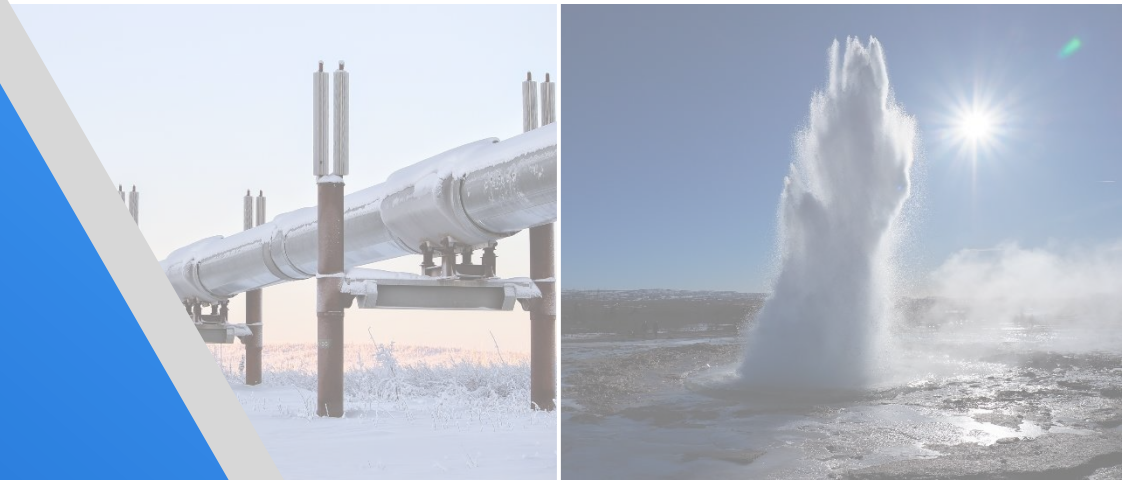
CARBON SOLUTIONS

Advances in Nationwide Carbon Storage Estimates to Support a Net-Zero Economy

Richard Middleton, Ben Adams, Kyle Cox, Peter Johnson, Erin Middleton, Jonathan Ogland-Hand
CARBON SOLUTIONS
richard.middleton@carbonsolutionsllc.com

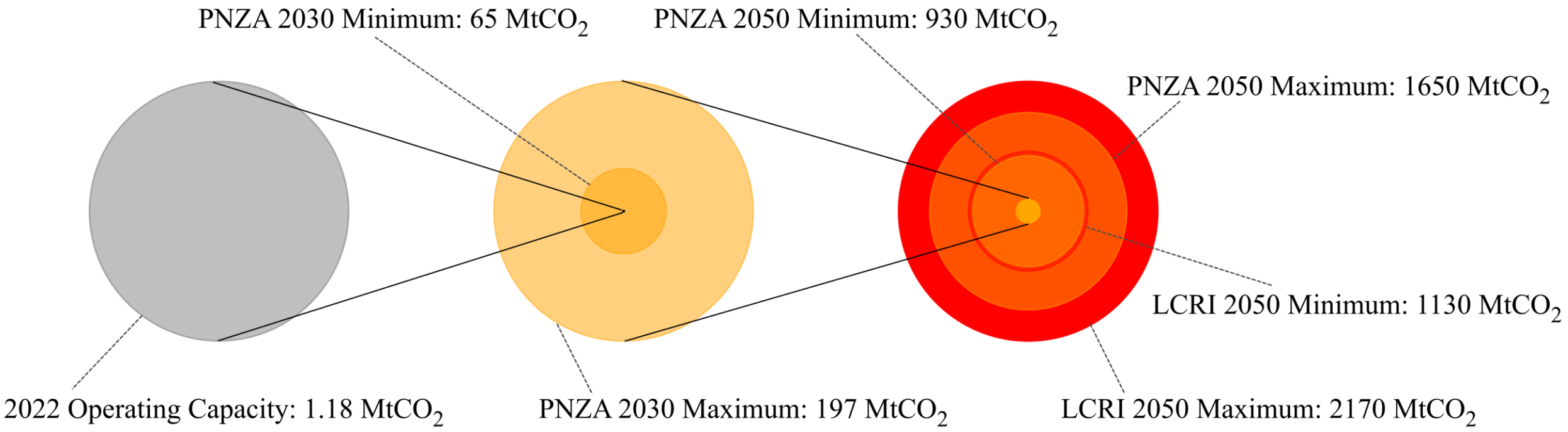
AGU Fall Meeting | December 15th, 2023





Geologic CO_2 Storage for a US Net-Zero Carbon Economy

Reaching net-zero requires a coordinated effort



Ogland-Hand et al. (2023), How to Net-Zero America: Nationwide Cost and Capacity Estimates for Geologic CO_2 Storage, *https://doi.org/10.31224/3293*.

