Nationwide Assessment of Saline Reservoir CO_2 Storage Properties for the United States using the SCO_2T^{PRO} Sequestration Screening Tool

Kyle Cox

Carbon Solutions LLC

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Introduction

Executive Summary

Geologic CO_2 storage cost and capacity were modeled for reservoirs from across the continental US and adjacent offshore areas

- This information is critical for regional planning and CO_2 storage site identification
- Existing regional/national scale geology storage property datasets lack coverage and spatial variability, limiting their utility

Storage properties were modeled using Carbon Solutions':

- *SCO_2T^{PRO}* CO_2 storage site evaluation & screening tool
- Geologic Reservoir Property Database

The model results indicate that saline aquifer reservoirs across the US could potentially store 100's of Gt of CO_2 for <$10/t, but distribution of that storage is not equitable across the country

- Gulf Coast, Southeast, W Texas, CA Central Valley, portions of the Rocky Mountains region, and Central IN & IL provide the highest capacity/lowest cost storage
- Marginal regional geologic reservoir quality limits storage prospects in areas such as Appalachia
- Limited to no aquifer storage opportunities modeled throughout onshore East Coast, much of the Southwest, Pacific NW, many North Central/Plains states
- Estimated offshore reservoir storage capacities are immense, but the cost of storage is significantly higher than onshore reservoirs with similar geologic conditions

Results were compared to storage data from the NATCARB Carbon Storage Atlas V

- Similar cumulative storage capacities and high-level trends
- Geographic and stratigraphic coverage differ significantly
- This study's dataset better reflects the spatial variability inherent and provides estimates for important storage properties such as cost, making it a better tool for regional planning and site screening purposes.

Acknowledgments-Contributing Carbon Solutions LLC Team Members

Richard Middleton

Jonathan Ogland-Hand

Jeff Bennett

Kyle Cox

Kevin Ellet

Ben Adams

Peter Johnson

Anna Turnini

Erin Middleton

Kelsey Seals

Carl Talsma

Veronika Lubeck

Why?

Meeting US net zero emissions goals could require 1000's of geologic CO2 storage sites across the nation

Geologic CO2 storage is not plausible everywhere

- Storage properties can range widely greatly between locations due to variability in the geology

100's of 1000's of locations will need to be screened to:

- Develop an understanding of the spatial distribution of storage properties to help guide regional planning
- Identify the most prospective storage sites

Complications

- There is no suitable nationwide dataset of location specific geologic CO_2 storage properties
- Screening for CO_2 storage reservoirs is a difficult and resource intensive process

Need

- Screening tool capable of rapidly characterizing CO_2 storage properties for 100's of 1000's of locations
- Nationwide geologic reservoir property dataset for model input

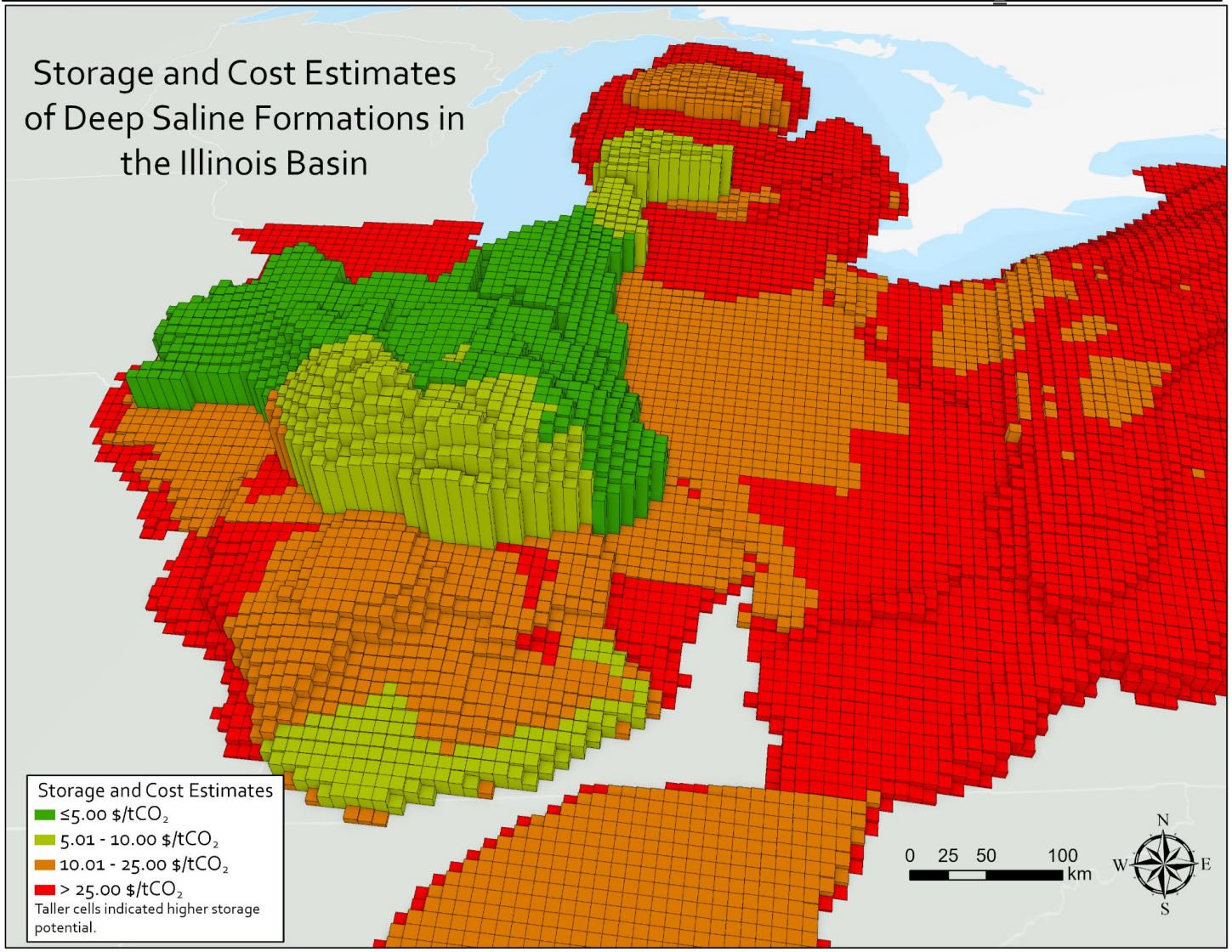
Methods

Screening Tool: Carbon Solutions' SCO_2T^{PRO} Tool

CO_2 storage site evaluation & screening tool

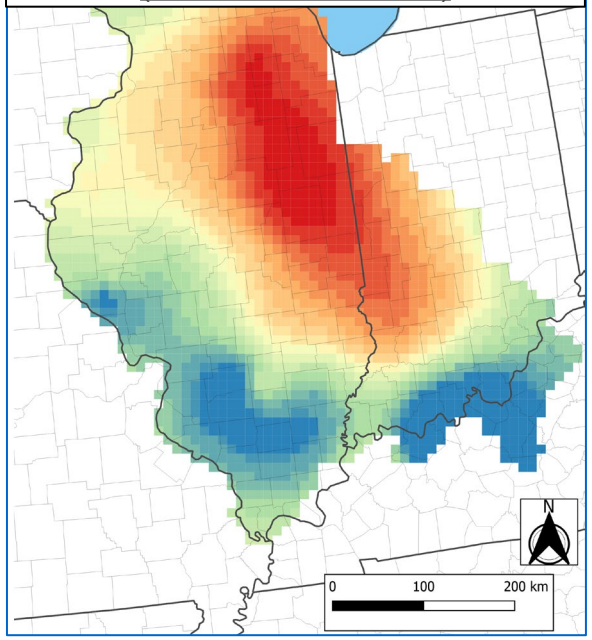
- Can rapidly calculate location-specific CO_2 storage capacity & costs for 10's of 1000's of locations simultaneously.
- Utilizes machine learning/AI developed reduced order models (ROMs) created from 10's of 1000's of full-physics simulations to dynamically model CO_2 injection, storage capacities, and plume area.
- Connects advanced CO_2 injection & storage modeling with comprehensive sequestration economics to estimate storage costs.

Example Dataset Produced Using Carbon Solutions' SCO_2T^{PRO} Tool



Modeling Process Example

Example Input Data
(Reservoir Thickness)



- Depth
- Pressure
- Thickness
- Permeability
- Porosity
- Temperature

Geologic Input Data

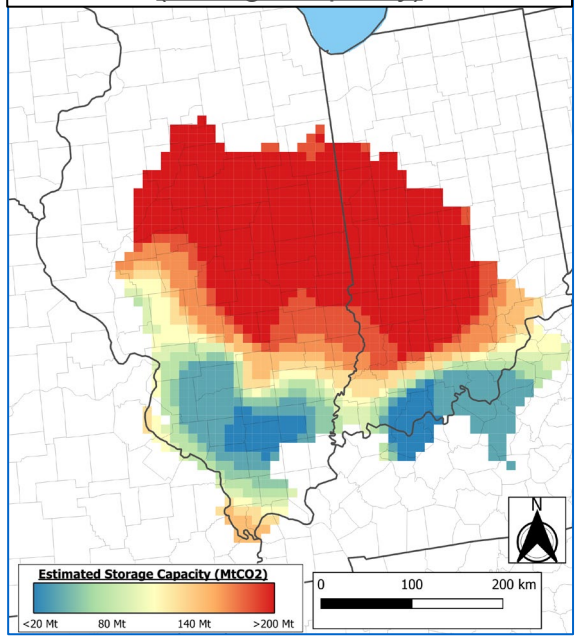
Carbon Solutions'
SCO_2T^{PRO} Tool

- Machine Learning/AI based tool built using 10's of 1000's of full-physics injection simulations.
- Can dynamically modeling CO2 storage properties for 100's of 1000's of locations in minutes
- Comprehensive sequestration economics cost model for estimating storage costs

- Capacity ($MtCO_2/km^2$)
- Cost ($/ton)
- Injectivity ($MtCO_2/yr$)
- Plume radius/area (km/km^2)

Location Specific
Storage Properties
across modeled area

Example Output Data
(Storage Capacity)



Nationwide Geologic Dataset: Carbon Solutions' Geologic Reservoir Database

Geologic reservoir properties for the Continental US and adjacent offshore areas

- 140 reservoirs covering >3.3 million km^2

Why not just use existing databases as is?

- Lack coverage
- Lack spatial variability
- Accessibility/usability

Where did the data come from?

- NATCARB Atlas, RCSP products, USGS, State Geological Surveys, BOEM, DOE funded offshore studies, NETL, CCUS pilot/demonstration projects, random academic publications, and in-house generated datasets

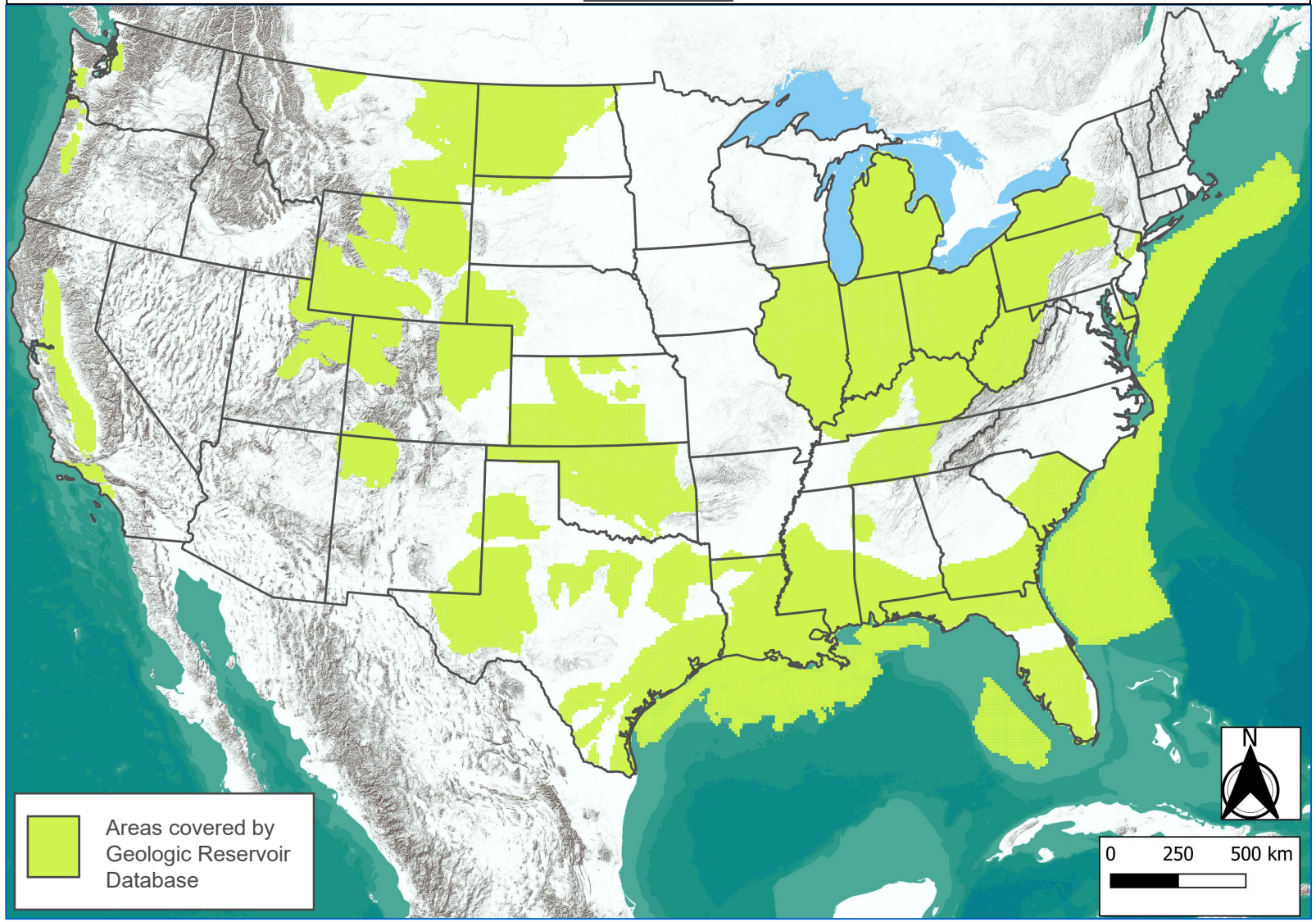
How did we incorporate data?

