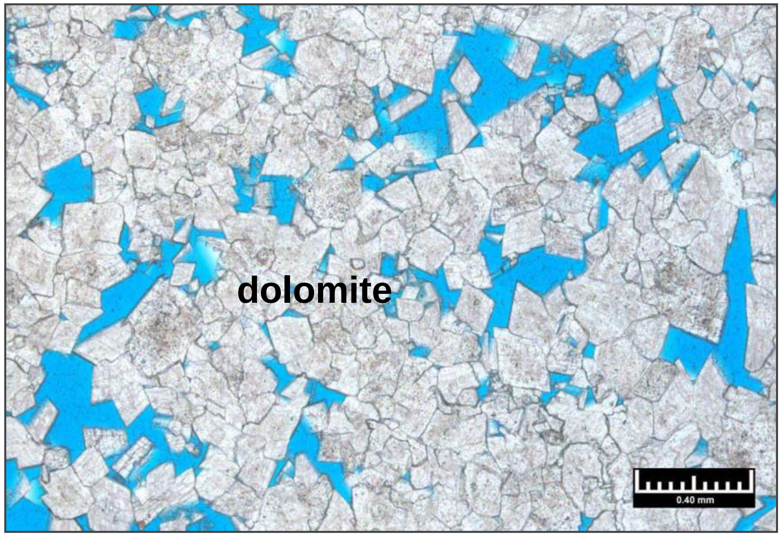
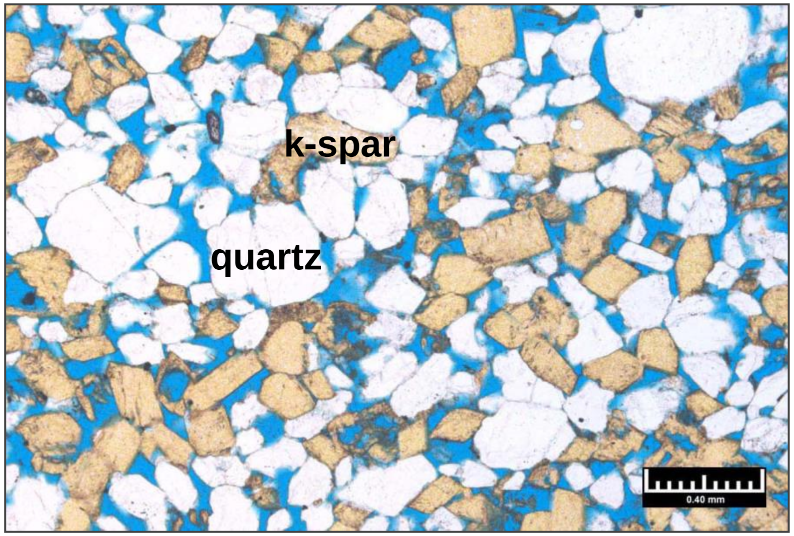
Formations of Interest

Upper Copper Ridge Dolomite



Thin-section photomicrograph in plane-polarized light showing an Upper Copper Ridge dolomite sample from the south-central portion of the study area (blue: porosity).

Basal Cambrian Sandstone



Thin-section photomicrograph in plane-polarized light showing a basal Cambrian sandstone sample from the south-central portion of the study area (blue: porosity).

Formation	Area (mi^2)*	Avg. Depth (ft.)	Avg. Gross Thickness (ft.)	Avg. Porosity (%)
Upper Copper Ridge dolomite	23,643	5,157	184	5
basal Cambrian sandstone	23,643	5,834	131	8

* Specific to the eastern Ohio study area

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Static Storage Resource Assessment

Static (volumetric) method: Uses subsurface pore volumes & in-situ fluid saturation to estimate an equivalent quantity of CO_2 that could potentially be stored

Total Pore Volume = **Theoretical Maximum Storage Resource**

↓ Storage Efficiency

Net Pore Volume = **Prospective Storage Resource**[1]

