CO_2 Storage Resource Assessment of Deep Saline Cambrian-Ordovician Formations in Eastern Ohio*

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Search and Discovery Article #80561 (2016)**
Posted November 21, 2016

*Adapted from oral presentation given at AAPG Eastern Section Meeting, Lexington, Kentucky, September 25-27, 2016

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Abstract

Screening-level carbon dioxide (CO_2) storage resource estimates are essential for providing initial constraints on the feasibility of geologic CO_2 storage at regional and site-specific scales. The volumetric methodology developed by the U.S. Department of Energy's National Energy Technology Laboratory (DOE-NETL) was applied to nine Cambrian-Ordovician saline formations in eastern Ohio to characterize the prospective CO_2 storage resource of this region. "CO_2 storage resource" is defined by DOE-NETL as the volume of porous and permeable rock available for storage of CO_2. Geologic and petrophysical properties characterized as part of this project were used as input into the DOE-NETL CO_2-SCREEN tool to calculate CO_2 storage resource at the P10, P50, and P90 percentiles. Area, depth, thickness, pressure, temperature, and porosity were mapped for each formation and incorporated into single-layer static earth models (SEMs) for the heterogeneous scenarios. Multiple scenarios compare probabilistic heterogeneous and homogenous averaged values to evaluate resource estimation at various levels of input data resolution. Sensitivity analyses were conducted to determine the minimum representative number of grid cells, appropriate efficiency factors, and how to best represent mixed-lithology formations. The resulting static storage resource estimates were finally mapped for each formation to help create a roadmap to CO_2 storage in eastern Ohio.

Results suggest that the basal/Mt. Simon sandstone, Maryville dolomite, and Lower Copper Ridge dolomite have the greatest CO_2 storage potential of the formations examined. The highest values were generally observed in central and south-central Ohio within the extent of Delaware, Fairfield, and Scioto Counties. Storage resource results are similar across the carbonate formations (Maryville, Conasauga, Copper Ridge, and Beekmantown), with spatial trends correlating to the presence of vugs, faults, and facies changes. This feasibility study provides insight into the storage potential of deep saline formations in eastern Ohio and highlights potential storage sites with the highest CO_2 storage resource. This project is funded by the Ohio Development Services Agency OCDO Grant OOE-CDO-D-13-22 and the U.S. DOE through the Midwest Regional Carbon Sequestration Partnership (MRCSP) award DE-FC26-05NT42589. The DOE-NETL CO2-SCREEN tool (beta V1) was downloaded from the U.S. DOE's Energy Data Exchange (EDX) online platform.

Selected References

DOE-NETL (U.S. Department of Energy – National Energy Technology Laboratory – Office of Fossil Energy), 2008, Carbon Sequestration Atlas of the United States and Canada, 2nd ed., http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/

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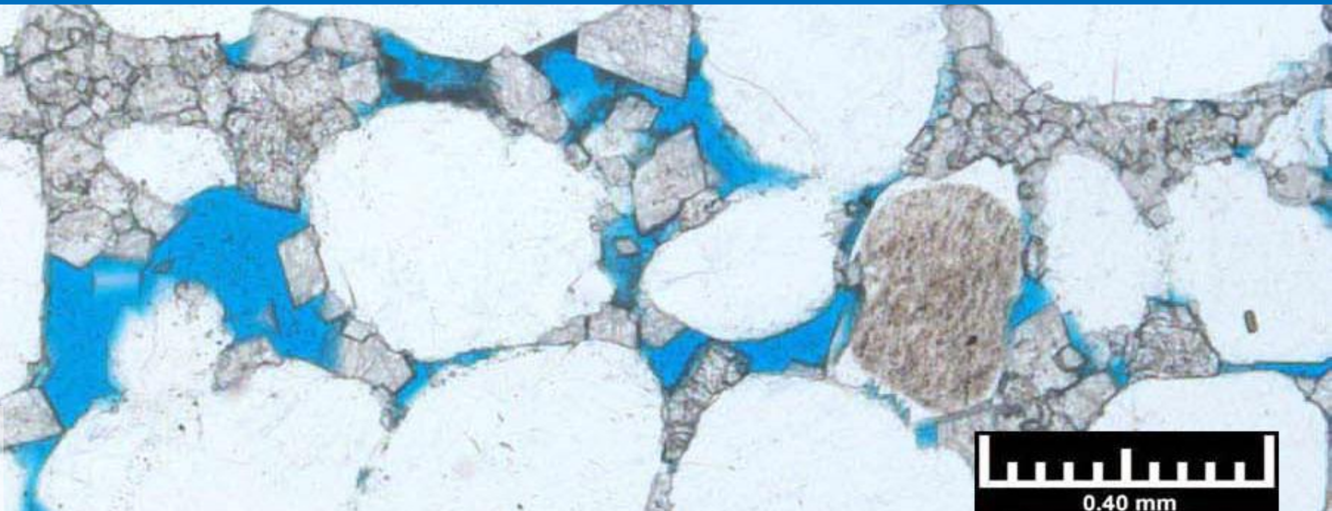

September 27th, 2016
Session: CO_2 Use and Storage

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Acknowledgments

This work is funded by the Ohio Development Services Agency – The Ohio Coal Development Office and the U.S. Department of Energy - National Energy Technology Laboratory.

Thanks to colleagues at NETL for guidance with CO2-SCREEN; Coauthors & team members who contributed to the research

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Presentation Outline

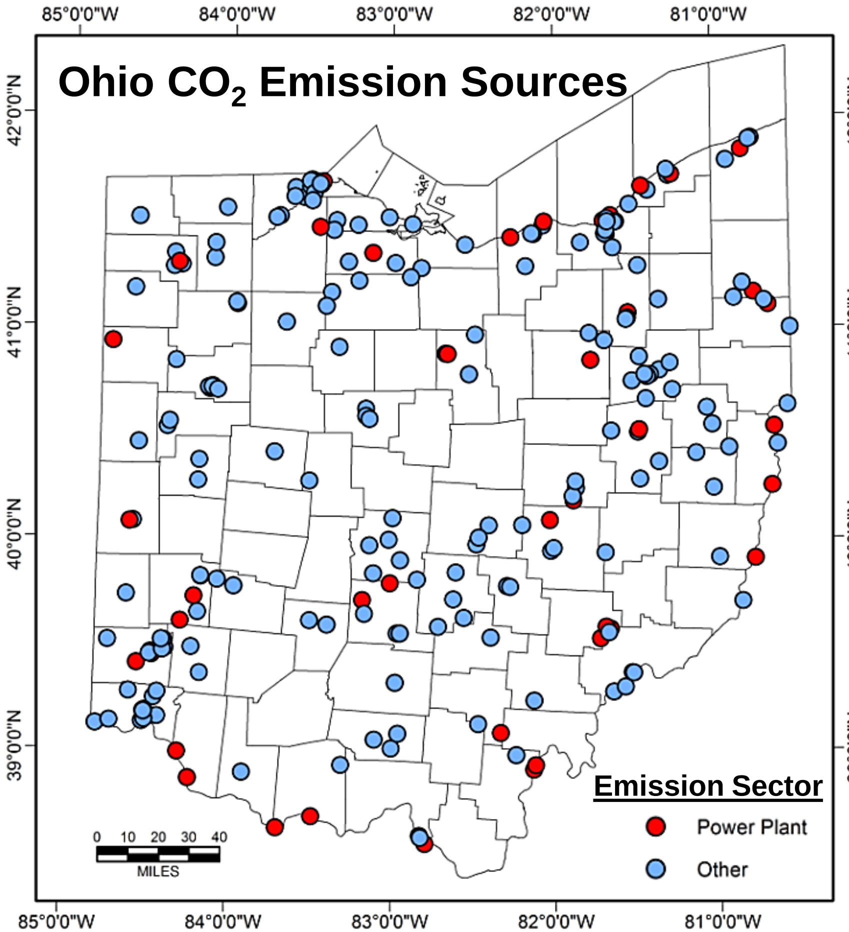
- **Project Objectives and Scope**
- **Reservoir Feasibility Analysis**
- **Static CO_2 Storage Resource Assessment**
  - Study Area & Formations of Interest
  - Calculation Methodology
- **Results**
  - Total/Cumulative CO_2 Storage Estimates
  - Mapped CO_2 Storage Estimates
- **Discussion**