- Data type by data type one reservoir at a time

What about reservoir/basin x?

- "Triage"

Geographic Coverage for Carbon Solution's Geologic Reservoir Property Database



Results

Model Results Coverage

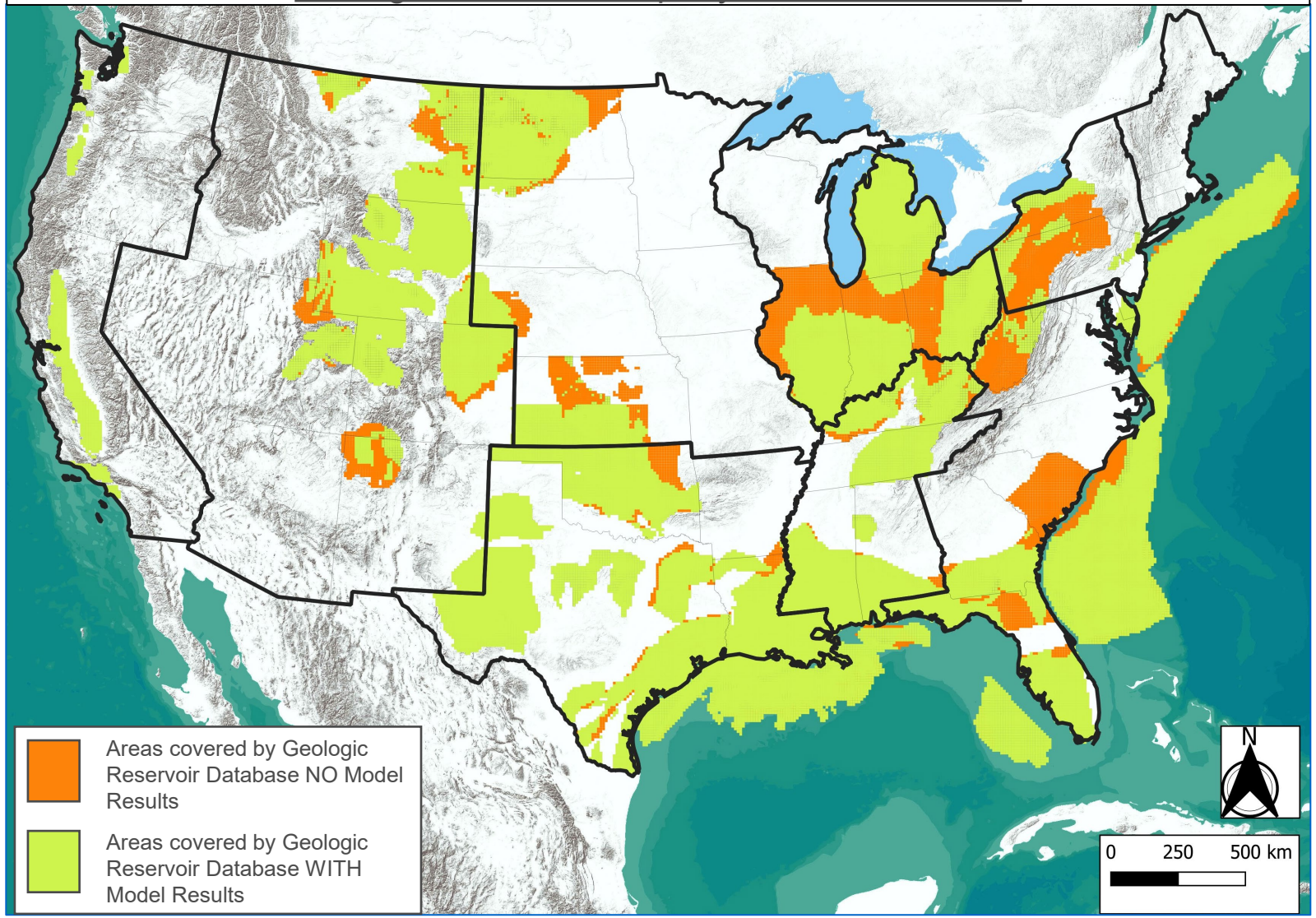
Modeled CO2 storage properties

- Capacity, cost, injectivity, plume dimensions
- Location specific results
  - 10 km resolution
- Results for 135 reservoirs covering >2.7 million km^2

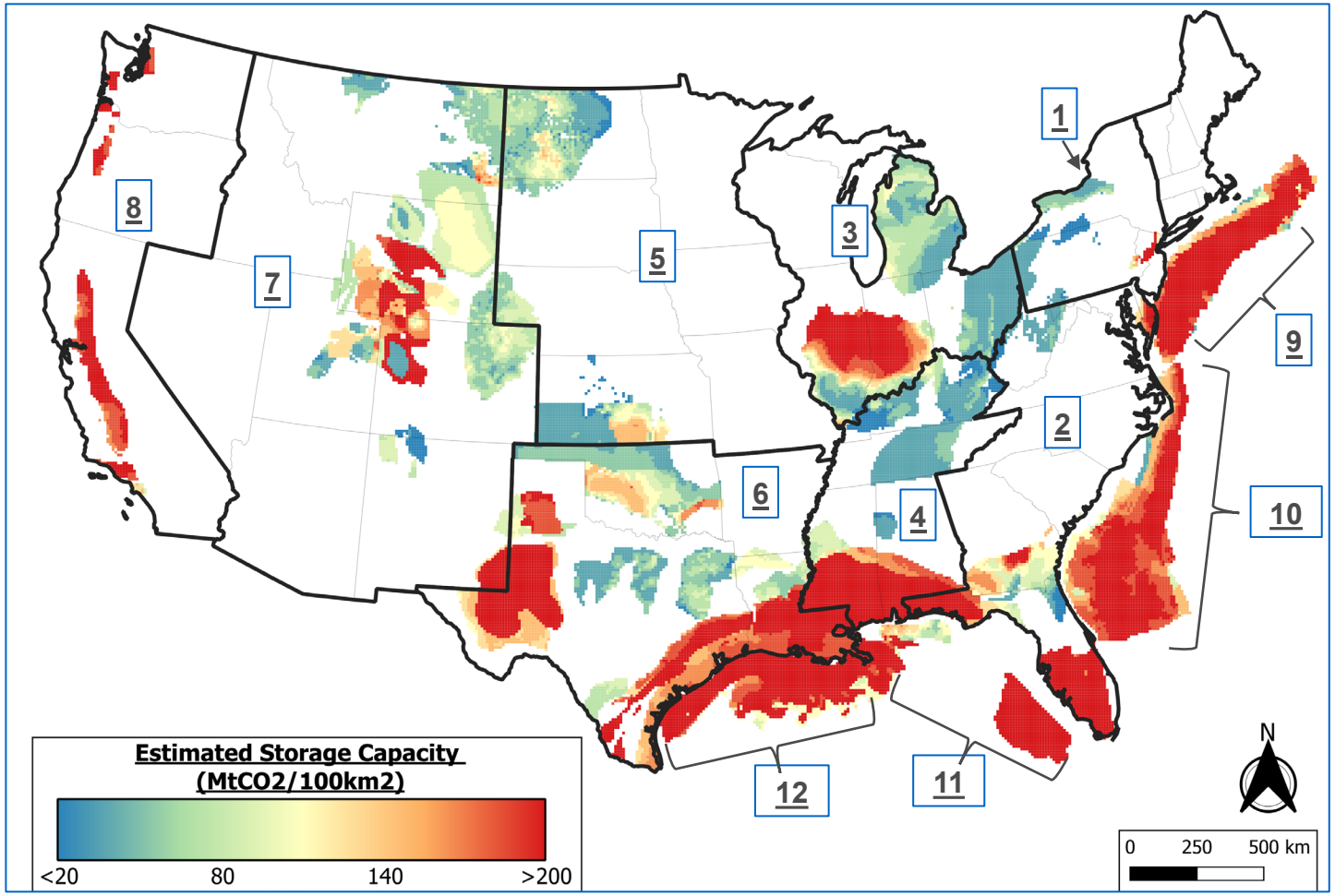
Why are there no results for some areas?

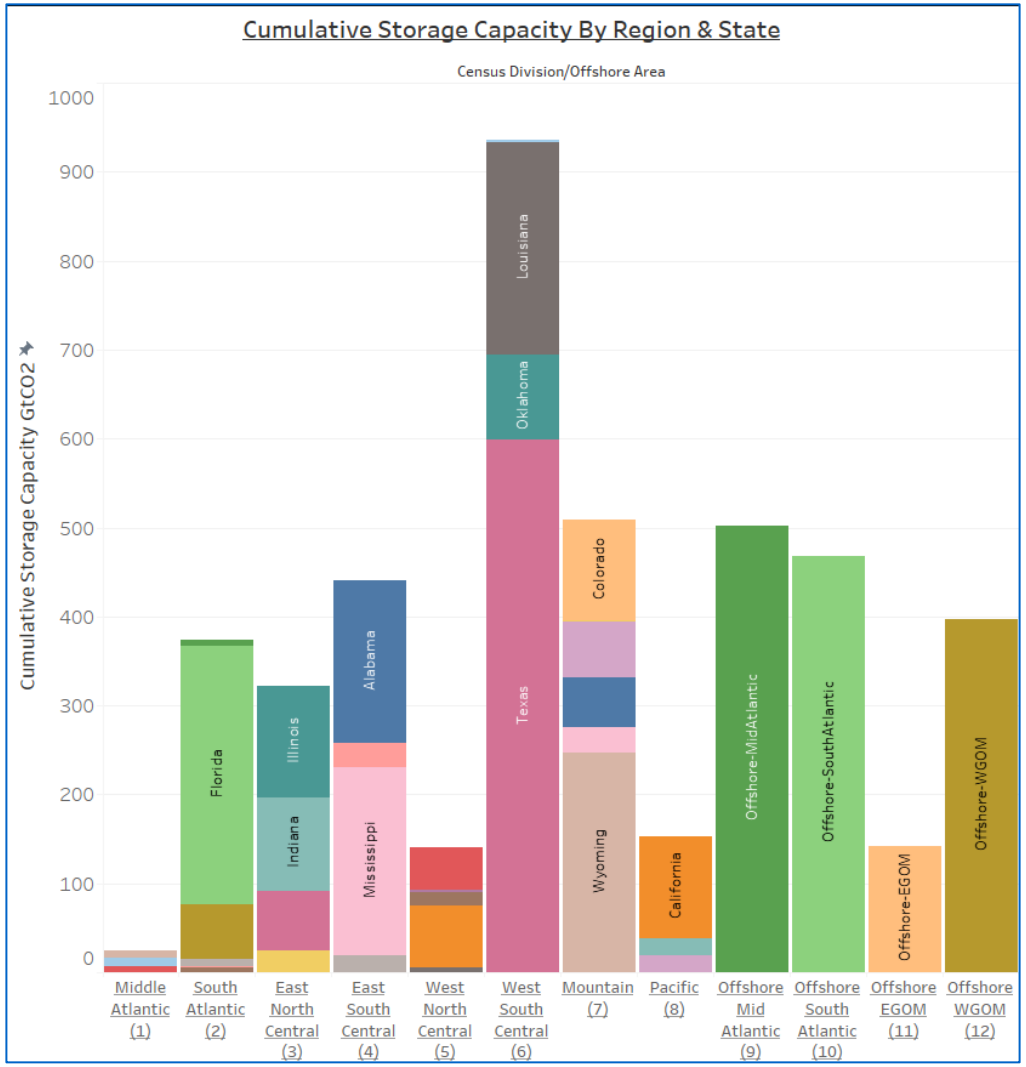
- Marginal ***regional scale*** reservoir quality
- Depth/reservoir conditions unable to support supercritical CO_2
- Other

Geographic Coverage for Modeled CO_2 Storage Properties vs Carbon Solution's Geologic Reservoir Property Database Extents