DOE-NETL Storage Resource Equation[1]

$$G_{CO2} = A_t \, h_g \, \phi_t \, \rho_{CO2res} \, E_{saline}$$

G_{CO2}: Prospective Storage Resource

$A_t \, h_g \, \phi_t \, \rho_{CO2res}$: Theoretical Maximum Storage Resource

Parameter[1]	Definition
Total Area (A_t)	Total area of formation
Gross Thickness (h_g)	Gross formation thickness
Total Porosity (ϕ_t)	Total formation porosity (interconnected+isolated+clay-bound)
ρ_{CO2res}	Density of CO_2 at reservoir temperature and pressure
Storage Efficiency (E_{saline})	Fraction of pore volume that is technically accessible for CO_2 storage

1. DOE-NETL, 2010; 2012; Goodman et al., 2011; 2016

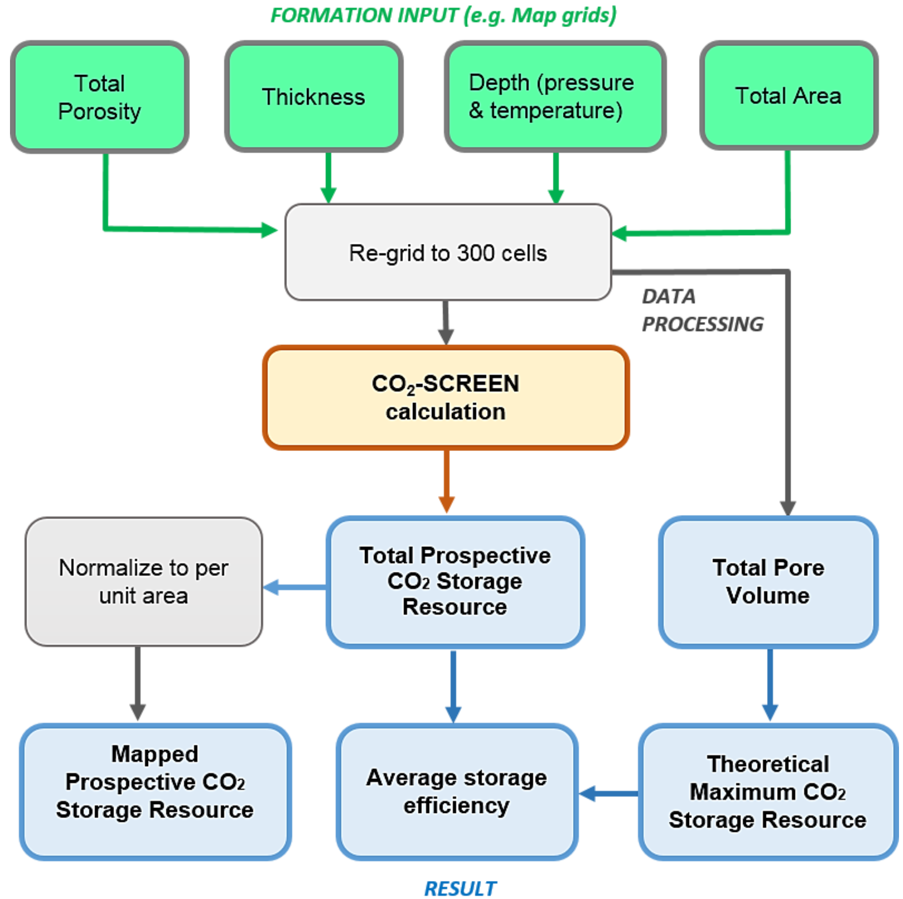
Static Storage Resource Calculation

Two grid-based methods:

1. Static Earth Model (SEM)
   (3D, high resolution, deterministic)
2. CO_2-SCREEN[1]
   (low resolution, stochastic)

Same input data used for both grid calculations

Results compared to assess effects of model resolution and calculation method on Storage Resource outcomes



Schematic showing the workflow for the CO_2-SCREEN calculation, with 2D maps grids from the SEM re-gridded to the required resolution and then used to calculate and map the Prospective Storage Resource (Battelle, 2017).