Project Objectives & Scope

Problem: Availability of subsurface resources in OH for climate change mitigation, e.g. Carbon Capture Utilization & Storage (CCUS), is uncertain

Objective: characterize deep saline formations & overlying caprocks in context of geologic CO_2 storage

Results can help guide site-selection process, and inform policy, business decisions impacting CCUS implementation in Ohio



Map of CO_2 emission sources in Ohio in 2013 (from EPA Greenhouse Gas Reporting Program, 2014)

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Reservoir Feasibility Analysis: Saline Formations

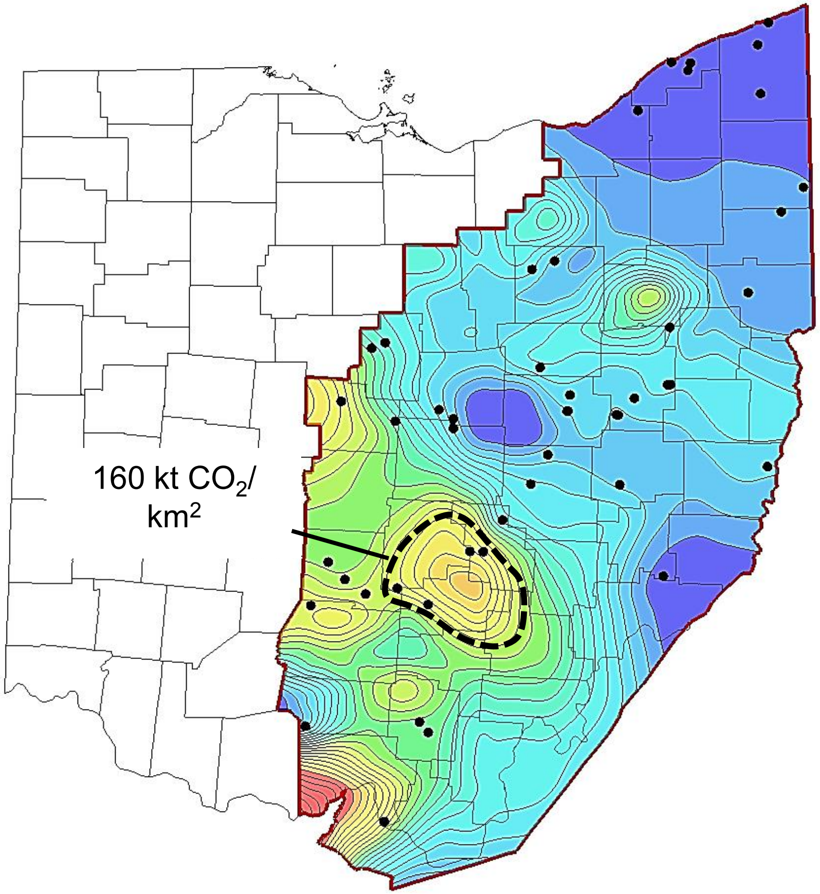
Saline formations (reservoirs):
brine-saturated sandstones and dolomites targeted for CO_2 storage

Static CO_2 Storage Estimation:
Initial pore-volume assessment; *screening-level* constraints on potential CO_2 storage quantities

- Single total value per formation
- Map representation

Integration for comprehensive storage reservoir feasibility assessment with

- 3-D Static Earth Model (SEM)
- Dynamic Numerical Simulations

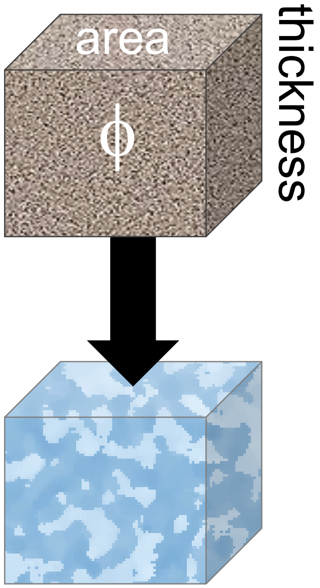


Static CO_2 Storage Resource Assessment

Static Volumetric Methodology

For calculating subsurface pore volumes

Includes: formation area, thickness, porosity (ϕ), & in-situ fluids (avg) = *equivalent quantity of* CO_2