Modeled Storage Capacity

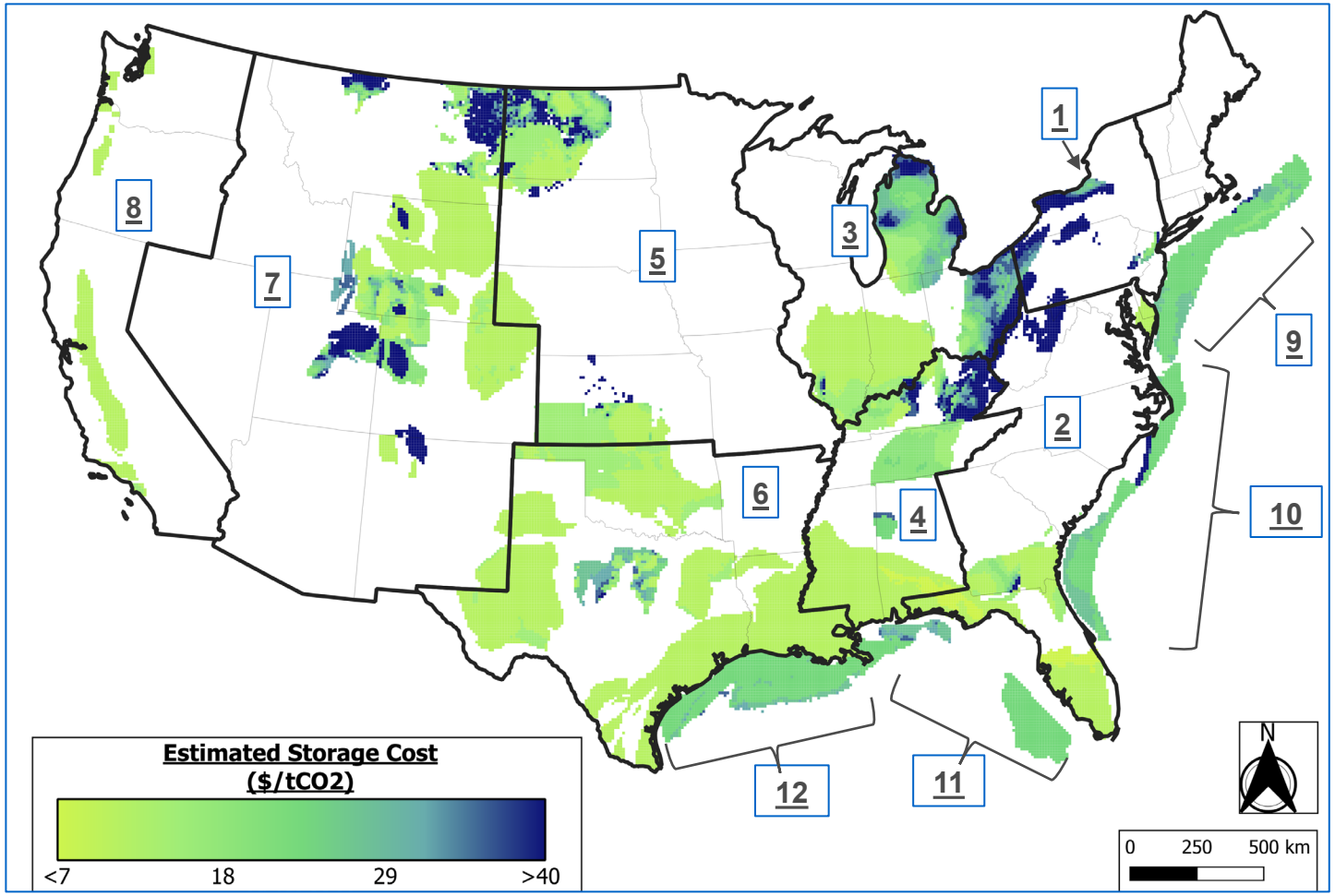


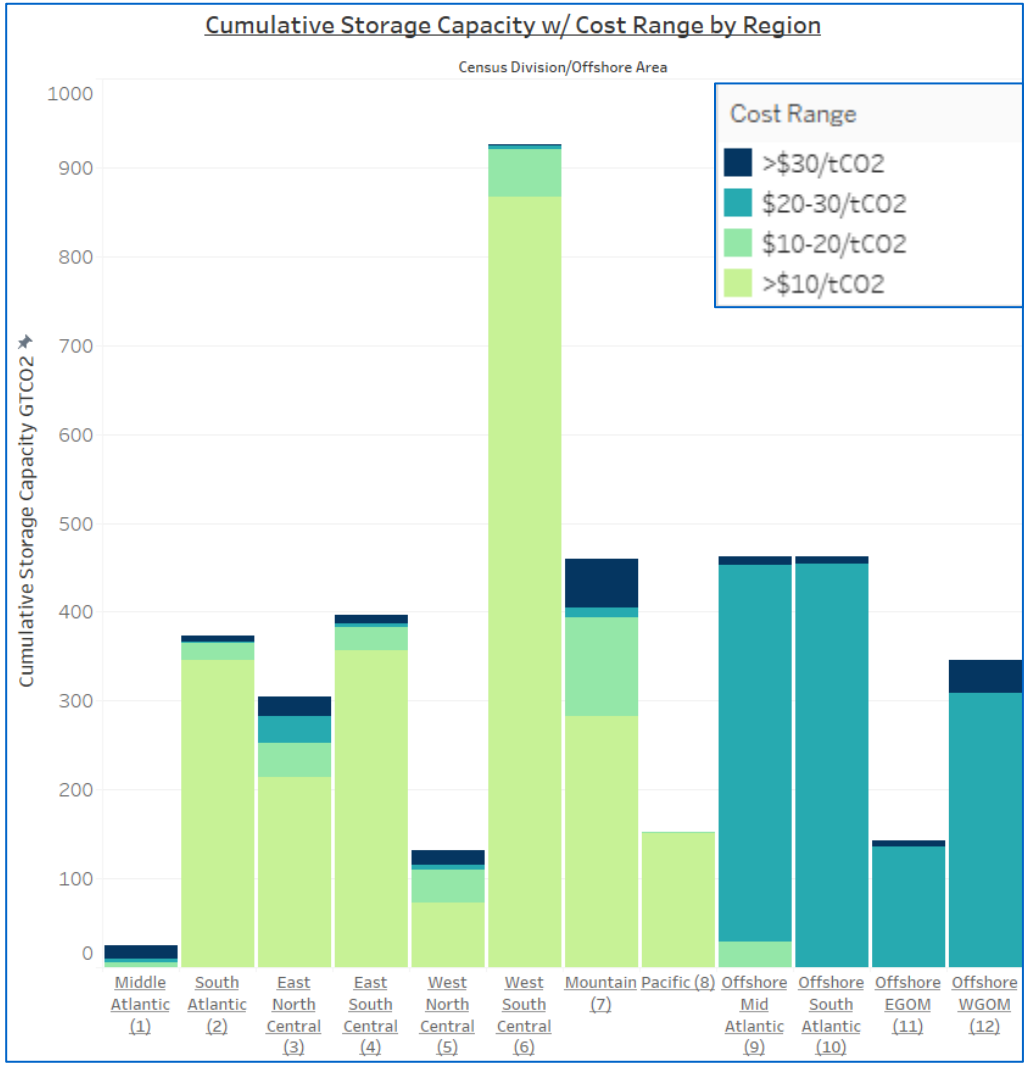


Map and chart reflect storage volumes for 1 reservoir per location

- If multiple reservoirs are present in specific a location, only results for the highest capacity reservoir are shown

Modeled Storage Cost



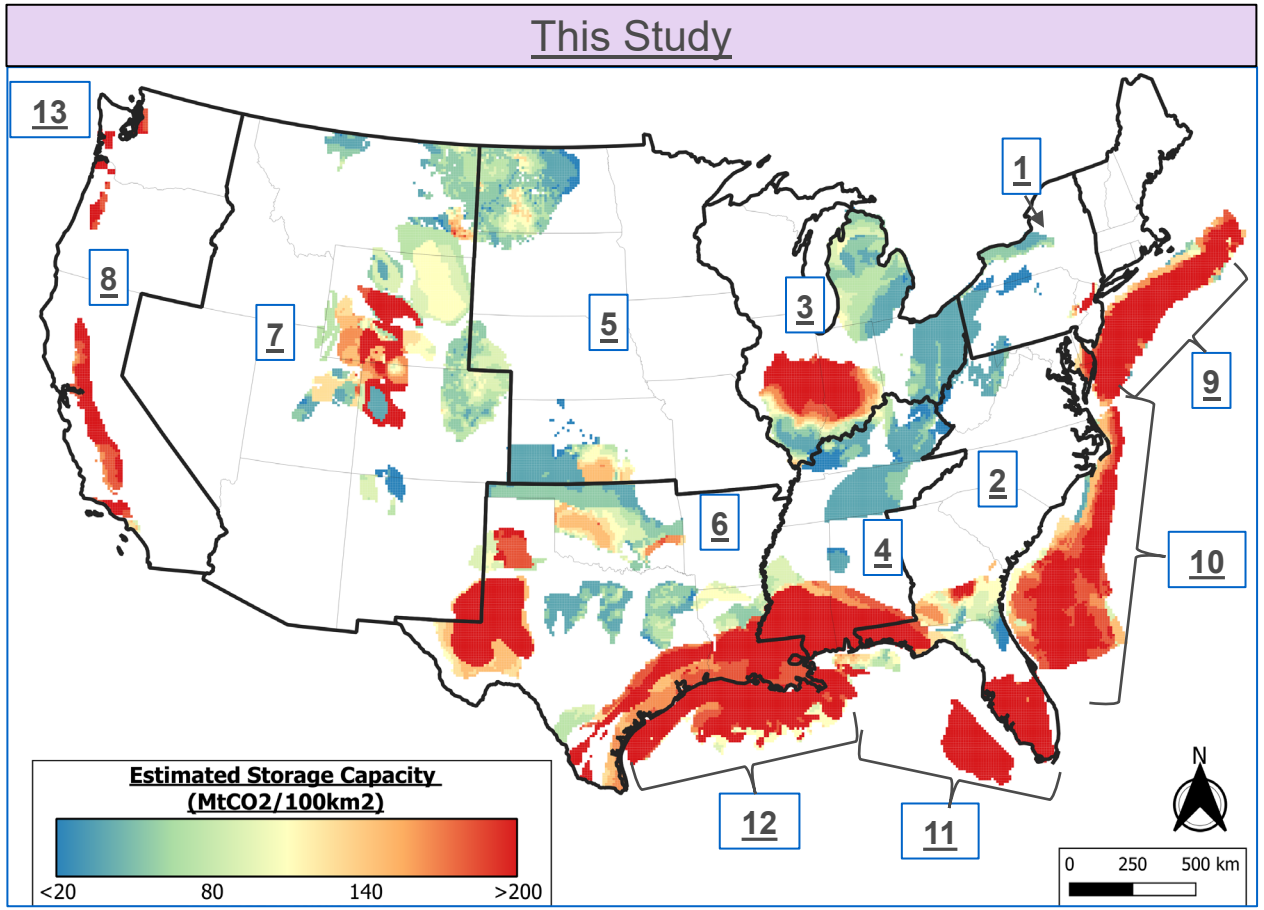


Map and chart reflect storage costs and volumes for 1 reservoir per location

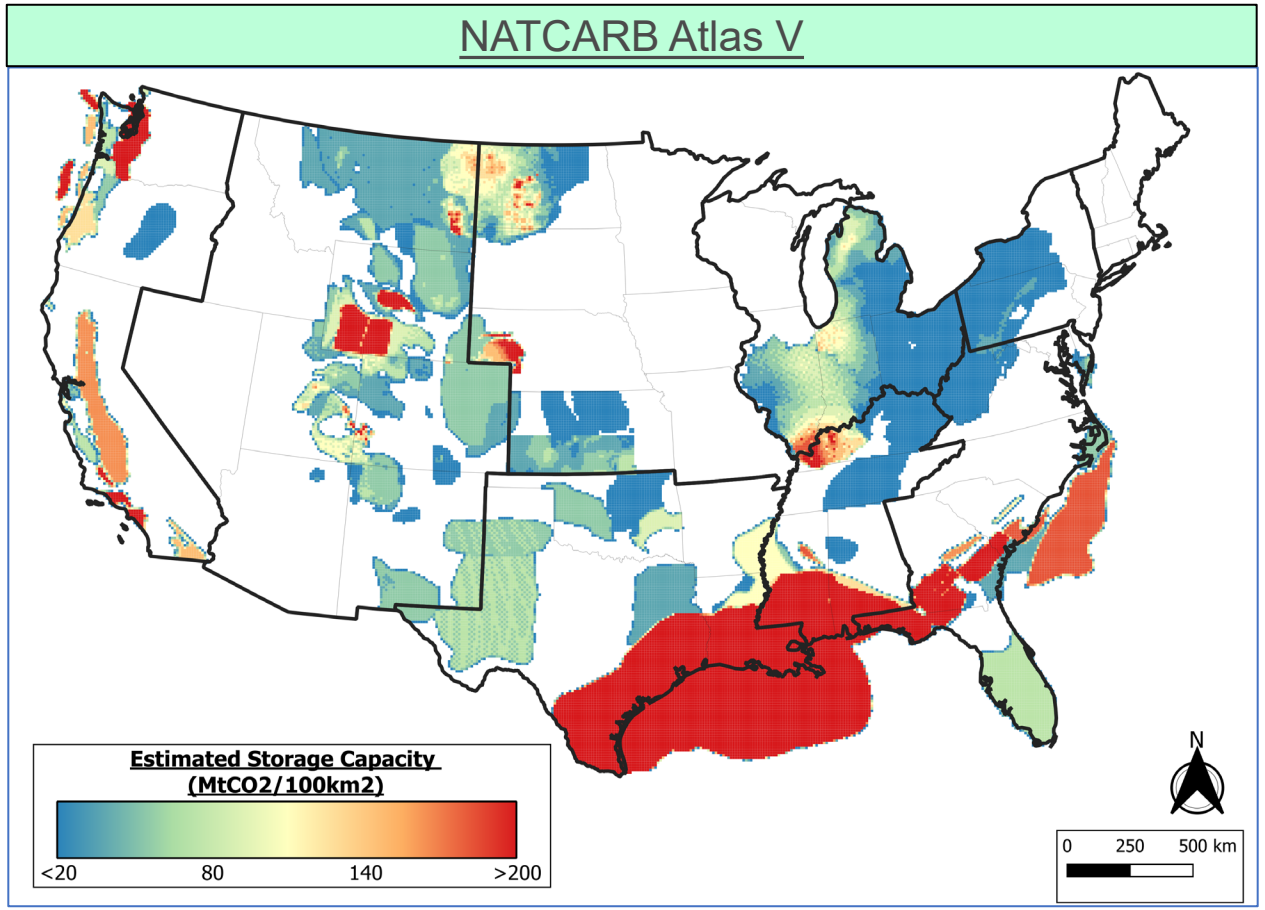
- If multiple reservoirs are present in specific a location, only results for the lowest cost reservoir are shown