1. Sanguinito et al., 2016; https://edx.netl.doe.gov/organization/co2-screen.

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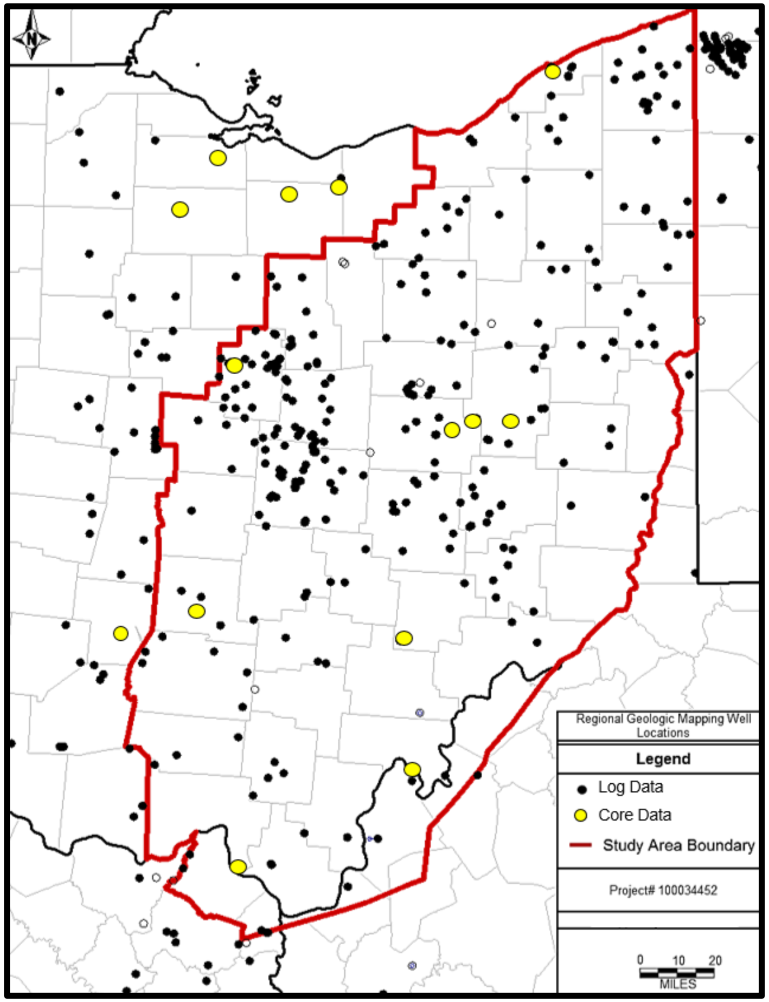
Static Storage Resource Calculations: Data Input

New and existing data compiled in previous tasks

- Well logs from 413 wells in the study region: basic and advanced wireline logs
- Core data from ~15 wells

Data used to construct and populate Static Earth Model (SEM) for Storage Resource calculations



Locations of wells with log data and core data used to construct structure, thickness, and porosity maps for the formations of interest in the study area (Battelle, 2017).

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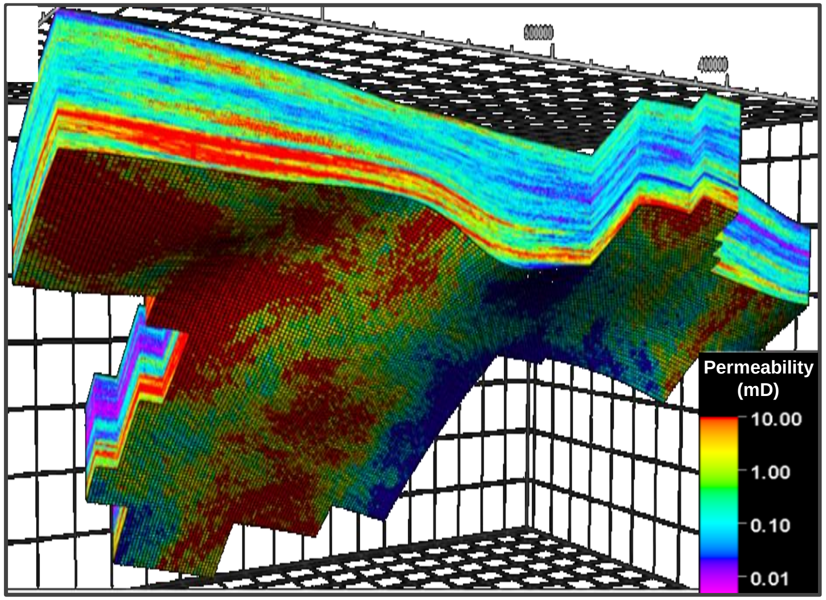
Static Storage Resource Calculation:
Static Earth Model (SEM)