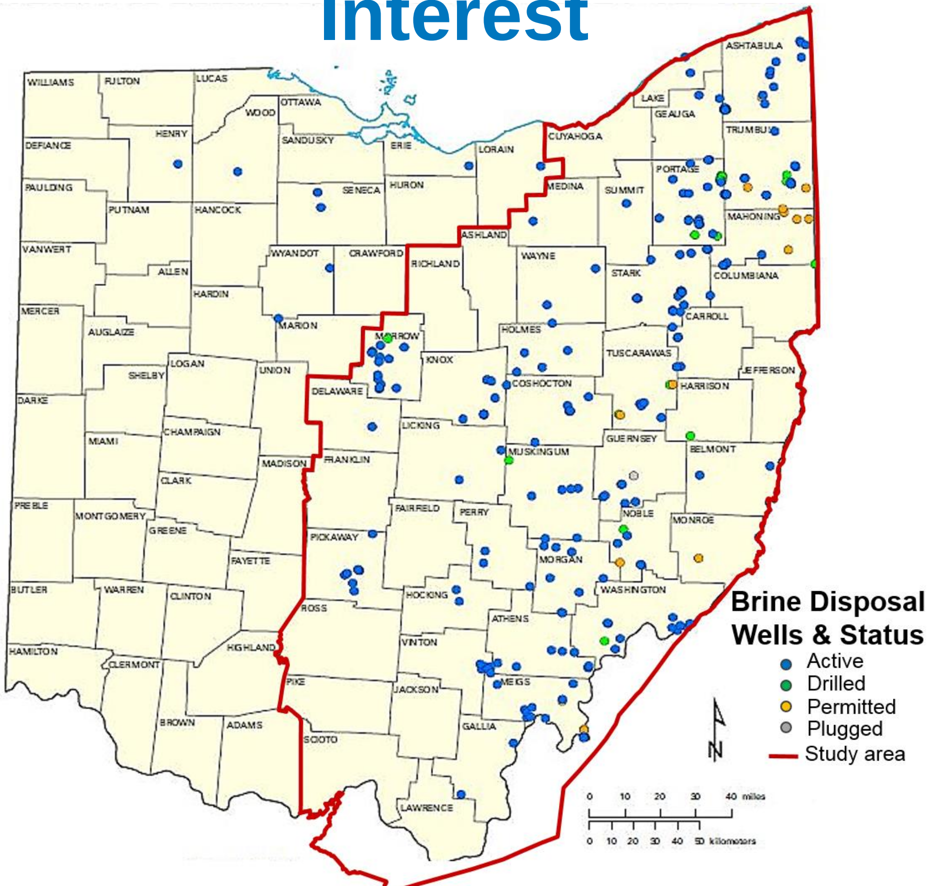


Can be applied broadly to derive an upper bound on CO_2 storage

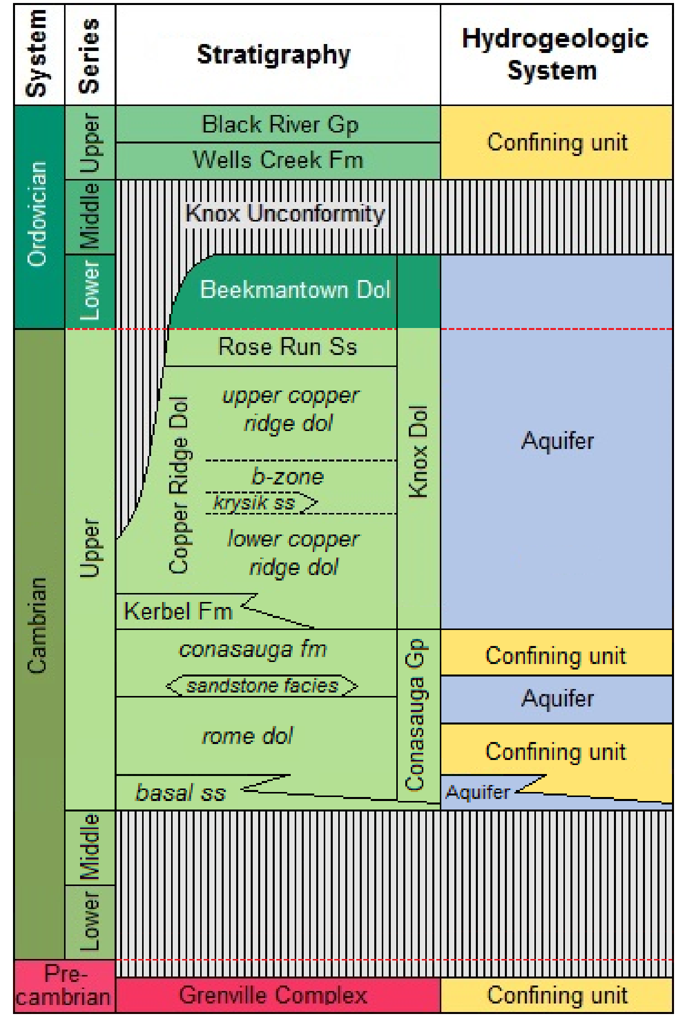
- Initial site-screening & selection purposes
- Scenarios of limited data availability

Estimates do not incorporate: Operational or temporal components (*injection rates, pressure response, well count, etc.*)

Study Area & Formations of Interest



Modified from Ohio Department of Natural Resources, 2014



23,643 mi² study area *(61,236 km²)*

Corridor of subsurface brine disposal wells in E. Ohio

Nine deep saline formations

Cambrian-Ordovician dol. & ss

Depths > 2,800 ft. *(853 m)*

Static CO_2 Storage Resource Calculation

Prospective CO_2 storage resource estimates analogous to prospective resource estimates in the exploration phase of petroleum resource characterization

US DOE Methodology

$$G_{CO2} = A_t \, h_g \, \phi_{tot} \, \rho_{CO2r} \, E_{saline}$$

Mass of CO_2 stored = *Pore volume* ($A_t \, h_g \, \phi_{tot}$) × *fluid properties* (ρ_{CO2r}) × *storage efficiency* (E_{saline})

A_t = Total formation area
H_g = gross formation thickness
ϕ_{tot} = total porosity
ρ_{CO2} = density of CO_2 at reservoir conditions
E_{saline} = CO_2 storage efficiency

CO_2 Storage Classification Framework

Petroleum Industry		CO_2 Geological Storage
Reserves	Implementation	**Capacity**
On Production	Implementation	Active Injection
Approved for Development	Implementation	Approved for Development
Justified for Development	Implementation	Justified for Development
Contingent Resources	Site Characterization	**Contingent Storage Resources**
Development Pending	Site Characterization	Development Pending
Development Unclarified or On Hold	Site Characterization	Development Unclarified or On Hold
Development Not Viable	Site Characterization	Development Not Viable
Prospective Resources	Exploration	**Prospective Storage Resources**
Prospect	Exploration	Qualified Site(s)
Lead	Exploration	Selected Areas
Play	Exploration	Potential Sub-Regions

	Prospective Storage Resources	
	Project Sub-class	**Evaluation Process**
Exploration	Qualified Site(s)	Initial Characterization
Exploration	Selected Areas	Site Selection
Exploration	Potential Sub-Regions	Site Screening

US-DOE-NETL (2008; 2010)

Static CO_2 Storage Resource Calculation: Storage Efficiency

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

Storage Efficiency (US DOE):

Fraction of the total theoretical pore volume that will be accessed for CO_2 storage (e.g net volume)

Accounts for technical storage limitations due to *regional-scale* variability/uncertainty

(1) Low and High p-values are assigned to each parameter

(2) Results calculated stochastically to derive GCO2 estimates at P10, P50, P90

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

USDOE-NETL, 2008, 2010; Goodman et al., 2011

Static CO_2 Storage Calculations: CO2-SCREEN Tool (Beta v.1)*

- **Developed by USDOE-NETL to apply DOE storage resource calculation methodology**

- **Excel interface for input and output:** user-specified input for deterministic parameters (e.g. A, h, ϕ), up to 300 grid-cell entries, with option to assign individual efficiencies per cell*

- **Stochastic efficiency calculation:** Monte Carlo simulations on GoldSim player; 10,000 realizations

EDX NETL Data-Driven Tool For Science-Based Decision Making

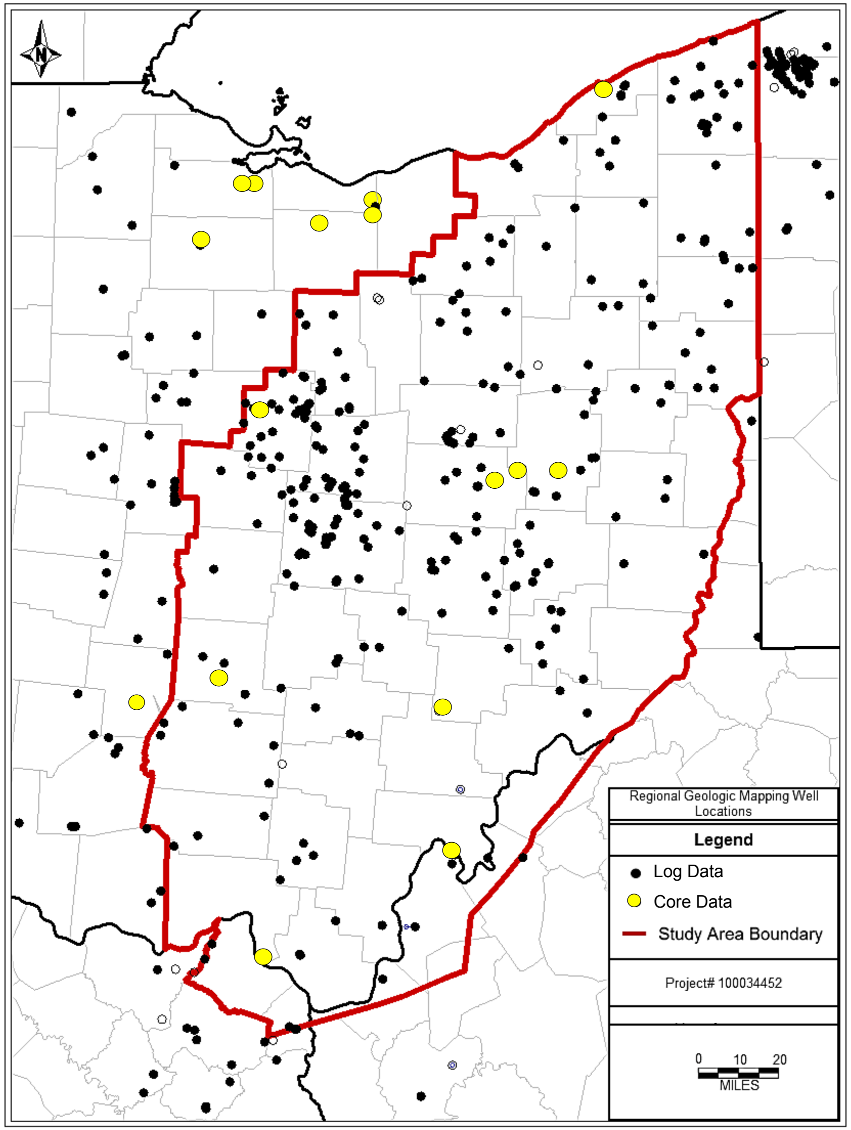
*https://edx.netl.doe.gov/carbonstorage/?page_id=914