- Princeton Net-Zero America Report (PNZA): *https://netzeroamerica.princeton.edu*
- Low-Carbon Resources Initiative (LCRI): *https://lcri-netzero.epri.com/*
- 2022 Operating Capacity: *https://www.globalccsinstitute.com/resources/global-status-of-ccs-2022/*

Carbon Solutions

How To Net-Zero America: Nationwide Cost and Capacity Estimates for Geologic CO_2 Storage

Authors: Jonathan D. Ogland-Hand, Kyle J. Cox, Benjamin M. Adams, Jeffrey A. Bennett, Peter J. Johnson, Erin J. Middleton, Carl J. Talsma, Richard S. Middleton

Contributors: Tara Gross and Jacqueline Taylor

Date: October 18, 2023

Timeline

2012 | Pre-SCO_2T for *SimCCS*.
2014 | Version 1.00 released (*link*)
2018 | SCO_2T public domain release with *SimCCS*.
2019 | Open-source SCO_2T as part of R&D 100 Award.
2020 | Publication-release of ROMs with publication.
2021 | Carbon Solutions LLC formed.
2021–2024 | SCO_2T^{PRO}, DOE Office of Science.

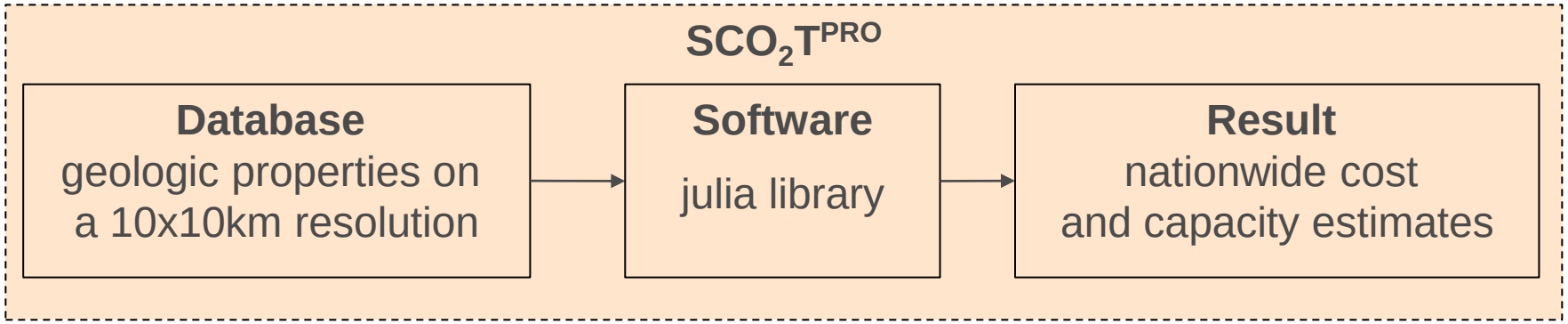
Publications

- SCO_2T **Part I** (2020): *link*.
- SCO_2T **Part II** (2021): *link*.
- SCO_2T **Part III** (2021): *link*.
- SCO_2T **Part IV** (2022): *link*.
- Application: **Plume Geothermal** (2022): *link*.
- Application: **Electricity Planning** (2022): *link*.
- Application: **Nationwide Potential** (2023): *link*.
- White paper: **How to net Zero** (2023): *link*.