Comparison with NATCARB Storage Capacity

This Study



NATCARB Atlas V



Map and table reflect storage volumes for 1 reservoir per location

Region	*Middle Atlantic*	*South Atlantic*	*East North Central*	*East South Central*	*West North Central*	*West South Central*	*Mountain*	*Pacific*	*Offshore Mid Atlantic*	*Offshore South Atlantic*	*Offshore EGOM*	*Offshore WGOM*	*Offshore PNW*	*Total*
Area #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	
Cumulative Storage Capacity (GtCO2)	25	374	322	441	140	936	509	153	502	468	142	397	0	*4409*
NATCARB Cumulative Storage Capacity (GtCO2)	11	367	170	440	164	1239	452	351	0	191	47	1601	41	*5074*
Difference	56%	2%	47%	0%	-17%	-32%	11%	-129%	100%	59%	67%	-303%	-100%	*-15%*

Summary

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Geologic CO_2 storage cost and capacity were modeled for reservoirs from across the continental US and adjacent offshore areas

- This information is critical for regional planning and CO_2 storage site identification
- Existing regional/national scale geology storage property datasets lack coverage and spatial variability, limiting their utility

Storage properties were modeled using Carbon Solutions':

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- Geologic Reservoir Property Database

The model results indicate that saline aquifer reservoirs across the US could potentially store 100's of Gt of CO_2 for <$10/t, but distribution of that storage is not equitable across the country

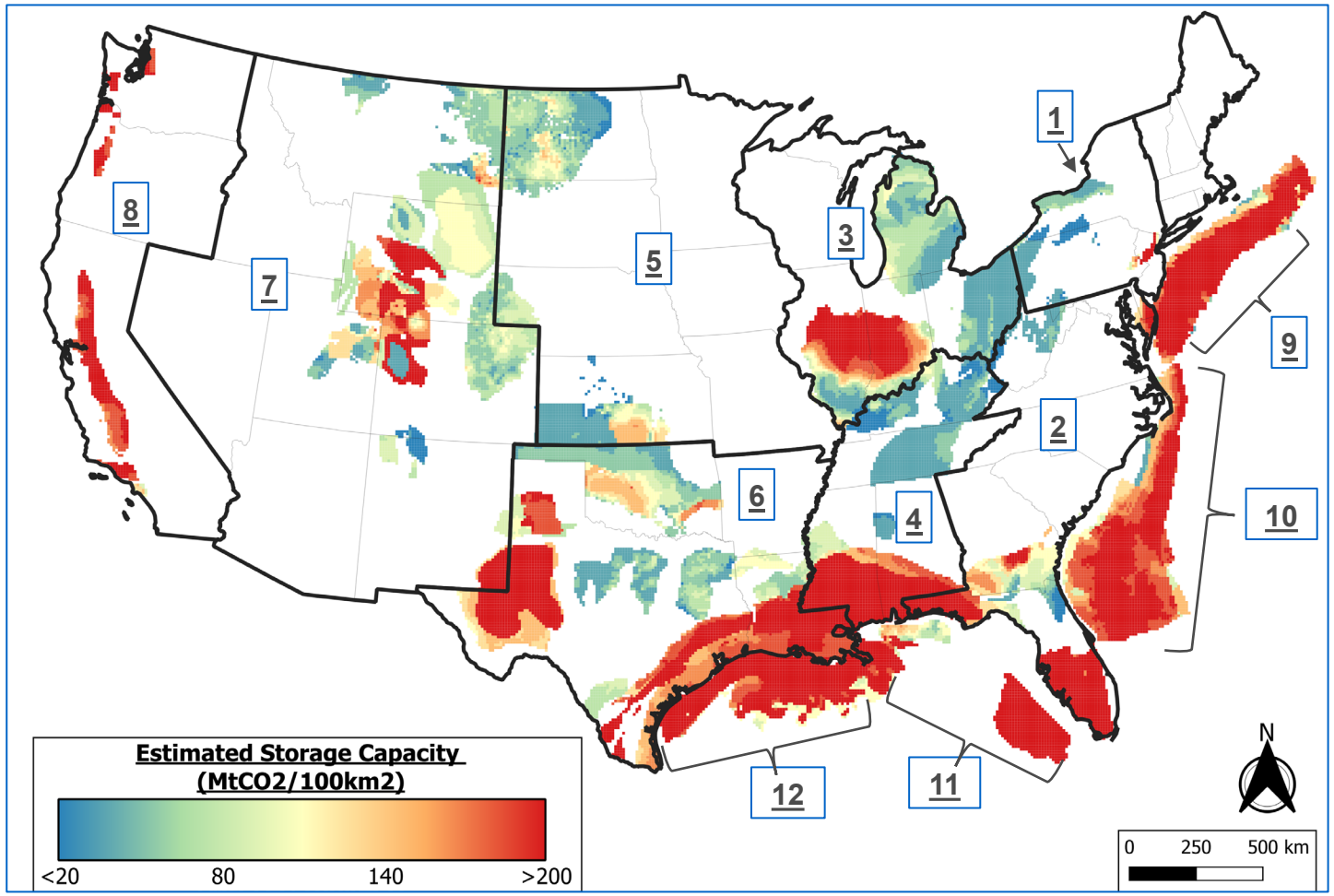
- Gulf Coast, Southeast, W Texas, CA Central Valley, portions of the Rocky Mountains region, and Central IN & IL provide the highest capacity/lowest cost storage
  - This does not mean storage is viable at any given location in these regions
    - Lack of data, geohazards, competition for pore space, and limited reservoir options
- Marginal regional geologic reservoir quality limits storage prospects in areas such as Appalachia
  - More localized areas with more prospective storage properties will exist, detailed geologic investigation and characterization of extra importance in such areas
- Limited to no aquifer storage opportunities modeled throughout onshore East Coast, much of the Southwest, Pacific NW, many North Central/Plains states
  - Part due to lack of suitable geologic reservoirs
  - Part due to lack of accessible regional scale geologic datasets suitable for modeling CO_2 storage properties
- Estimated offshore reservoir storage capacities are immense
  - But the cost of storage is significantly higher than onshore reservoirs with similar geologic conditions

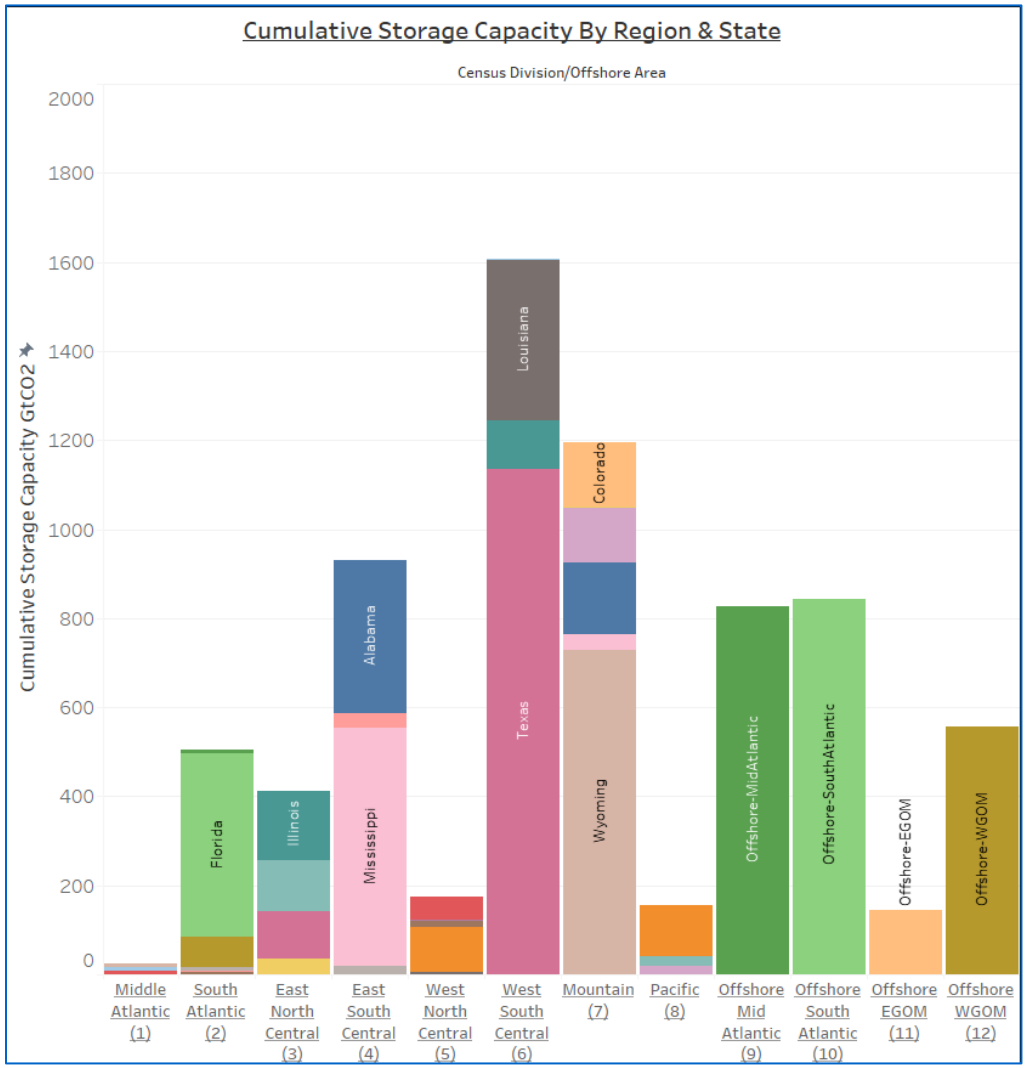
Results were compared to storage data from the NATCARB Carbon Storage Atlas V

- Cumulative storage capacities and high-level trends in the distribution were similar
- Geographic and stratigraphic coverage differ significantly for a variety of reasons
- This study's dataset better reflects the spatial variability inherent and provides estimates for important storage properties such as cost, making it a better tool for regional planning and site screening purposes.

Appendix

Modeled Storage Capacity (All Reservoirs)