Static CO_2 Storage Calculation:
Data Sources/Input

Structure, thickness, and porosity maps from previous characterization efforts

Log data from ~430 wells:
gamma ray, neutron, density logs
(~50-100 per fm)

Core data from ~15 wells: to cross-check interpolations & averages from log data



Location of wells with core and log data used in geologic characterization efforts and CO_2 storage resource calculations. (well locations approximate)

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Static CO_2 Storage Resource Calculation:
CO2-SCREEN Input & Interface

Calculations performed for two data scenarios:

- <u>Homogenous Fm Model:</u> limited, avg. formation data; one row/ grid-cell entry
- <u>Heterogeneous Fm Model:</u> data w/ spatial variation; 300 rows/grid-cell entries

Efficiency defaults
(IEAGHG, 2009)

Storage Efficiency Factors

Auto-populate: Choose lithology and depositional environment

User Specified: Directly enter P_{10} and P_{90} values

Lithology and Depositional Environment	Clastics: Shallow Shelf

	Auto-populated		User Specified					
	P_{10}	P_{90}	P_{10}	P_{90}	X_{10}	X_{90}	μ_X	σ_X
Net-to-Total Area	0.20	0.80	0.00	0.00	-1.39	1.39	0.00	1.08
Net-to-Gross Thickness	0.21	0.76	0.00	0.00	-1.32	1.15	-0.09	0.97
Effective-to-Total Porosity	0.62	0.78	0.00	0.00	0.49	1.27	0.88	0.30
Volumetric Displacement	0.18	0.63	0.00	0.00	-1.52	0.53	-0.49	0.80
Microscopic Displacement	0.39	0.82	0.00	0.00	-0.45	1.52	0.53	0.77

Physical Parameters

Mean and standard deviation values for each grid

Grid #	Area* (km²)	Gross Thickness* (m)		Total Porosity* (%)		Pressure† (MPa)		Temperature† (°C)	
	Mean	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	214	55	0	6	0	13	0	35	0
2	214	57	0	5	0	17	0	41	0
3	214	54	0	7	0	13	0	34	0
4	214	48	0	9	0	16	0	39	0

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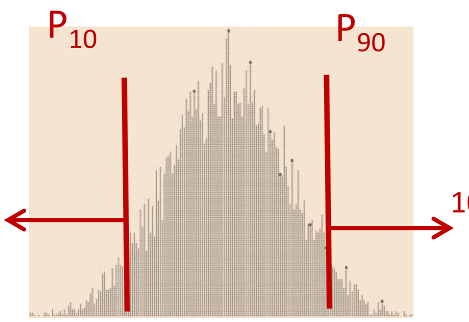
Static CO_2 Storage Resource Calculation: CO2-SCREEN Output

Log normal distribution & Monte Carlo sampling for E probability values
(GoldSim v. 11.1.5)



CO_2 Storage Resource at P10, P50, and P90 percentiles *for each grid cell*

	Megatonnes (Mt) CO2			Storage Efficiency:
Grid	**P10**	**P50**	**P90**	**Option 2**
1	2	7	21	Clastics: Shallow Shelf
2	2	6	19	Clastics: Shallow Shelf
3	2	8	25	Clastics: Shallow Shelf
4	2	6	19	Clastics: Shallow Shelf
5	1	5	16	Clastics: Shallow Shelf
6	2	7	21	Clastics: Shallow Shelf
7	2	10	28	Clastics: Shallow Shelf
8	2	6	20	Clastics: Shallow Shelf
9	1	6	17	Clastics: Shallow Shelf
10	1	6	18	Clastics: Shallow Shelf

Cumulative/total CO_2 storage (sum of all grids) reported

CO_2 Storage Statistics				
	P10	**P50**	**P90**	
Summed CO_2 Total	237	895	2523	Mt
Average CO_2 per Grid	1	5	14	Mt

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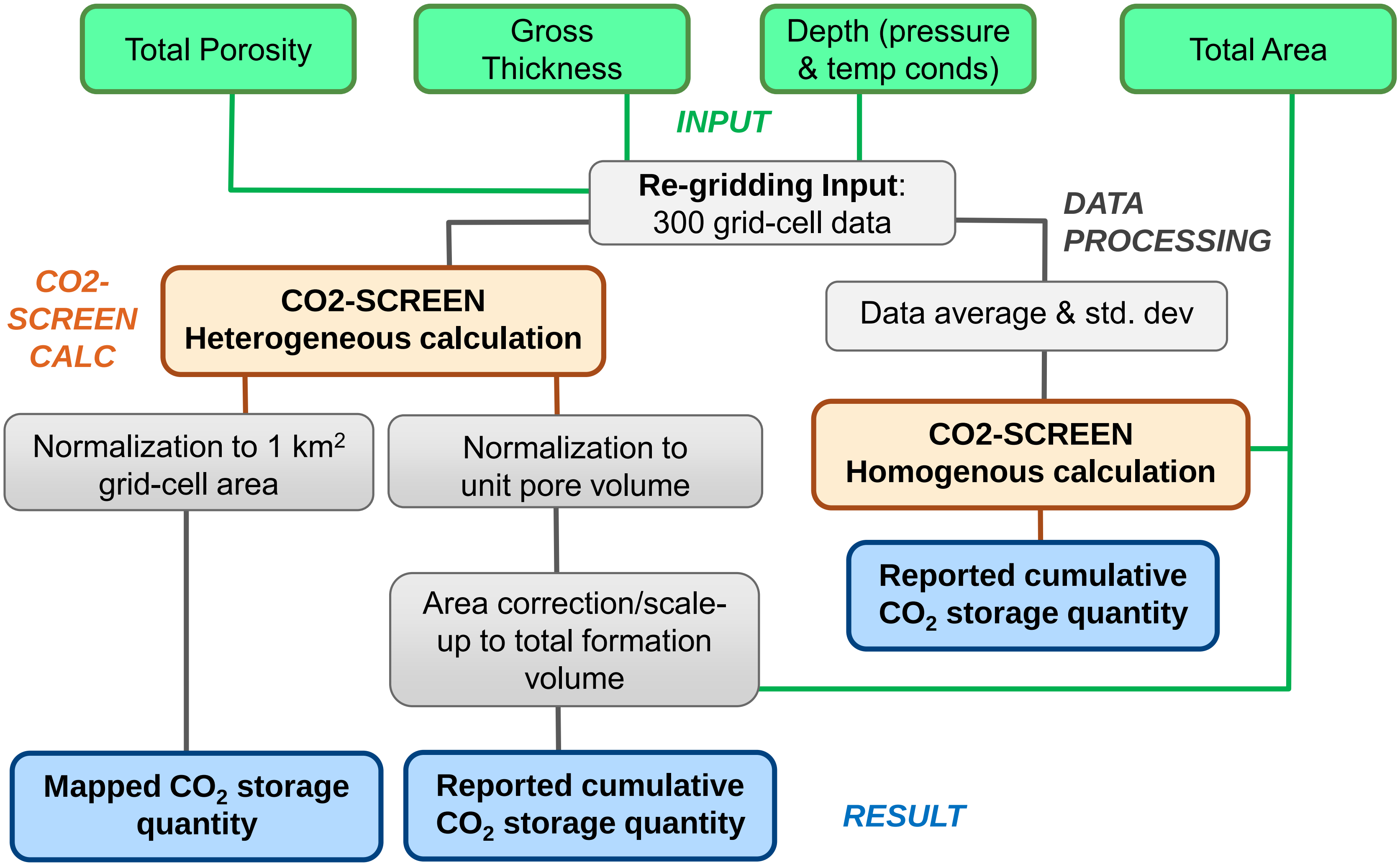
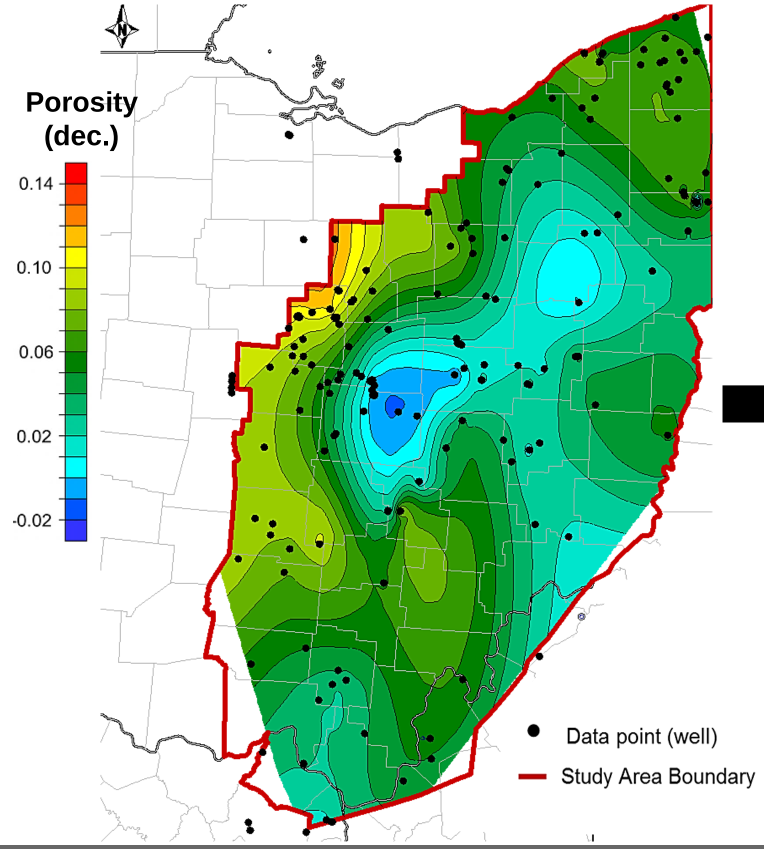
Static CO_2 Storage Resource Calculation: Workflow