SEM: 3D model of subsurface geology and pore volume for Cambrian-Ordovician deep saline formations in the study area

- Formation Structure
  (depth, thickness, lateral continuity)
- Petrophysical Properties
  (porosity, permeability)

2D map grids from SEM coarsened & used as input for CO_2-SCREEN



Portion of the SEM developed for the eastern OH study area clipped to show the basal Cambrian sandstone interval at a selected site. The entire SEM has a total of 145,413,098 grid cells with X-Y-Z dimensions of 1,875 x 1,875 x 3ft (Battelle, 2017).

CO_2 Storage Resource calculated deterministically directly in model using DOE-NETL equation & E_{saline} from CO_2-SCREEN

$$G_{CO2} = A_t \, h_g \, \phi_t \, \rho_{CO2res} \, E_{saline}$$

Prospective Storage Resource (G_{CO2})

Theoretical Maximum Storage Resource ($A_t \, h_g \, \phi_t \, \rho_{CO2res}$)

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Static Storage Resource Calculation: DOE-NETL CO_2-SCREEN Tool[1]

INPUT

Storage Efficiency Input	Auto-populated		User Specified		
	P_{10}	P_{90}	P_{10}	P_{90}	X_{10}
Net-to-Total Area	0.20	0.80	0	0	-1.39
Net-to-Gross Thickness	0.21	0.76	0	0	-1.32
Effective-to-Total Porosity	0.62	0.78	0	0	0.49
Volumetric Displacement	0.18	0.63	0	0	-1.52
Microscopic Displacement	0.39	0.82	0	0	-0.45

Physical Parameters

Mean and standard deviation values for each grid cell

Grid cell #	Area* (km^2)	Gross Thickness* (m)		Total Porosity*(%)	
	Mean	Mean	Std Dev	Mean	Std Dev
1	109.2	97.1	0.0	4.4	0.0
2	109.2	104.9	0.0	4.5	0.0
3	109.2	116.6	0.0	4.1	0.0
4	109.2	135.1	0.0	3.8	0.0
5	63.8	157.2	0.0	2.9	0.0
6	109.3	76.4	0.0	4.3	0.0
7	109.2	92.6	0.0	5.2	0.0
8	109.2	103.4	0.0	5.6	0.0
9	109.2	110.1	0.0	4.8	0.0
10	109.2	124.0	0.0	3.7	0.0

RESULTS

GCO_2 (Mt)			
Grid Cell #	P10	P50	P90
1	2.4	8.1	19.5
2	2.7	9.0	21.6
3	2.8	9.2	22.2
4	2.9	9.7	23.5
5	1.6	5.2	12.5
6	1.8	6.1	14.8
7	2.7	9.1	21.9
8	3.3	10.9	26.3
9	3.0	10.0	24.1
10	2.7	8.8	21.2

CO_2 Storage Statistics	P10	P50	P90	Units
Summed CO_2 Total	564	1873	4517	Mt
	0.6	1.9	4.5	Gt

- Grid-based input & results: 300 cells
- Storage Efficiency defaults[2]
- Probabilistic Prospective Storage Resource estimates: P10, P50, P90

1. Sanguinito et al., 2016; https://edx.netl.doe.gov/organization/co2-screen.
2. IEAGHG, 2009

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Storage Resource Results: Upper Copper Ridge Dolomite