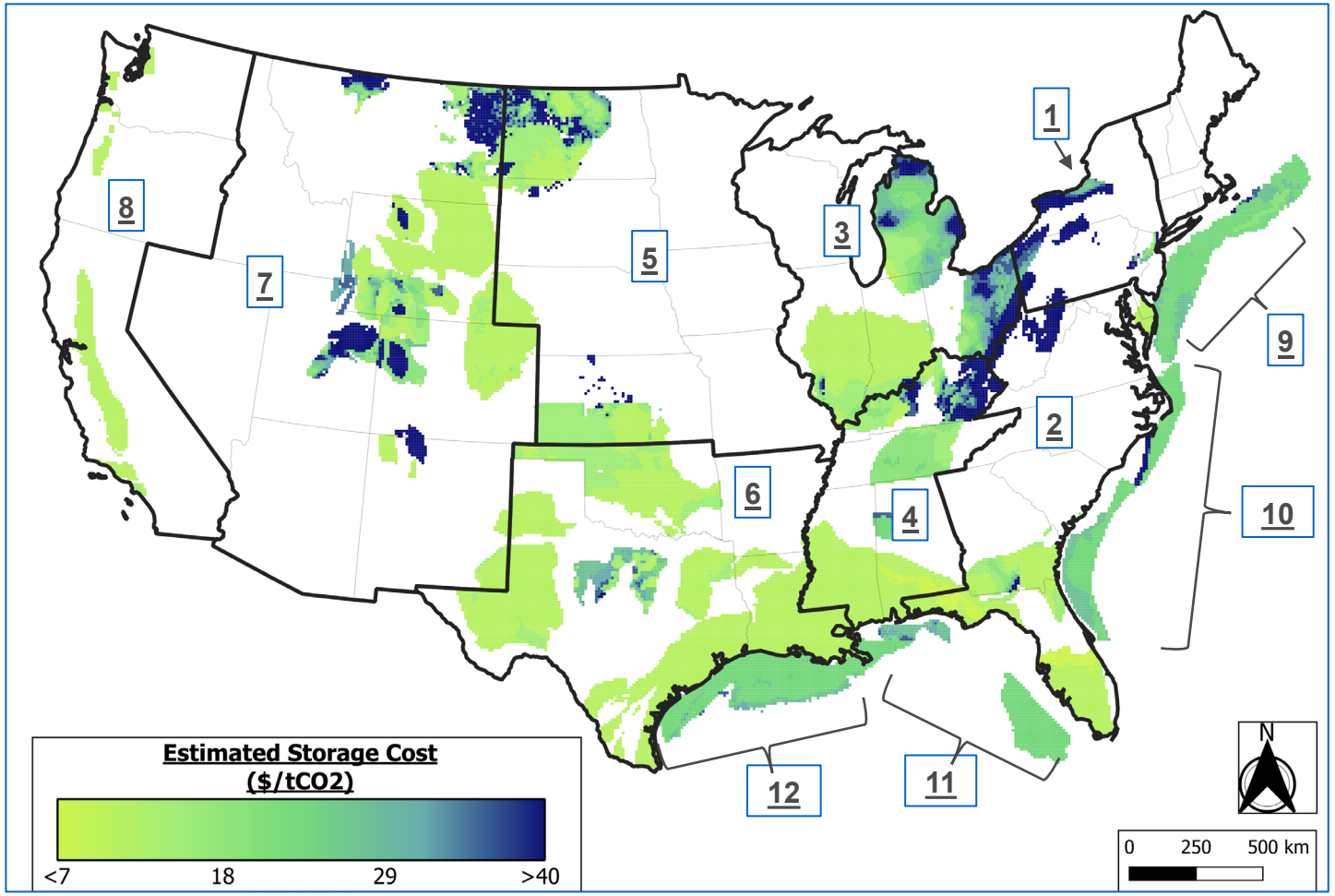


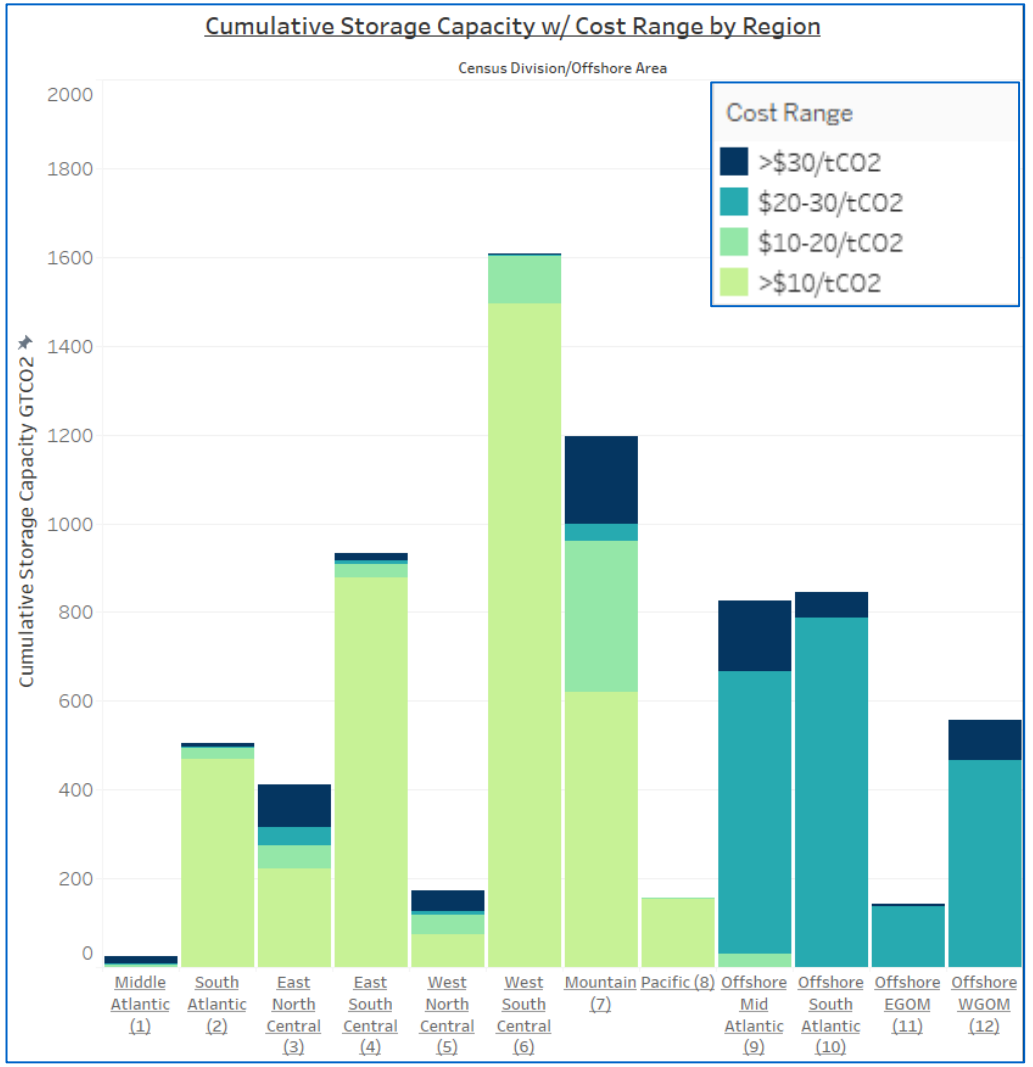
Map reflects storage capacity volumes for 1 reservoir per location

- If multiple reservoirs are present in specific a location, only results for the lowest cost reservoir are shown

Chart includes data for all reservoirs

Modeled Storage Cost (All Reservoirs)



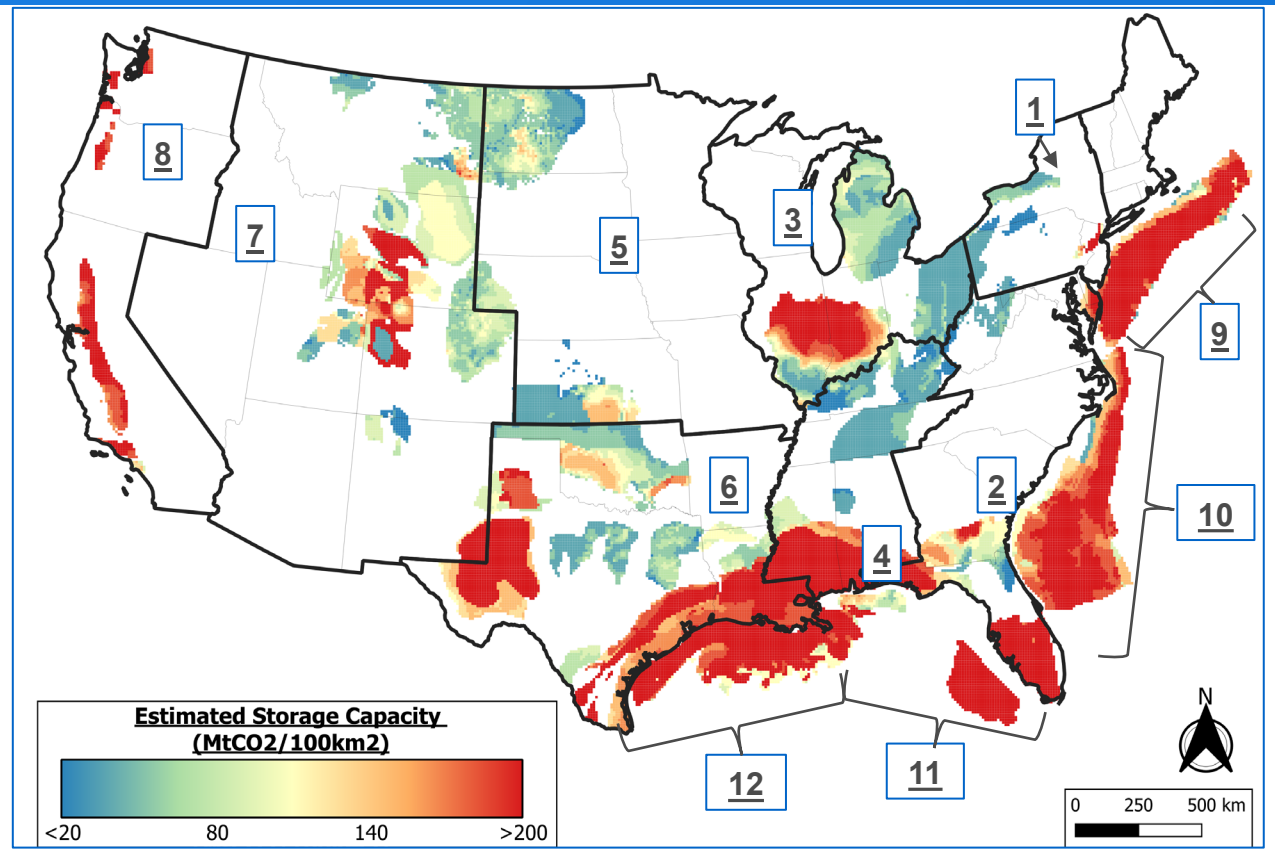


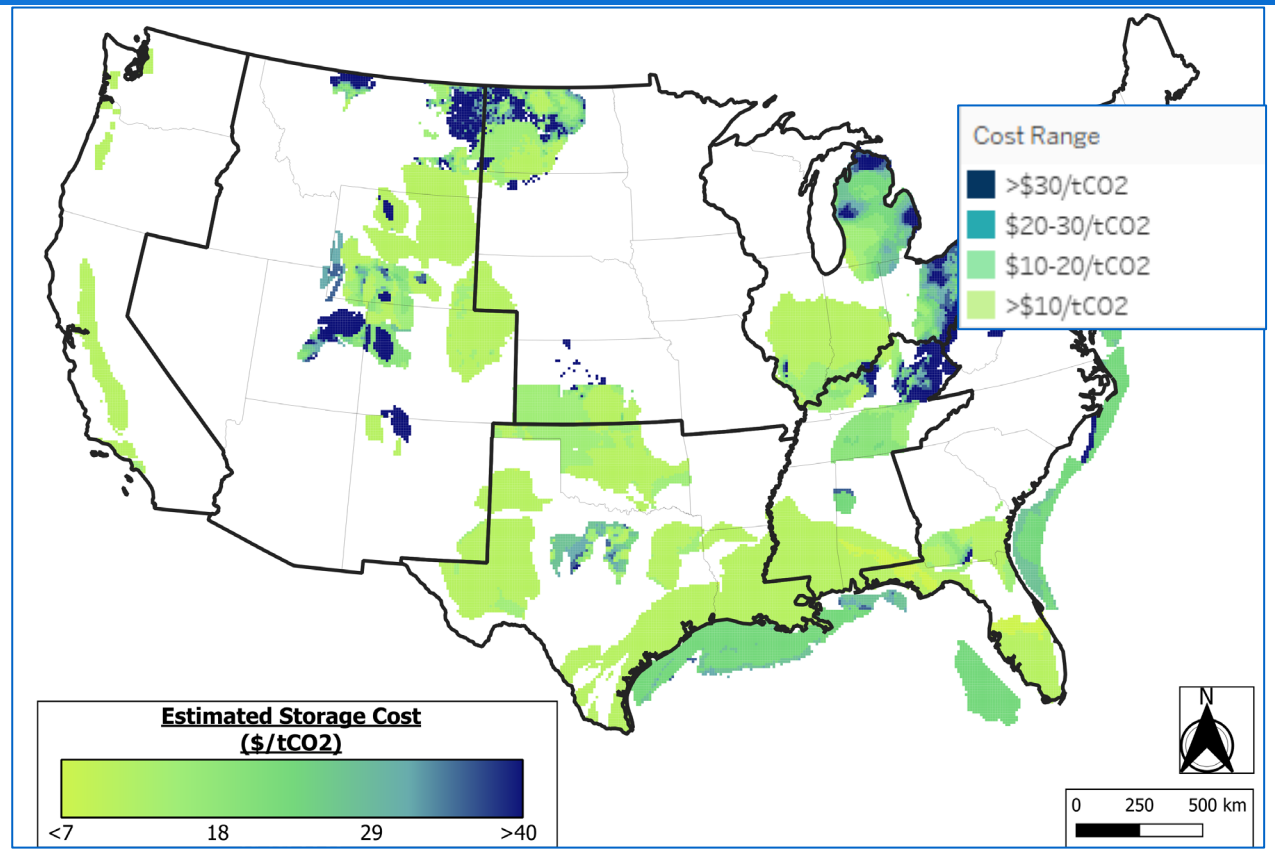
Map reflects storage costs and volumes for 1 reservoir per location

- If multiple reservoirs are present in specific a location, only results for the lowest cost reservoir are shown

Chart includes data for all reservoirs

Modeled Storage Cost & Capacity





Map and table reflect storage costs and volumes for 1 reservoir per location

- If multiple reservoirs are present in specific a location, only results for the lowest cost/highest capacity reservoir are shown