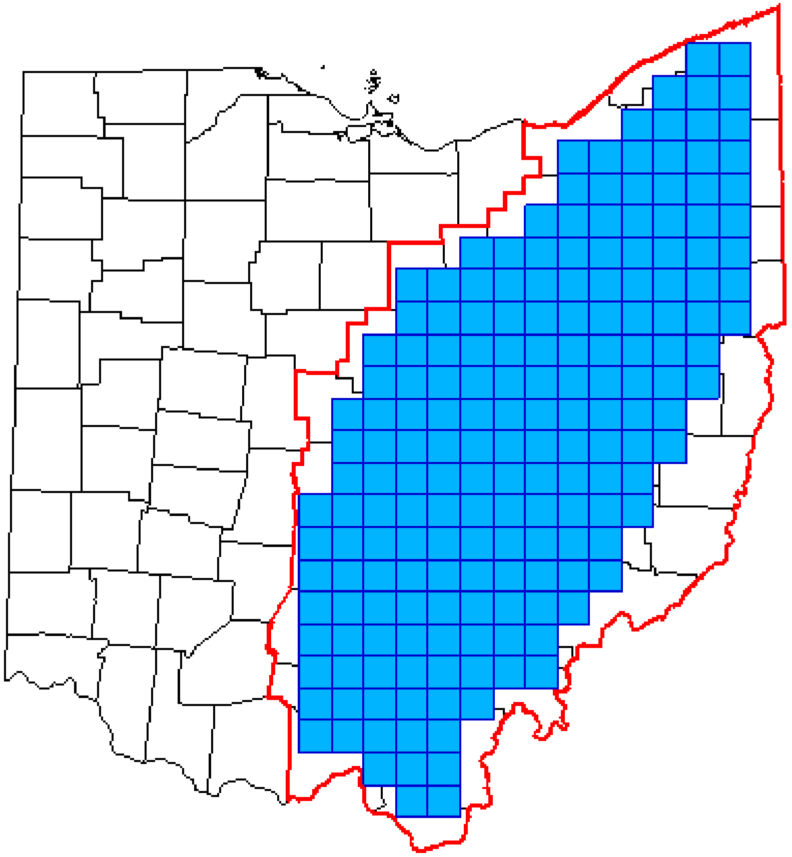


Static CO_2 Storage Calculation: Regridding Input

Heterogeneous model scenario

Regrid property maps to 300 grid cells (CO2-SCREEN beta v.1 limitation); lose some area around the boundaries of the map





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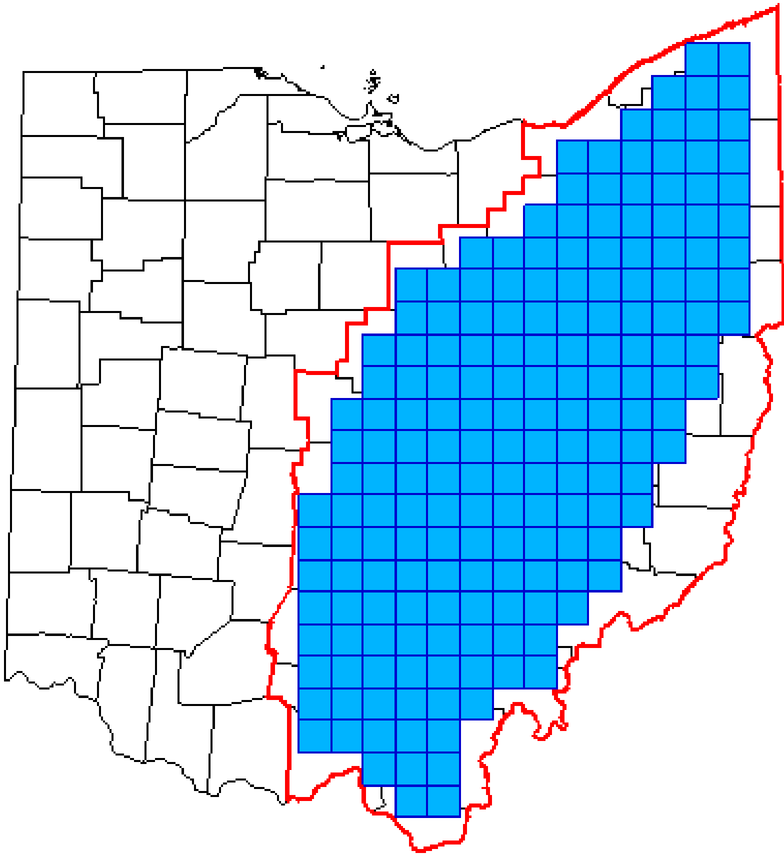
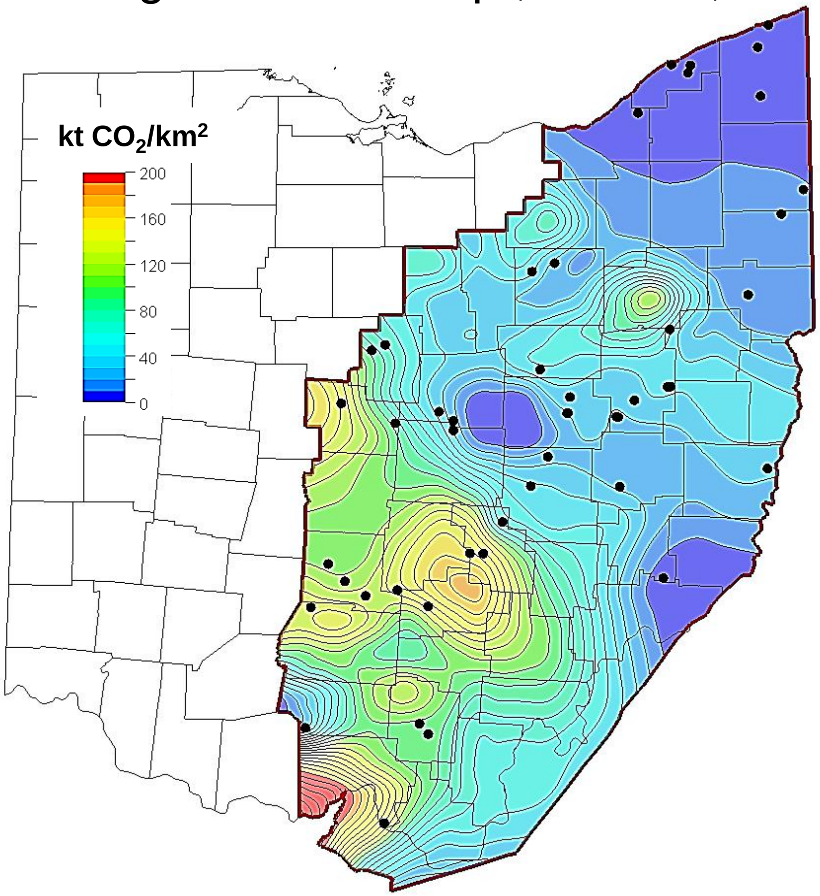
Static CO_2 Storage Calculation: Re-gridding Output