Theoretical Maximum CO_2 Storage Resource

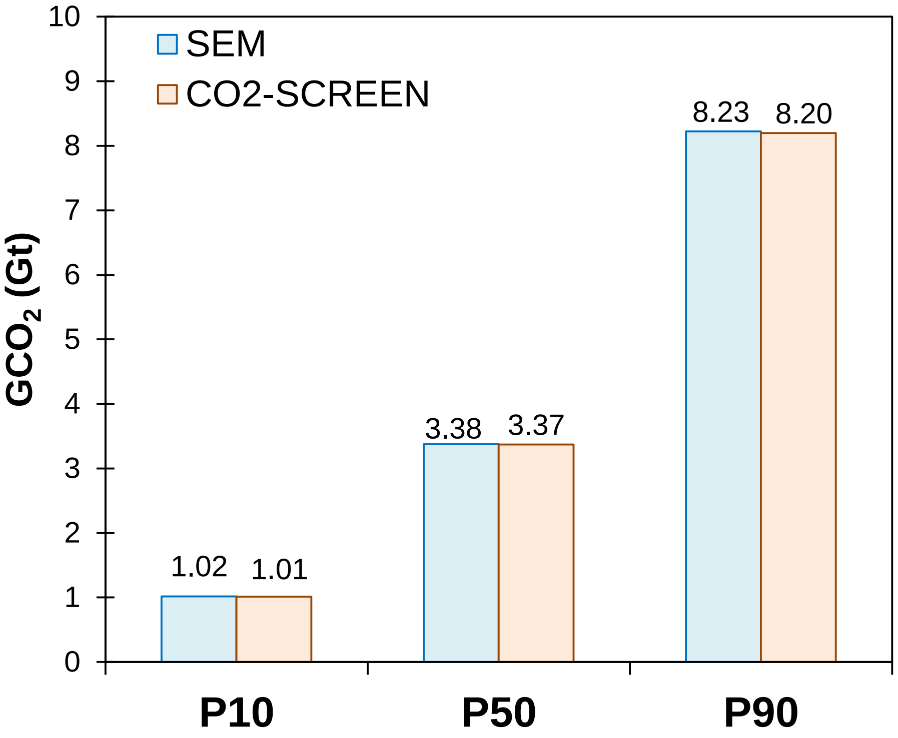
Total Pore Volume	195 km^3
Theoretical Maximum Storage Resource	155 Gt*

* Gt: gigatonnes: 10^9 tonnes

Storage Efficiency

E_{saline}		
P10	**P50**	**P90**
0.7%	2.2%	5.3%

Prospective CO_2 Storage Resource



Less than 1% difference between SEM and CO_2-SCREEN results

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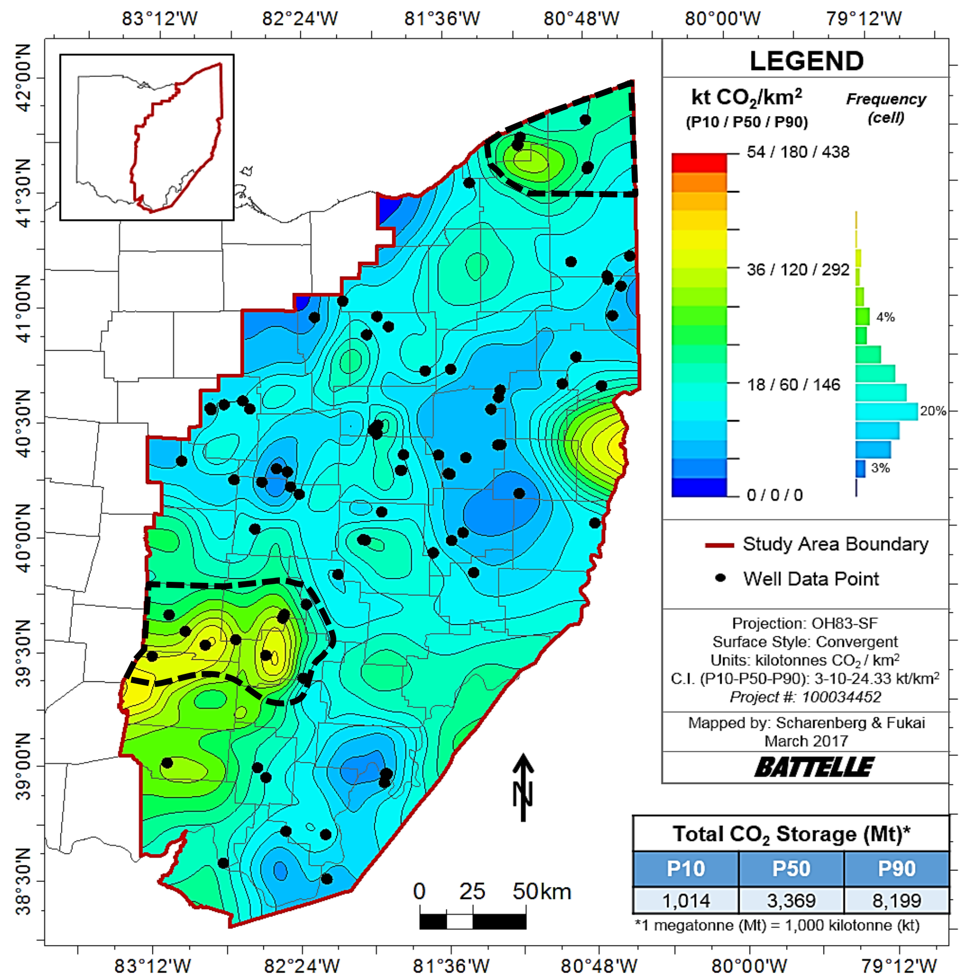
Storage Resource Results: Upper Copper Ridge Geospatial Analysis