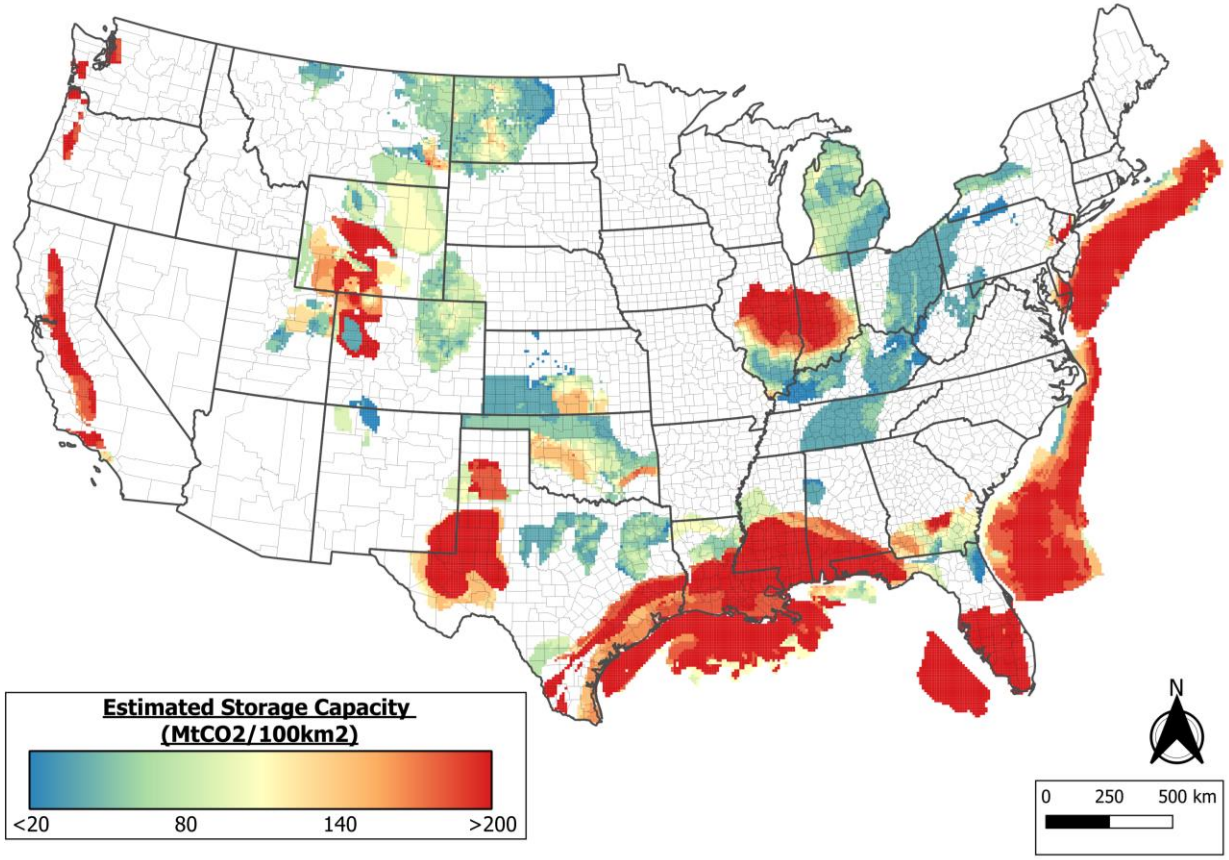
High-level Overview

Coupled Software *and* Database

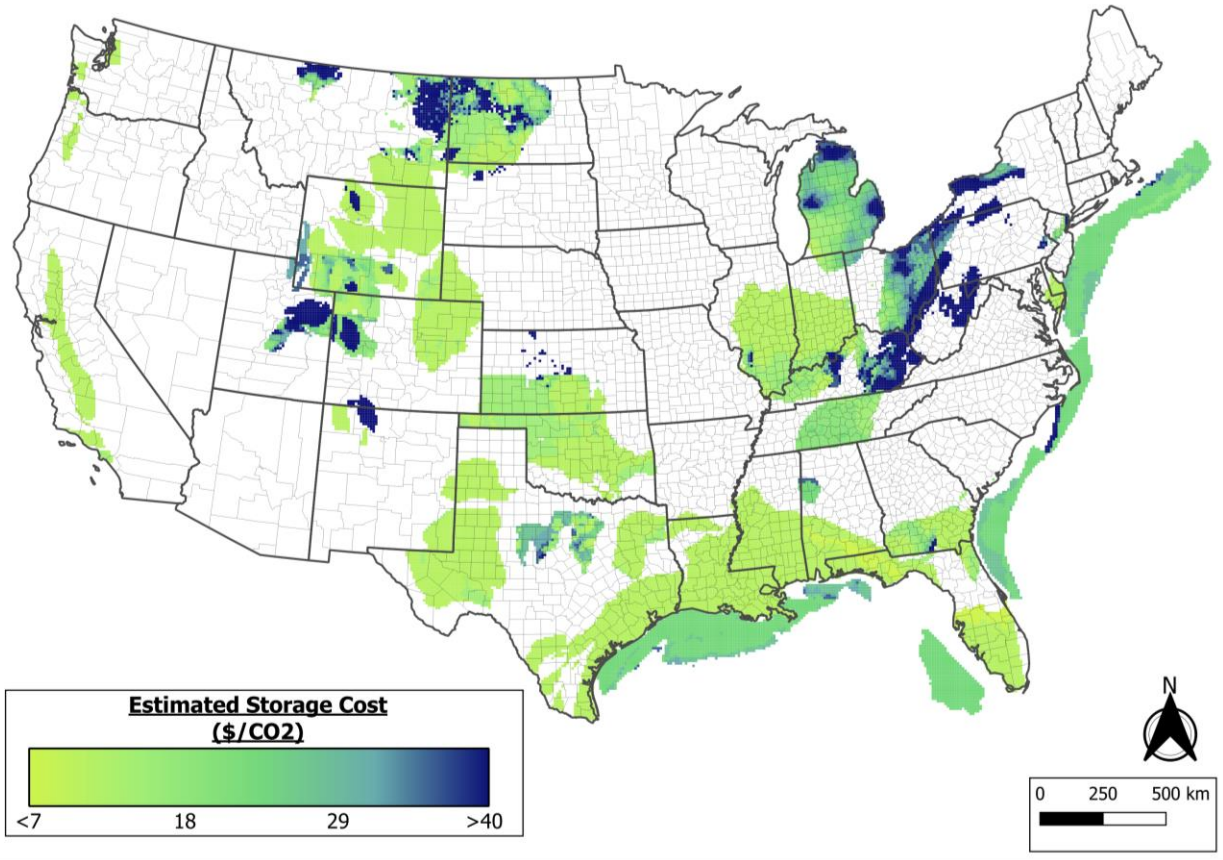
- Software uses reduced order models (ROMs) to estimate CO_2 injection rates, storage capacities, & per tonne costs
- ROMs trained with machine learning on reservoir simulation data
- Geology database currently covers over 119 reservoirs across 2.1 million km^2.