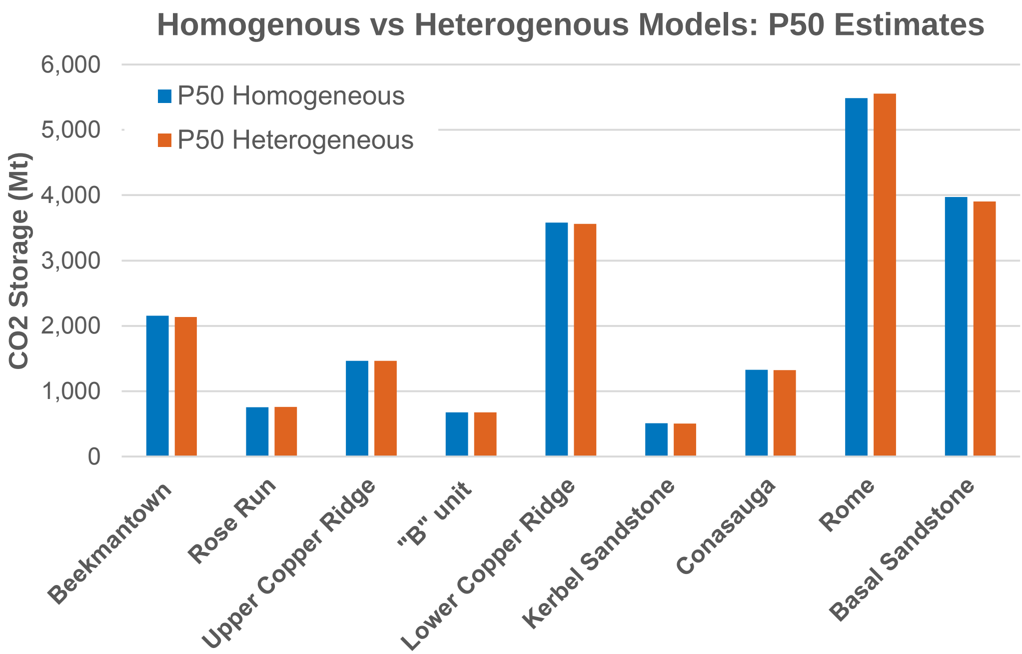
Heterogeneous model scenario

Coarse 300 grid-cell P50 results from CO2-SCREEN normalized to kt CO_2 per unit area (km^2) and re-gridded to higher resolution storage resource map (~61,000 cells)





Static CO_2 Storage Resource Results: Cumulative Heterogeneous vs Homogenous Scenarios



Percent difference between homogeneous and heterogeneous calculations is less than 2%

Rank	HETEROGENEOUS MODEL			
	Formation	Total Prospective CO_2 Storage Resource (Mt)		
		P10	P50	P90
1	Rome	1,639	5,556	13,281
2	Basal Sandstone	990	3,904	11,348
3	Lower Copper Ridge	1,090	3,561	8,637
4	Beekmantown	652	2,137	5,227
5	Upper Copper Ridge	436	1,462	3,498
6	Conasauga	393	1,321	3,195
7	Rose Run	188	757	2,305
8	“B” unit	205	674	1,634
9	Kerbel	134	505	1,464
	Total	**5,748**	**19,945**	**50,904**

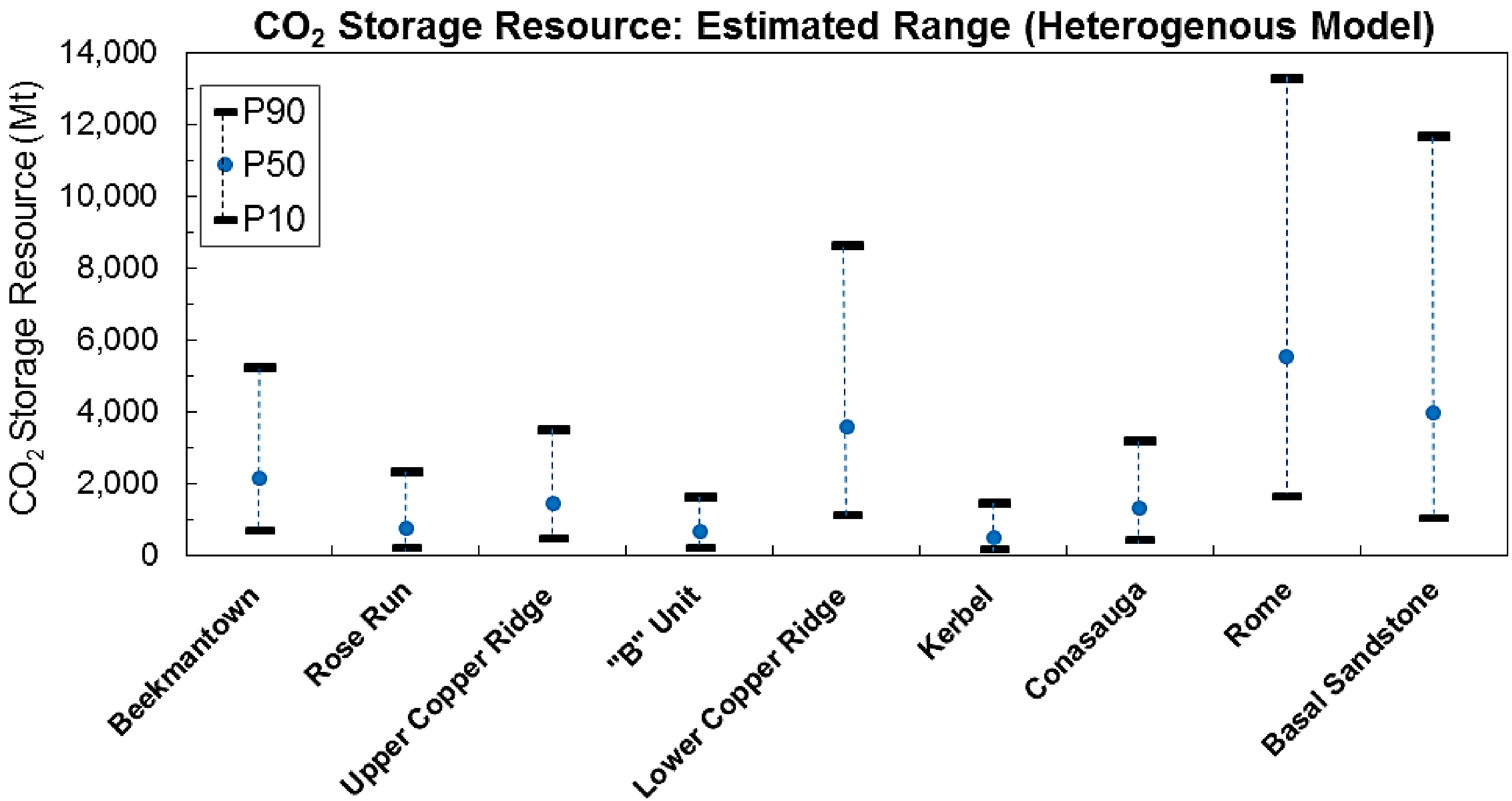
Static CO_2 Storage Resource Results: Heterogeneous Estimates