Local Storage Resource Highs:

- Northeastern Ohio
  (Lake, Ashtabula counties)
- South-central Ohio
  (Pickaway, Fairfield, Hocking counties)

Areas are constrained by data from three or more wells within < 20 mi (32 km) distance



Right: Map showing the Prospective CO_2 Storage Resource (in kt/km^2) for the Upper Copper Ridge Dolomite in the eastern Ohio study area (Battelle, 2017).

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Storage Resource Results: Basal Cambrian Sandstone

Theoretical Maximum CO_2 Storage Resource

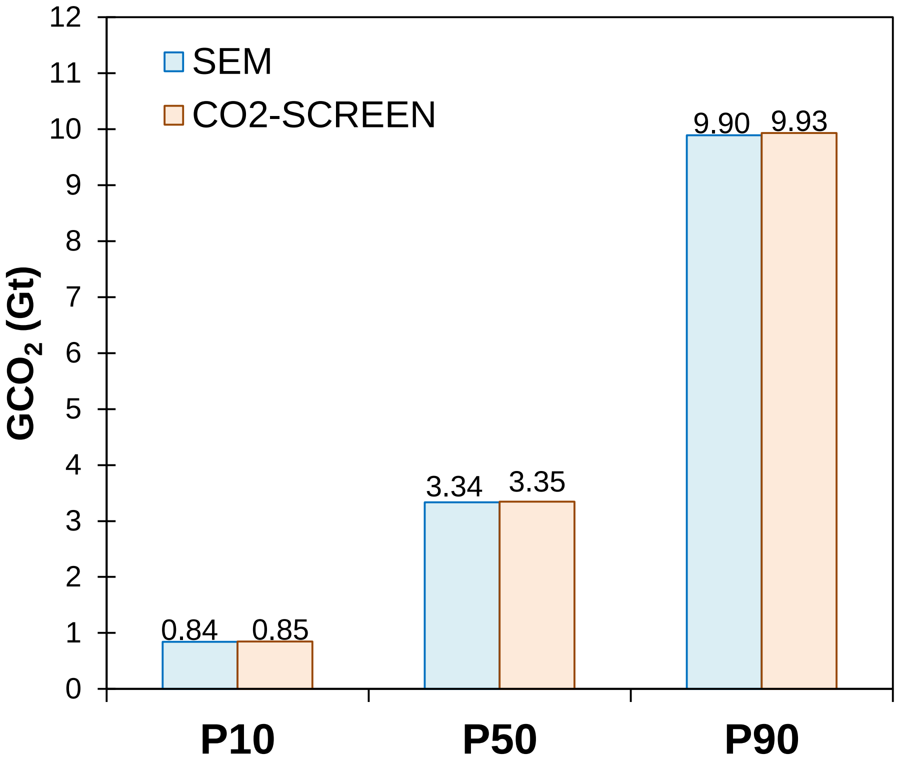
Total Pore Volume	138 km^3
Theoretical Maximum Storage Resource	111 Gt*