Nationwide Cost & Capacity of Geologic CO_2 Storage



Capacity



Cost

Nationwide Cost and Capacity of Geologic CO_2 Storage

Available storage

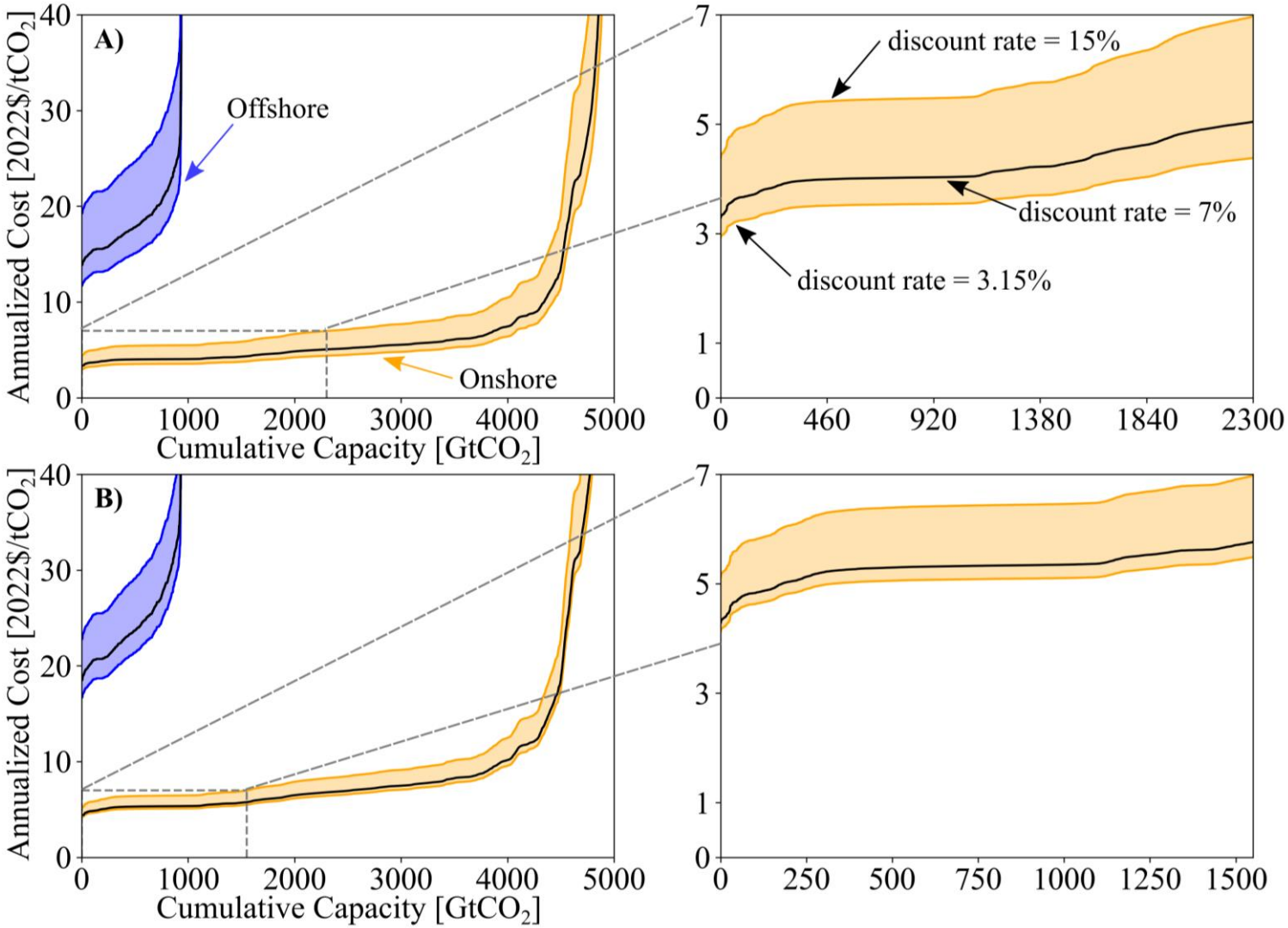
- Orders of magnitude more “low-cost” CO_2 storage than is needed to reach net-zero.
- 100s of years of stationary emissions.
- Spatial distribution.
- Coordination.