Ranked by CO_2 storage per unit pore volume

Sandstones have highest storage per unit pore volume and highest calculated efficiency

Rank	Formation	Mt CO_2 /km^3 Pore Volume			E_{saline} P50 (avg.)
		P10	P50	P90	
1	Basal Sandstone	6	24	70	3.0%
2	Kerbel Sandstone	6	22	63	2.7%
3	Rose Run	5	20	61	2.5%
4	Beekmantown	5	18	43	2.2%
	Upper Copper Ridge	5	18	42	2.2%
	Copper Ridge "B" Unit	5	18	42	2.2%
	Rome	5	18	42	2.2%
5	Lower Copper Ridge	5	17	42	2.2%
	Conasauga	5	17	42	2.2%

Static CO_2 Storage Resource Results:
Heterogeneous Estimates



Note: Large range in estimates, high uncertainty

Static CO_2 Storage Resource Results: Top 3

Spatial Distribution of P50 Estimates

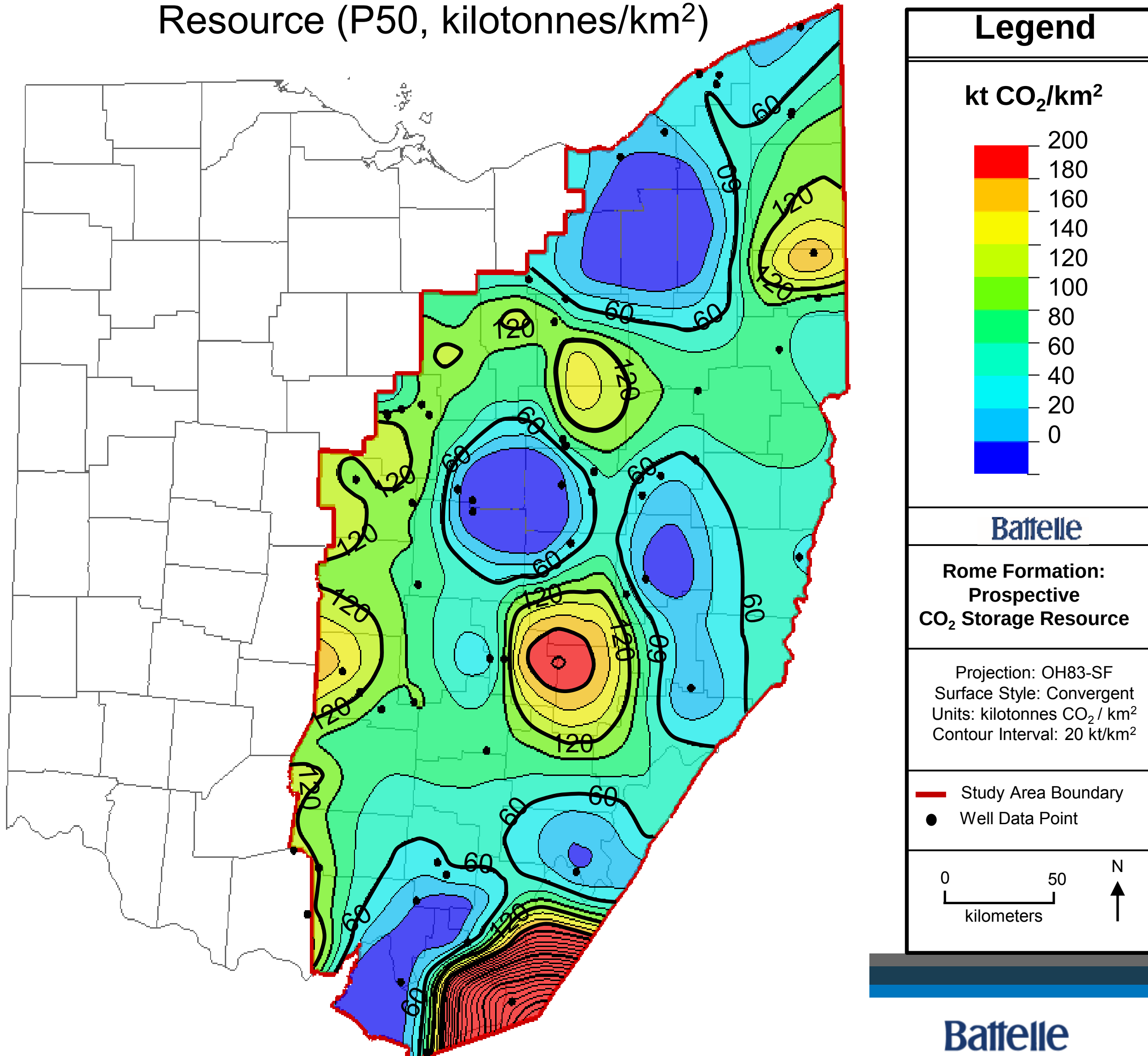
Rome Dolomite

Total CO_2 storage
P50 (Mt)*
5,556

**1 Megatonne (Mt) = 1000 kilotonne (kt)*

Observable effects of data quality/coverage on spatial distribution of storage estimates

Rome Formation: Prospective CO_2 Storage Resource (P50, kilotonnes/km^2)