* Gt: gigatonnes: 10^9 tonnes

Storage Efficiency

E_{saline}		
P10	**P50**	**P90**
0.8%	3.0%	8.9%

Prospective CO_2 Storage Resource



Less than 1% difference between SEM and CO_2-SCREEN results

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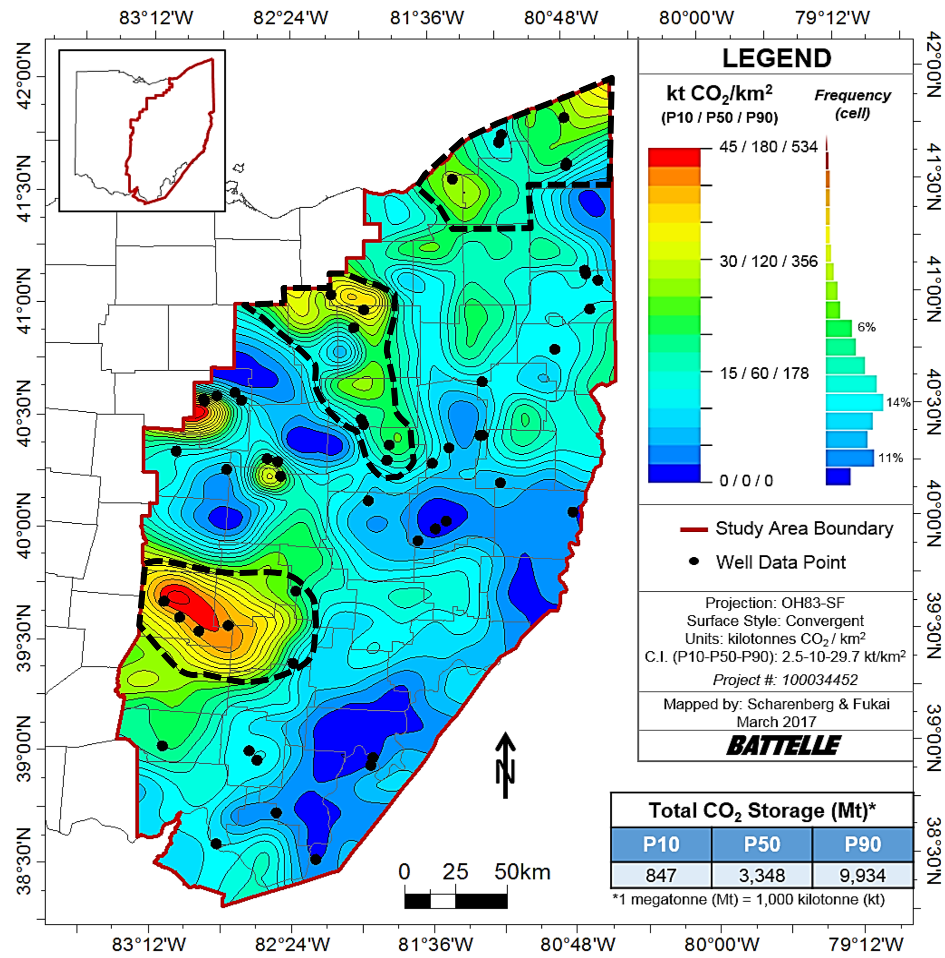
Storage Resource Results: Basal Cambrian Sandstone Geospatial Analysis

Local Storage Resource Highs:

- Northeastern Ohio
  (Lake, Ashtabula, Cuyahoga counties)
- East-central Ohio
  (Medina, Wayne, Coshocton counties)
- South-central Ohio
  (Pickaway, Fairfield, Hocking counties)

Storage resource highs in the northeast and south-central areas similar to Upper Copper Ridge

Local highs used to delineate site-scale models for dynamic analysis



Right: Map showing the Prospective CO_2 Storage Resource of the basal Cambrian sandstone in the eastern Ohio study area (Battelle, 2017).