Region	*Middle Atlantic*	*South Atlantic*	*East North Central*	*East South Central*	*West North Central*	*West South Central*	*Mountain*	*Pacific*	*Offshore Mid Atlantic*	*Offshore South Atlantic*	*Offshore EGOM*	*Offshore WGOM*	*Total*
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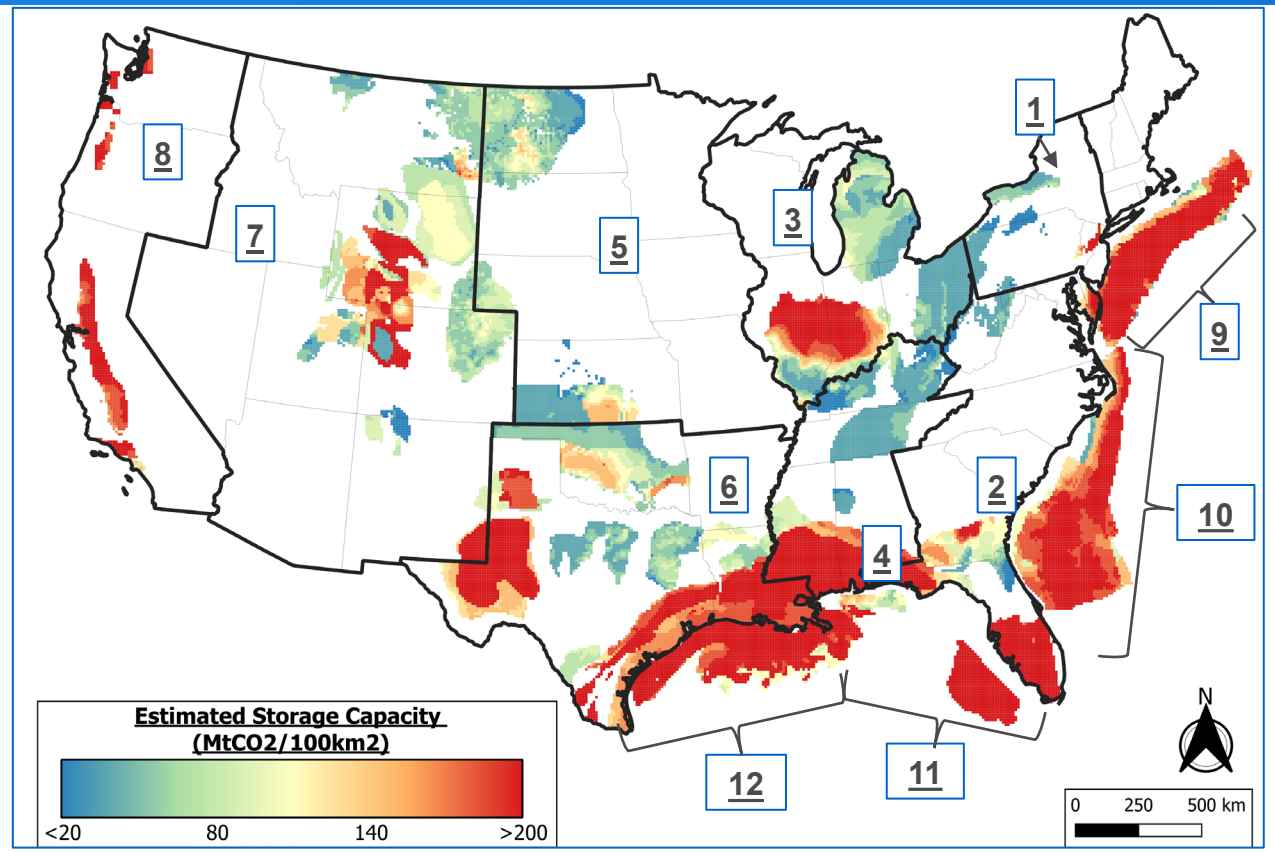
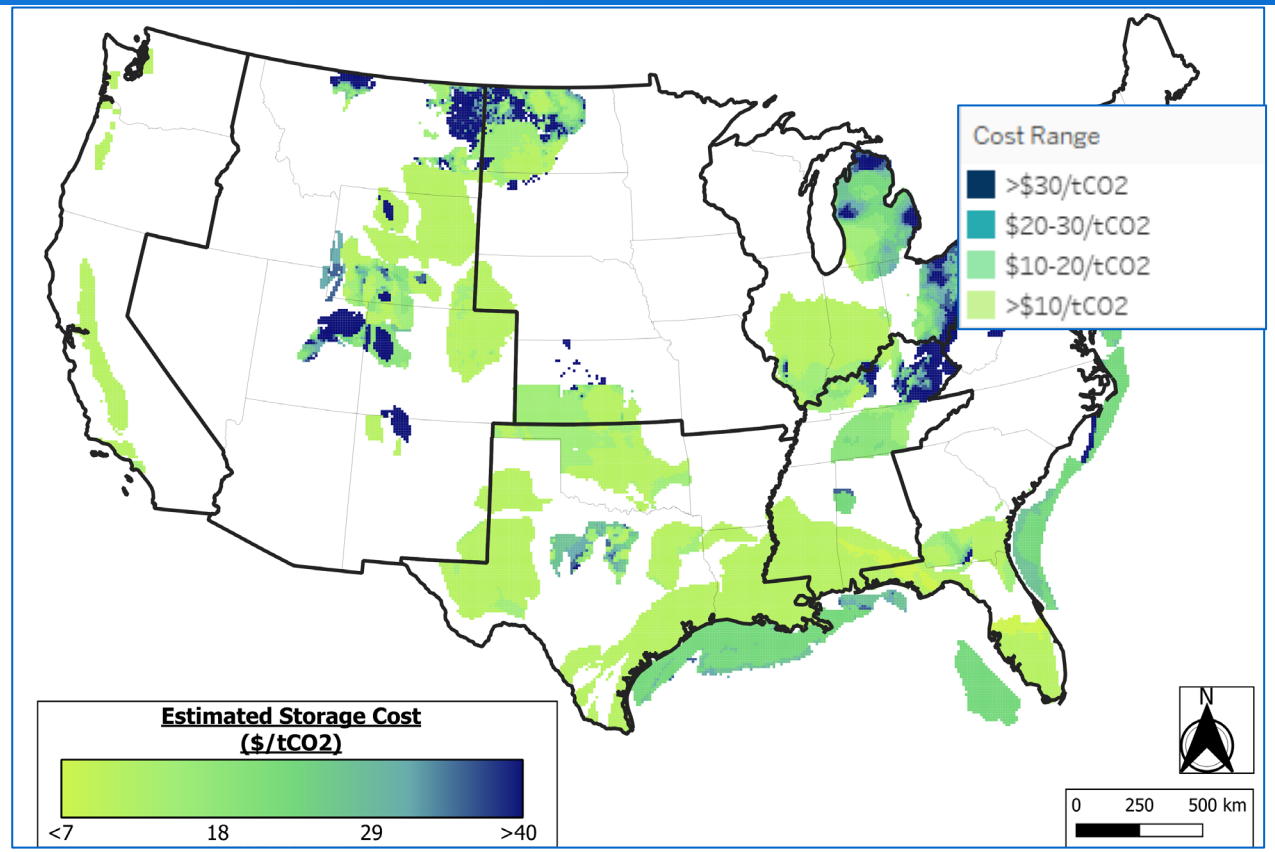
Cumulative Storage Capacity (GtCO2)	25	374	322	441	140	936	509	153	502	468	142	397	*4409*
Cumulative Storage Capacity w/ Storage Cost <$10/tCO2 (GtCO2)	0	346	214	357	73	867	282	151	0	0	0	0	*2290*
Cumulative Storage Capacity w/ Storage Cost $10-20/tCO2 (GtCO2)	5	19	39	26	37	53	112	1.4	30	0	0	0	*322.4*
Cumulative Storage Capacity w/ Storage Cost $20-30/tCO2 (GtCO2)	4	1	31	4	6	4	11	0	424	454	136	308	*1383*
Cumulative Storage Capacity w/ Storage Cost >$30/tCO2 (GtCO2)	16	7	21	9	15	2	54	0	10	8	6	38	*186*

Modeled Storage Cost & Capacity (All Reservoirs)





Map reflects storage costs and volumes for 1 reservoir per location

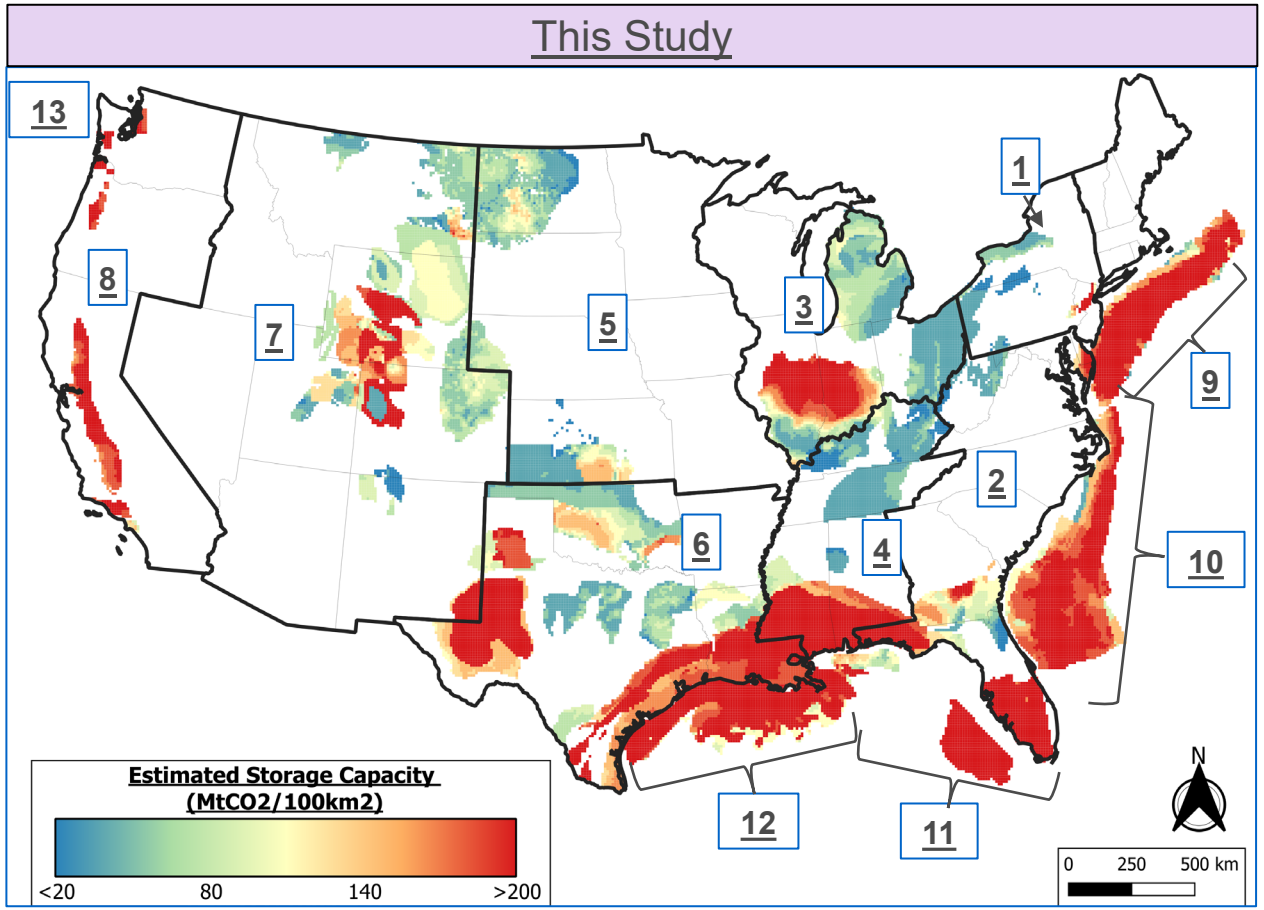
- If multiple reservoirs are present in specific a location, only results for the lowest cost/highest capacity reservoir are shown

Table includes data for all reservoirs

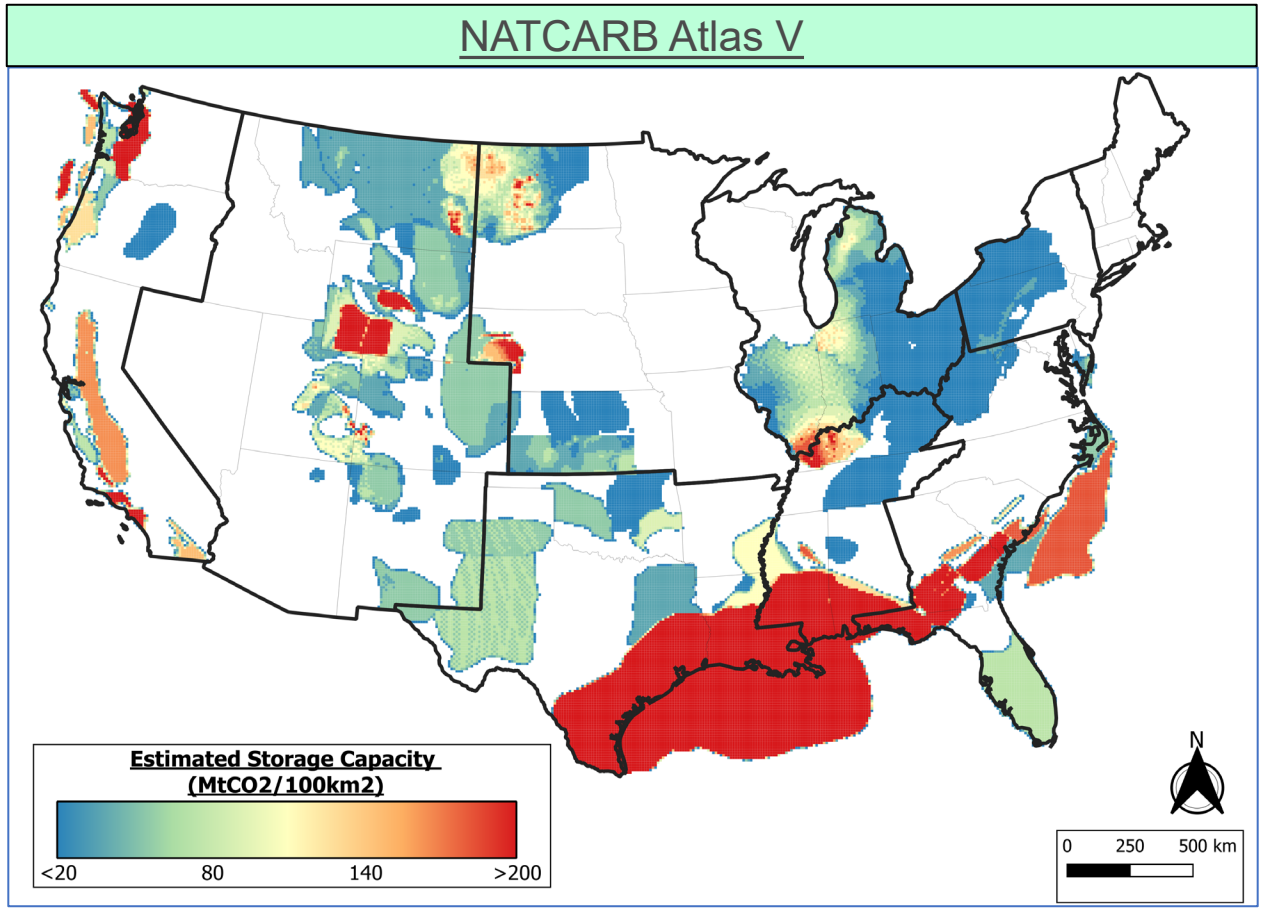
Region	*Middle Atlantic*	*South Atlantic*	*East North Central*	*East South Central*	*West North Central*	*West South Central*	*Mountain*	*Pacific*	*Offshore Mid Atlantic*	*Offshore South Atlantic*	*Offshore EGOM*	*Offshore WGOM*	*Total*
Area #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	
Cumulative Storage Capacity (GtCO2)	25	505	412	931	174	1608	1196	155	825	844	144	557	*7376*
Cumulative Storage Capacity w/ Storage Cost <$10/tCO2 (GtCO2)	0	469	223	877	73	1495	621	154	0	0	0	0	*3912*
Cumulative Storage Capacity w/ Storage Cost $10-20/tCO2 (GtCO2)	5	26	51	23	46	106	340	1	29	0	0	0	*627*
Cumulative Storage Capacity w/ Storage Cost $20-30/tCO2 (GtCO2)	4	2	42	6	6	4	38	0	636	787	136	465	*2126*
Cumulative Storage Capacity w/ Storage Cost >$30/tCO2 (GtCO2)	16	8	96	17	49	2	197	0	160	57	8	92	*702*

Comparison with NATCARB Storage Capacity (All Reservoirs)