Static CO_2 Storage Resource Results

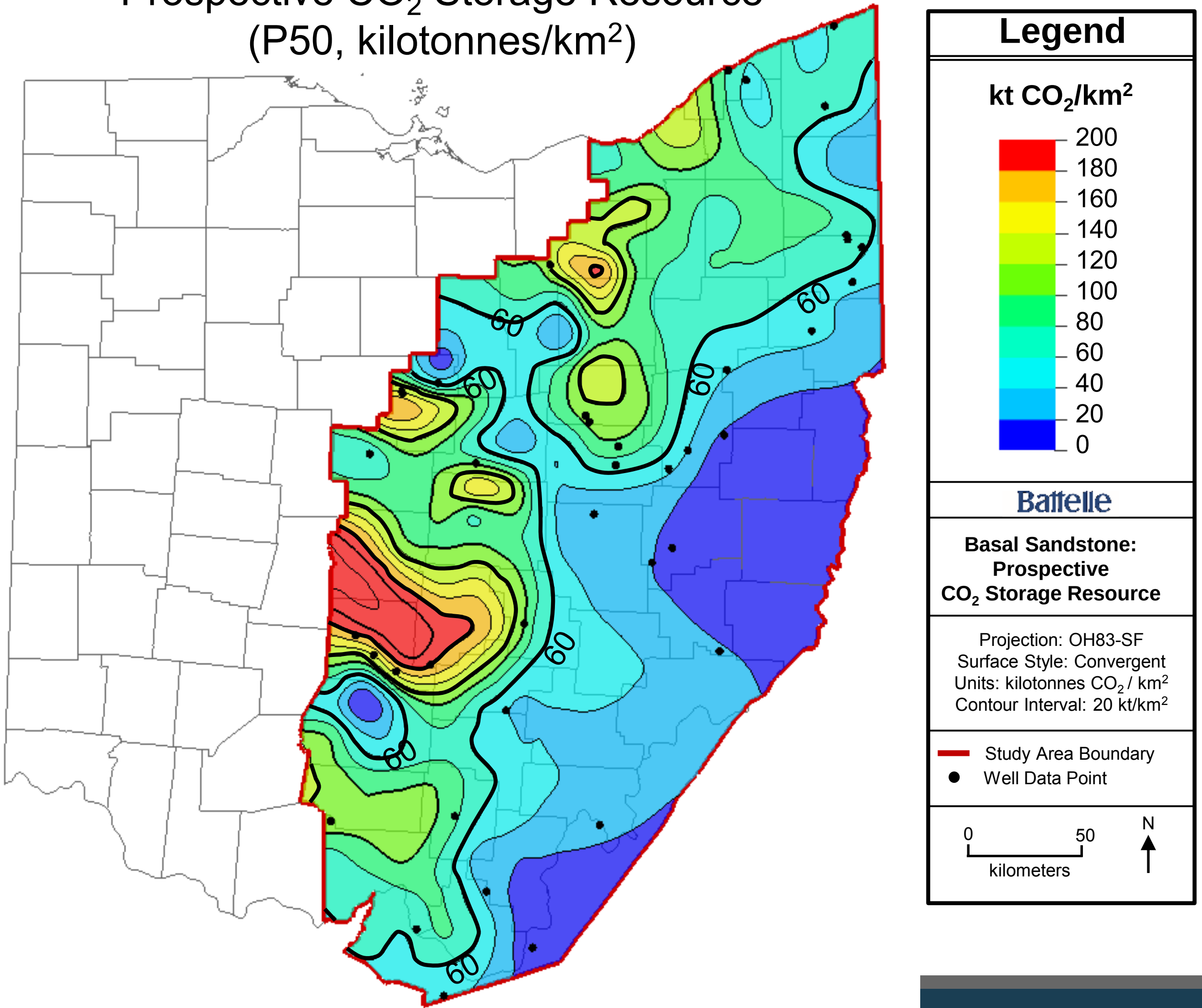
Spatial Distribution of P50 Estimates

Basal sandstone

Total CO_2 storage
P50 (Mt)*
3,904

**1 Megatonne (Mt) = 1000 kilotonne (kt)*

Basal Sandstone Formation:
Prospective CO_2 Storage Resource
(P50, kilotonnes/km^2)



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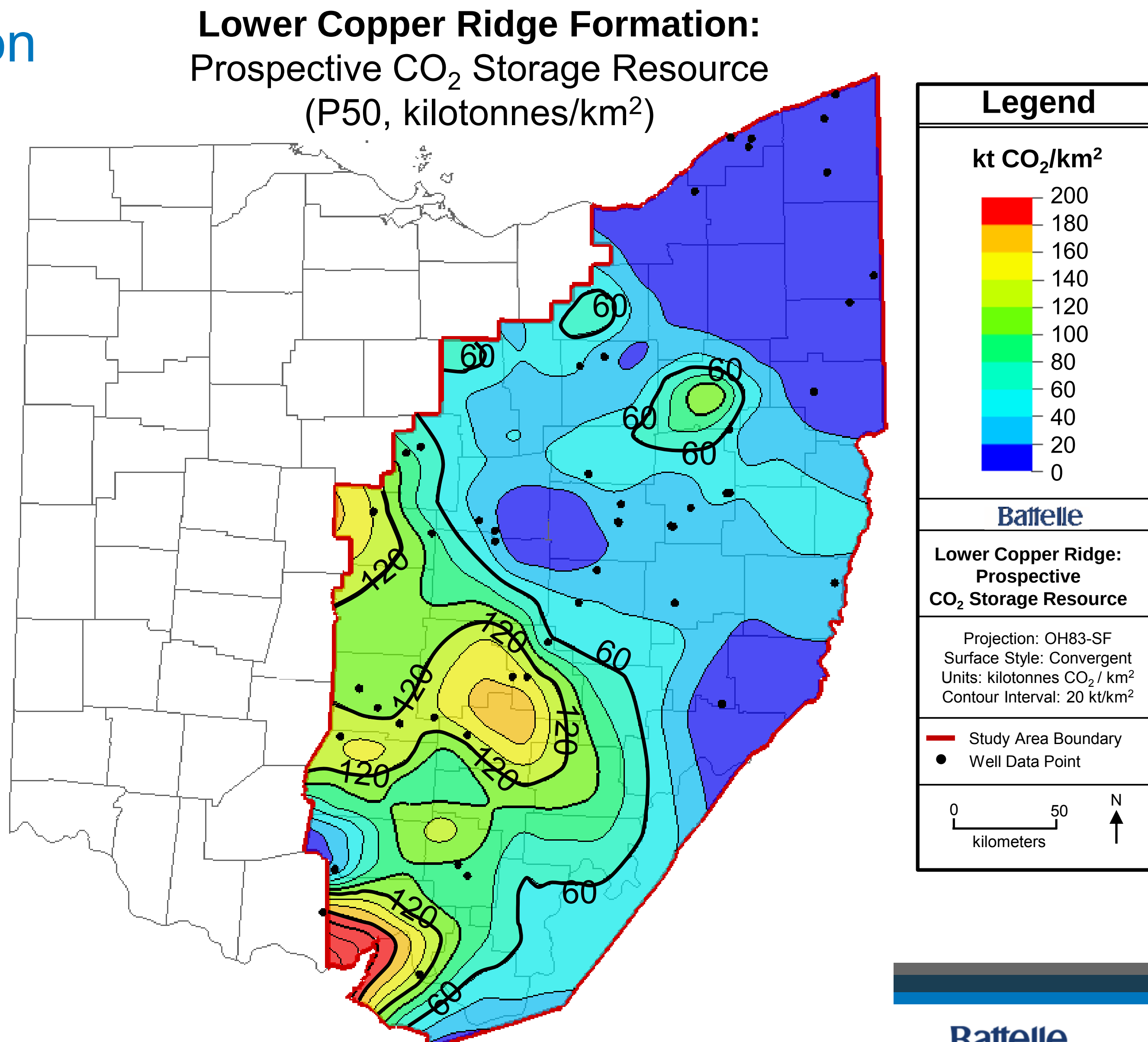
Static CO_2 Storage Resource Results

Spatial Distribution of P50 Estimates

Lower Copper Ridge

Total CO_2 storage
P50 (Mt)*
3,561

**1 Megatonne (Mt) = 1000 kilotonne (kt)*



Overlap of high potential storage resource in central - southern OH: stacked storage scenario

Summary

- **Beta tested CO2-SCREEN tool**
- **Initial screening-level estimates indicate the Rome, Basal sandstone, Copper Ridge dolomite** have high potential CO_2 storage resource in the study area; overlap in central OH.
- **Homogenous and heterogeneous scenarios produced similar results,** suggesting homogeneous model may be sufficient for estimating total storage resource
- **Storage Resource Maps** – Give valuable insight into storage resource distribution; applied to site-screening process & help focus site-specific evaluation efforts.
- **Future work** – integration of results with site-specific SEM & Dynamic modeling for a comprehensive reservoir feasibility analysis.

Thank you

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