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Summary & Conclusions

A systematic workflow of static modeling exercises is used to help define the regional geologic storage framework of the eastern Ohio study area

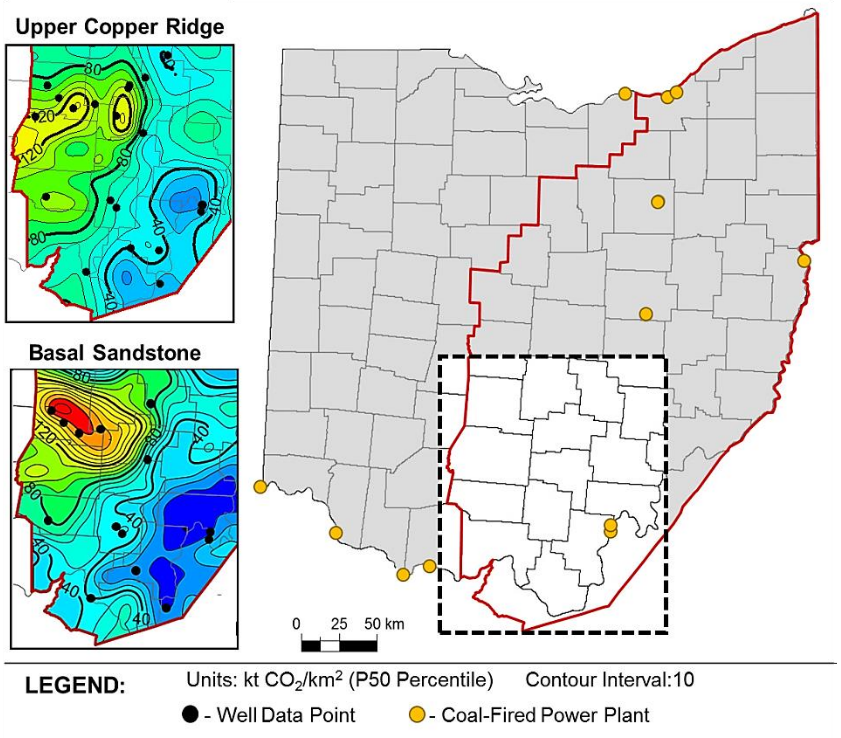
Quantification of CO_2 Storage Resource for major deep saline formations

- Theoretical Storage Resource: 111-155 Gt
- Prospective Storage Resource: 3.4 Gt (P50)
- CO_2 storage efficiency: 2.2 – 3.0% (P50)

Less than 1% difference between SEM & CO_2-SCREEN results

Generation of Storage Resource maps

- Spatial distribution of storage resource
- Help guide site selection for further analysis
- Potential for stacked storage in some areas



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BACKUP SLIDES

Storage Efficiency

$$E_{saline} = E_{An/At}\, E_{hn/hg}\, E_{\phi e/\phi t}\, E_v\, E_d$$

Parameter	Symbol	Definition
Net-to-Total Area	$E_{An/At}$	Fraction of the total area (map view) available for CO_2 storage
Net-to-Gross Thickness	$E_{hn/hg}$	Fraction of the gross thickness available for CO_2 storage
Effective-to-Total Porosity	$E_{\phi e/\phi t}$	Fraction of the total porosity that is interconnected, available for CO_2 storage
Volumetric Displacement Efficiency	E_V	Combined fraction of net volume surrounding an injection well that can be contacted by CO_2 as a consequence of density, buoyancy effects
Microscopic Displacement	E_d	The fraction of pore space occupied by immobile in-situ fluids

Input & well counts

Formation	Depth		Thickness		Porosity	
	Avg (ft.)	Well Data Count (n)	Avg (ft.)	Well Data Count (n)	Avg (%)	Well Data Count (n)
Upper Copper Ridge	5,157	252	184	202	2.1	84
basal sandstone	5,834	109	151	101	8.7	55