This Study



NATCARB Atlas V



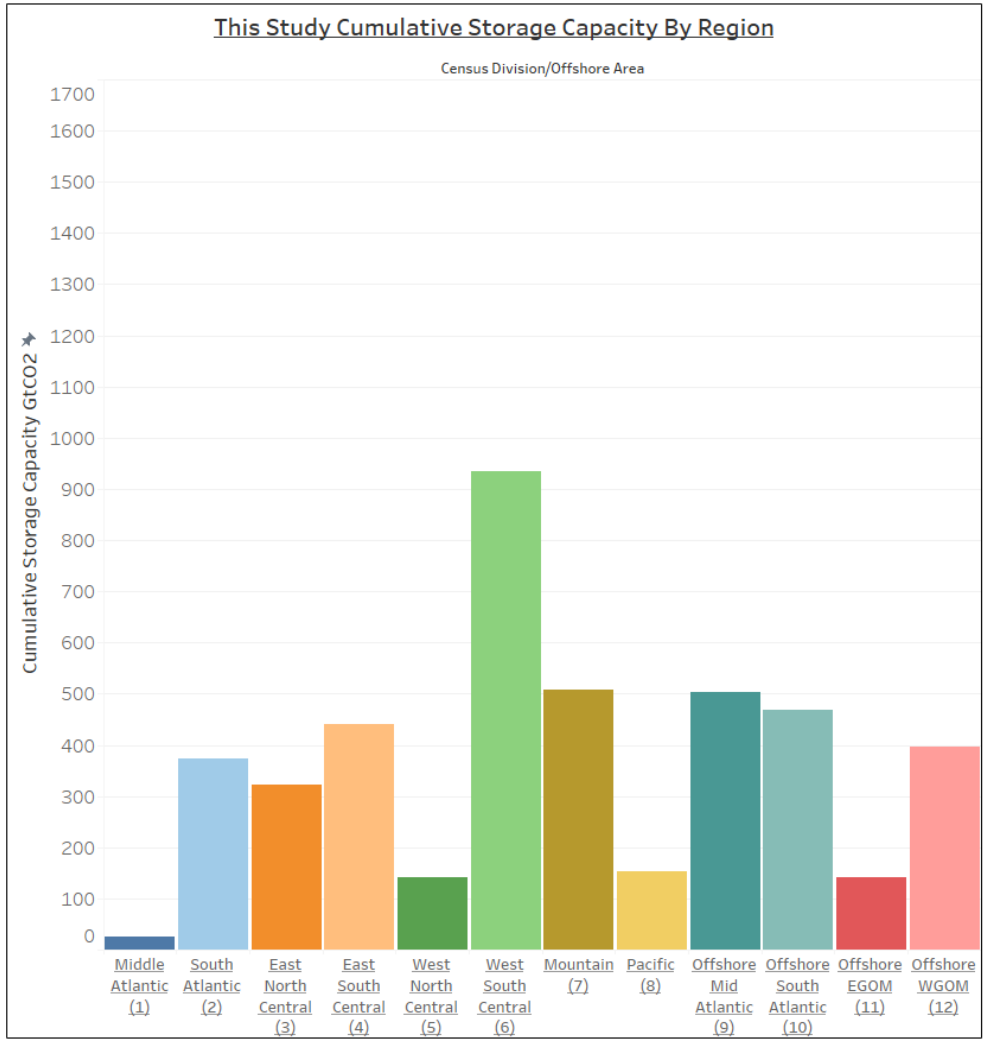
Map reflects storage capacity volumes for 1 reservoir per location

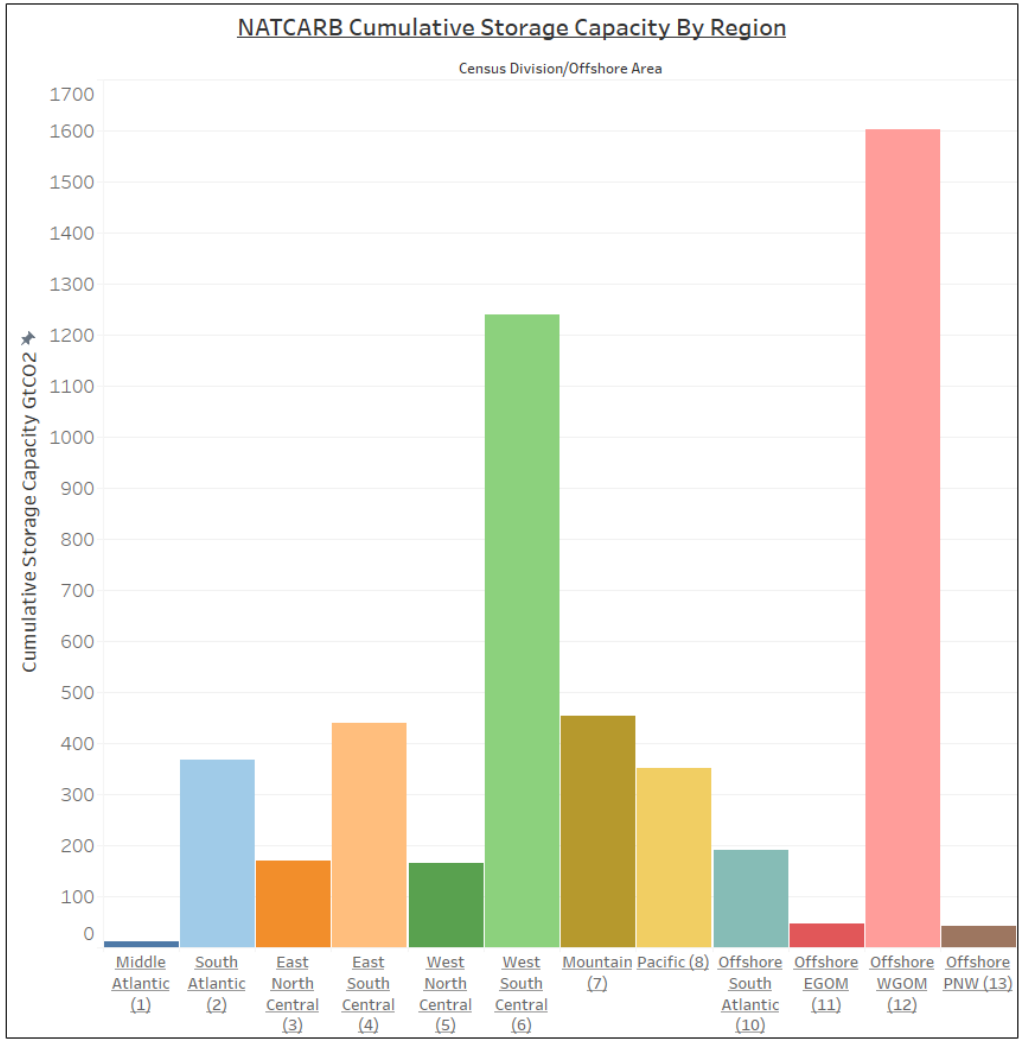
- If multiple reservoirs are present in specific a location, only results for the lowest cost reservoir are shown

Table includes data for all reservoirs

Region	*Middle Atlantic*	*South Atlantic*	*East North Central*	*East South Central*	*West North Central*	*West South Central*	*Mountain*	*Pacific*	*Offshore Mid Atlantic*	*Offshore South Atlantic*	*Offshore EGOM*	*Offshore WGOM*	*Offshore PNW*	*Total*
Area #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	
Cumulative Storage Capacity All Reservoirs (GtCO2)	25	505	412	931	174	1608	1196	155	825	844	144	557	0	*7376*
NATCARB Cumulative Storage Capacity All Reservoirs (GtCO2)	22	438	203	800	235	2221	1349	352	0	209	54	2102	41	*8026*
Difference All Reservoirs	12%	13%	51%	14%	-35%	-38%	-13%	-127%	100%	75%	63%	-277%	-100%	*-9%*

NATCARB Comparison Chart (Only 1 Reservoir Per Location)

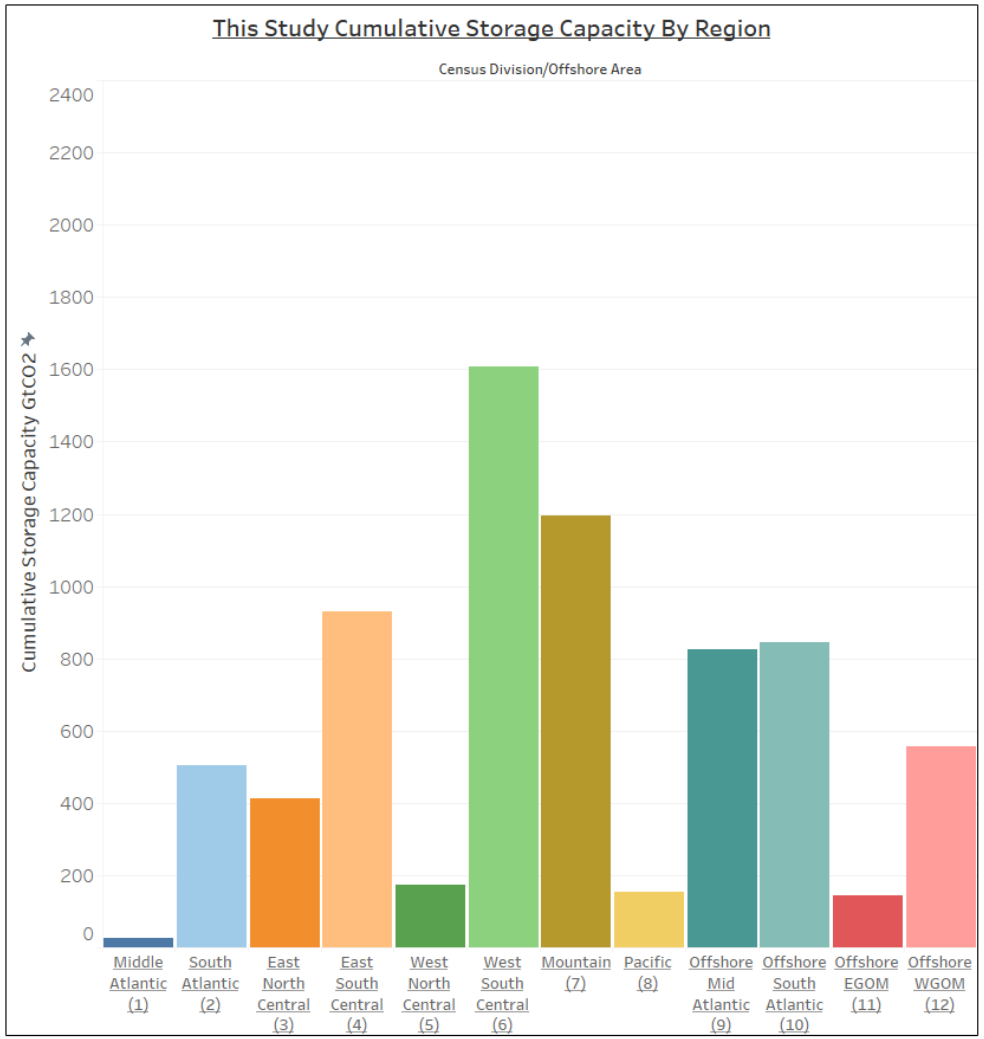


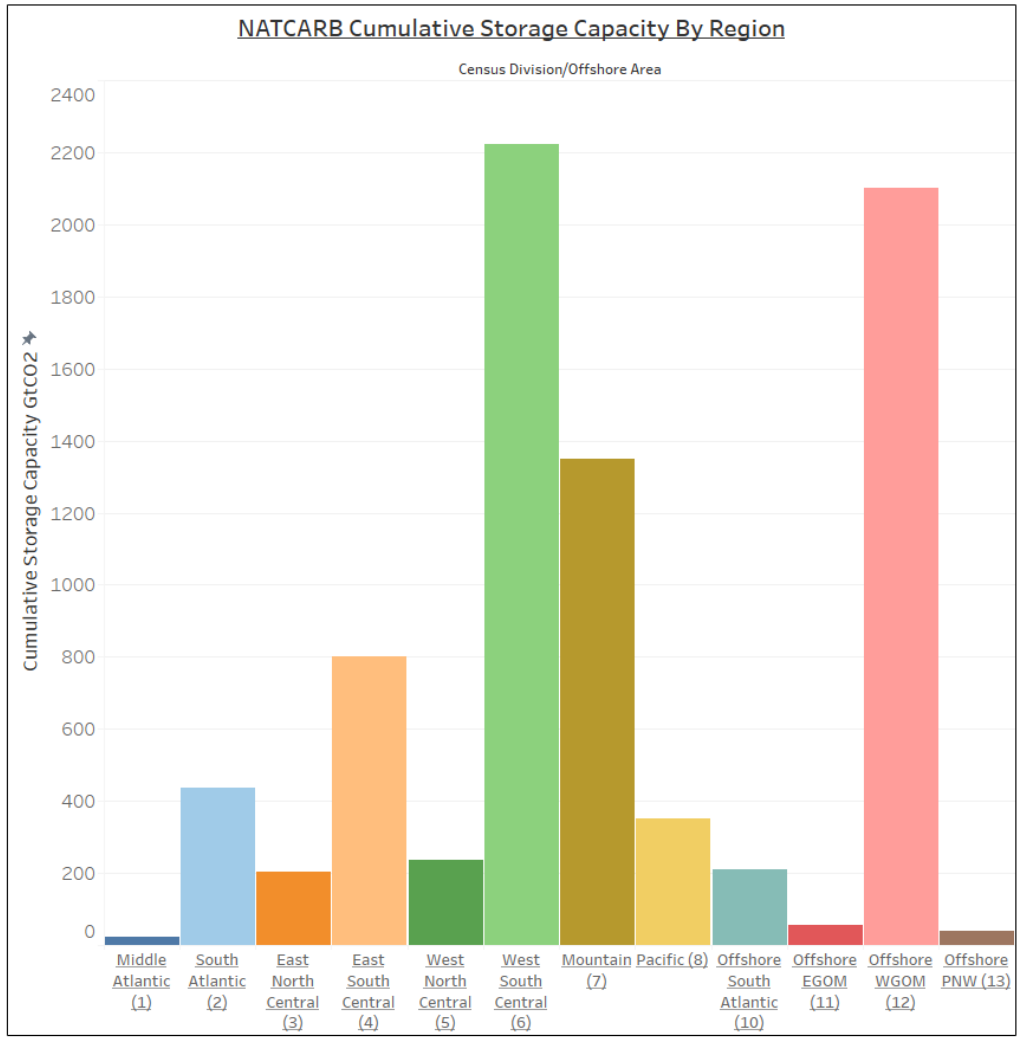


Charts reflect storage volumes for 1 reservoir per location

- If multiple reservoirs are present in specific a location, only results for the highest capacity reservoir are shown

NATCARB Comparison Chart (All Reservoirs)





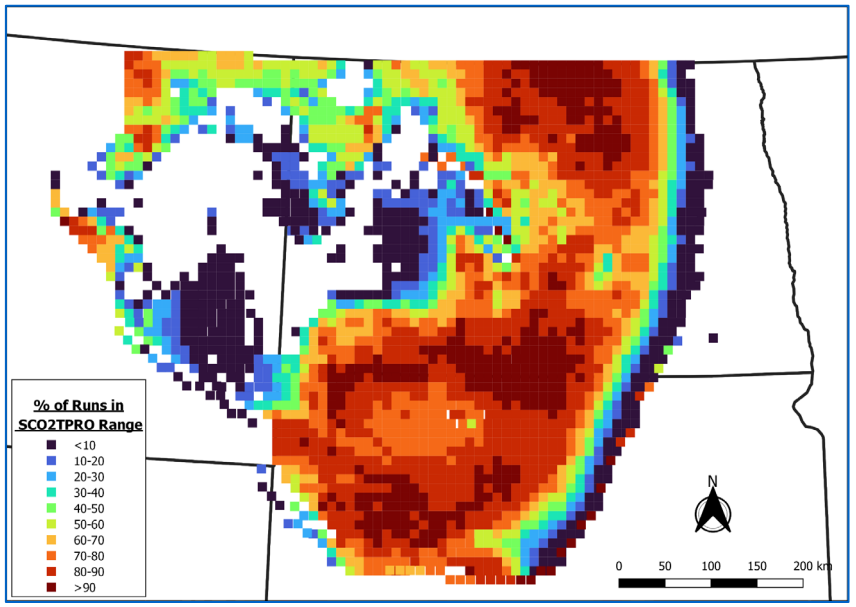
Charts reflect storage volumes for all reservoirs

- Not just the largest capacity reservoir at each location

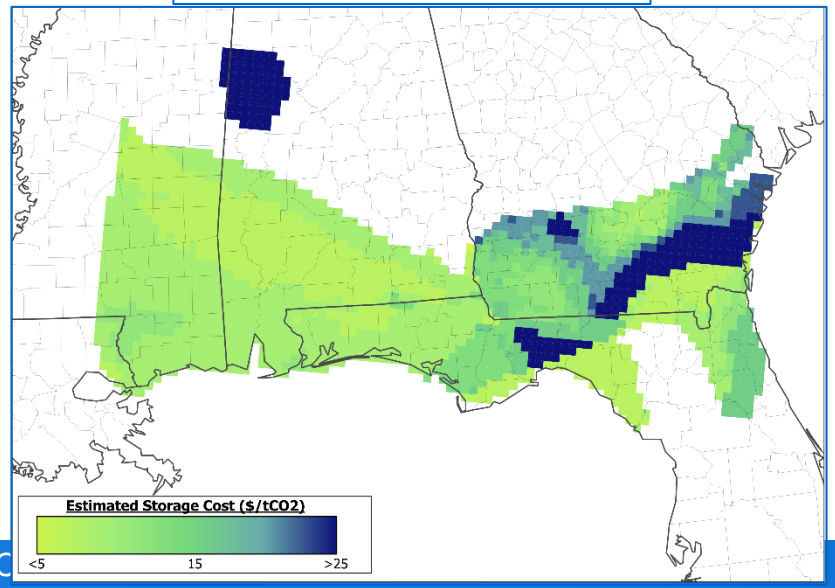
Data Summary

Region	Area #	Cumulative Storage Capacity (GtCO2)	Cumulative Storage Capacity All Reservoirs (GtCO2)	NATCARB Cumulative Storage Capacity (GtCO2)	NATCARB Cumulative Storage Capacity All Reservoirs (GtCO2)	Difference	Difference All Reservoirs	Cumulative Storage Capacity w/ Storage Cost <$10/tCO2 (GtCO2)	Cumulative Storage Capacity w/ Storage Cost $10-20/tCO2 (GtCO2)	Cumulative Storage Capacity w/ Storage Cost $20-30/tCO2 (GtCO2)	Cumulative Storage Capacity w/ Storage Cost >$30/tCO2 (GtCO2)	Cumulative Storage Capacity w/ Storage Cost <$10/tCO2 All Reservoirs (GtCO2)	Cumulative Storage Capacity w/ Storage Cost $10-20/tCO2 All Reservoirs (GtCO2)	Cumulative Storage Capacity w/ Storage Cost $20-30/tCO2 All Reservoirs (GtCO2)	Cumulative Storage Capacity w/ Storage Cost >$30/tCO2 All Reservoirs (GtCO2)
Middle Atlantic	*1*	25	25	11	22	56%	12%	0	5	4	16	0	5	4	16
South Atlantic	*2*	374	505	367	438	2%	13%	346	19	1	7	469	26	2	8
East North Central	*3*	322	412	170	203	47%	51%	214	39	31	21	223	51	42	96
East South Central	*4*	441	931	440	800	0%	14%	357	26	4	9	877	23	6	17
West North Central	*5*	140	174	164	235	-17%	-35%	73	37	6	15	73	46	6	49
West South Central	*6*	936	1608	1239	2221	-32%	-38%	867	53	4	2	1495	106	4	2
Mountain	*7*	509	1196	452	1349	11%	-13%	282	112	11	54	621	340	38	197
Pacific	*8*	153	155	351	352	-129%	-127%	151	1.4	0	0	154	1	0	0
Offshore Mid Atlantic	*9*	502	825	0	0	100%	100%	0	30	424	10	0	29	636	160
Offshore South Atlantic	*10*	468	844	191	209	59%	75%	0	0	454	8	0	0	787	57
Offshore EGOM	*11*	142	144	47	54	67%	63%	0	0	136	6	0	0	136	8
Offshore WGOM	*12*	397	557	1601	2102	-303%	-277%	0	0	308	38	0	0	465	92
Offshore PNW	*13*	0	0	41	41	-100%	-100%	0	0	0	0	0	0	0	0
Total		*4409*	*7376*	*5074*	*8026*	*-15%*	*-9%*	*2290*	*322.4*	*1383*	*186*	*3912*	*627*	*2126*	*702*

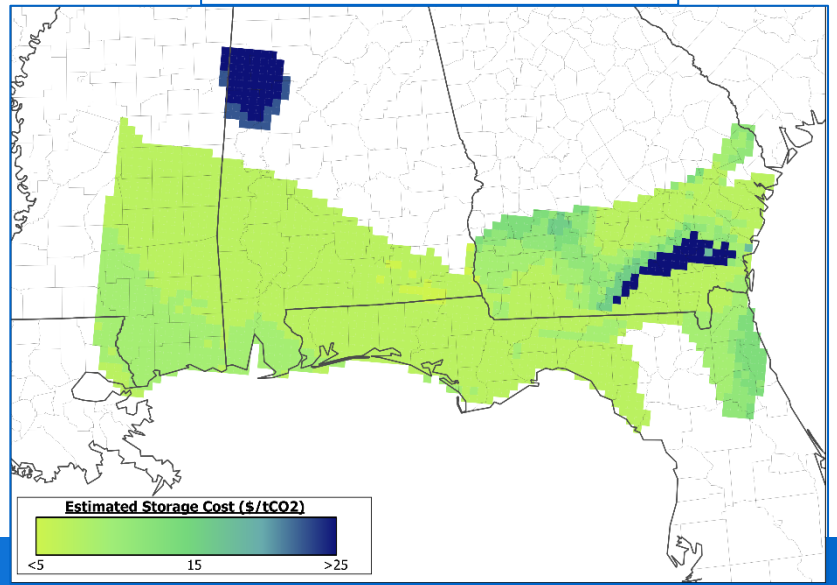
Next Steps: Uncertainty Analysis



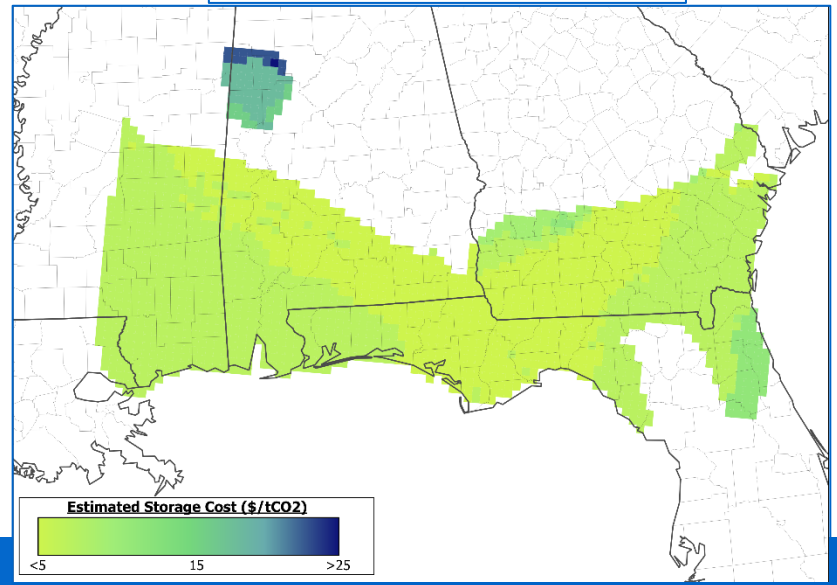
P10 Storage Cost



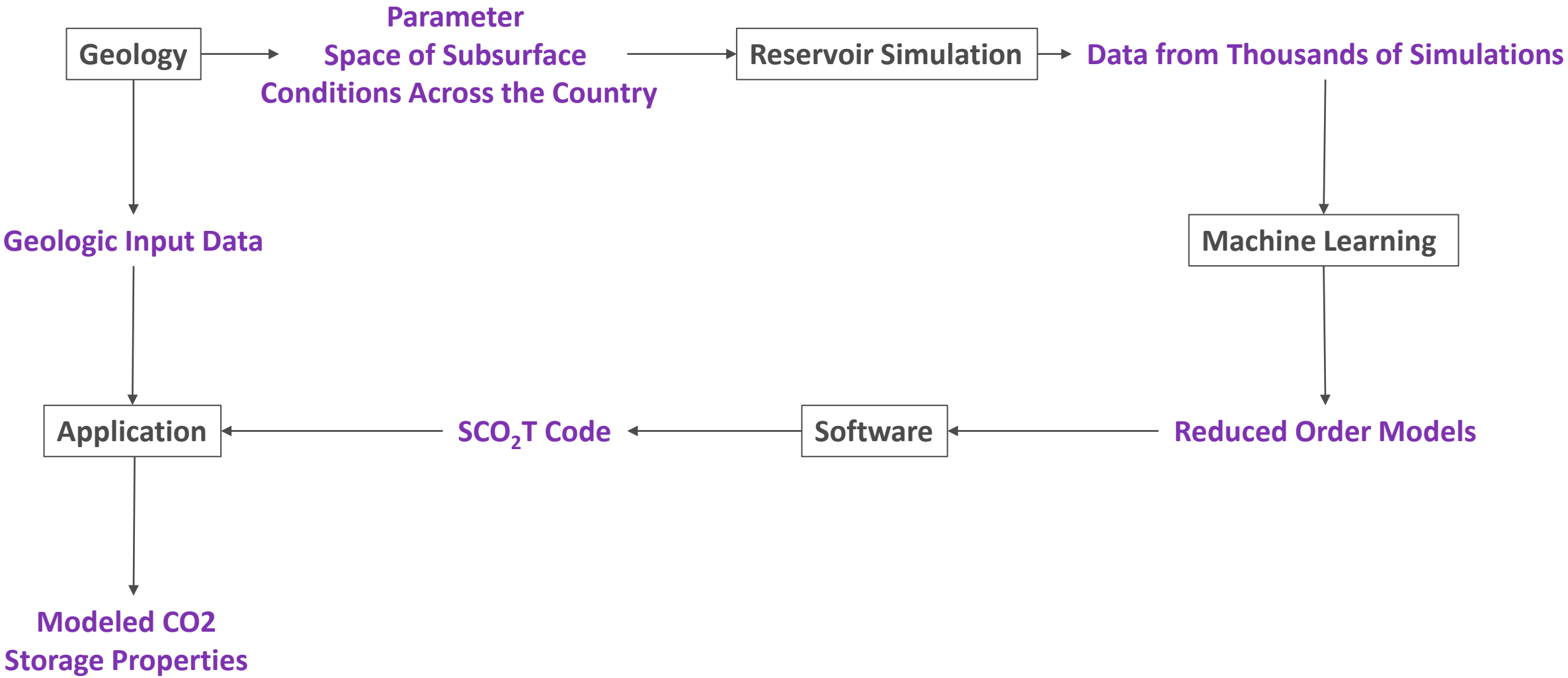
P50 Storage Cost



P90 Storage Cost



SCO_2T^{PRO} Process



SCO_2T^{PRO} Cost Model & Example

Cost Model inputs and assumptions include *but are not limited to:*

- Financing
  - Financing period
  - Discount rate
- Project duration
  - Injection period
  - PISC length
- Well design
  - Well diameter
  - Maximum injection rate
- Location
  - Onshore vs offshore
  - # of existing wells to plug