Offshore

- Approximately four times the cost of onshore injection & storage.
- Other advantages.

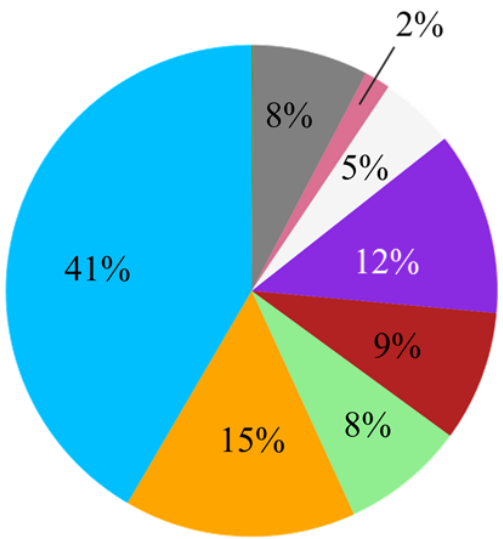
Financing

- Assumptions can impact costs by several dollars per tonne.



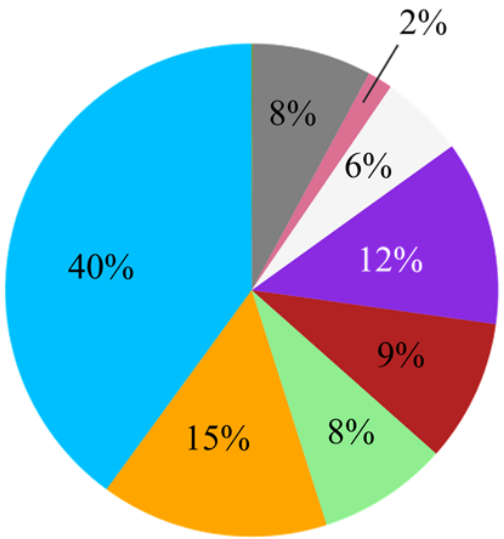
Onshore Deep Dive

Cost < $7/tCO$_2$



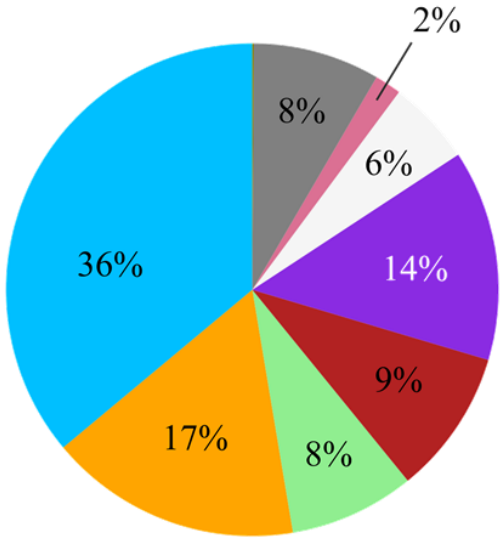
Total Capacity:
2,340 GtCO$_2$

$7/tCO$_2$ < Cost < $10/tCO$_2$



Total Capacity:
1,570 GtCO$_2$

Cost > $10/tCO$_2$



Total Capacity:
1,090 GtCO$_2$

Legend

- Operating Cost
- Injection Wells
- Surface Piping
- Permitting and Site Survey
- Monitoring Wells
- Surface Monitoring Equipment
- Stratigraphic Wells
- Contingency
- PISC

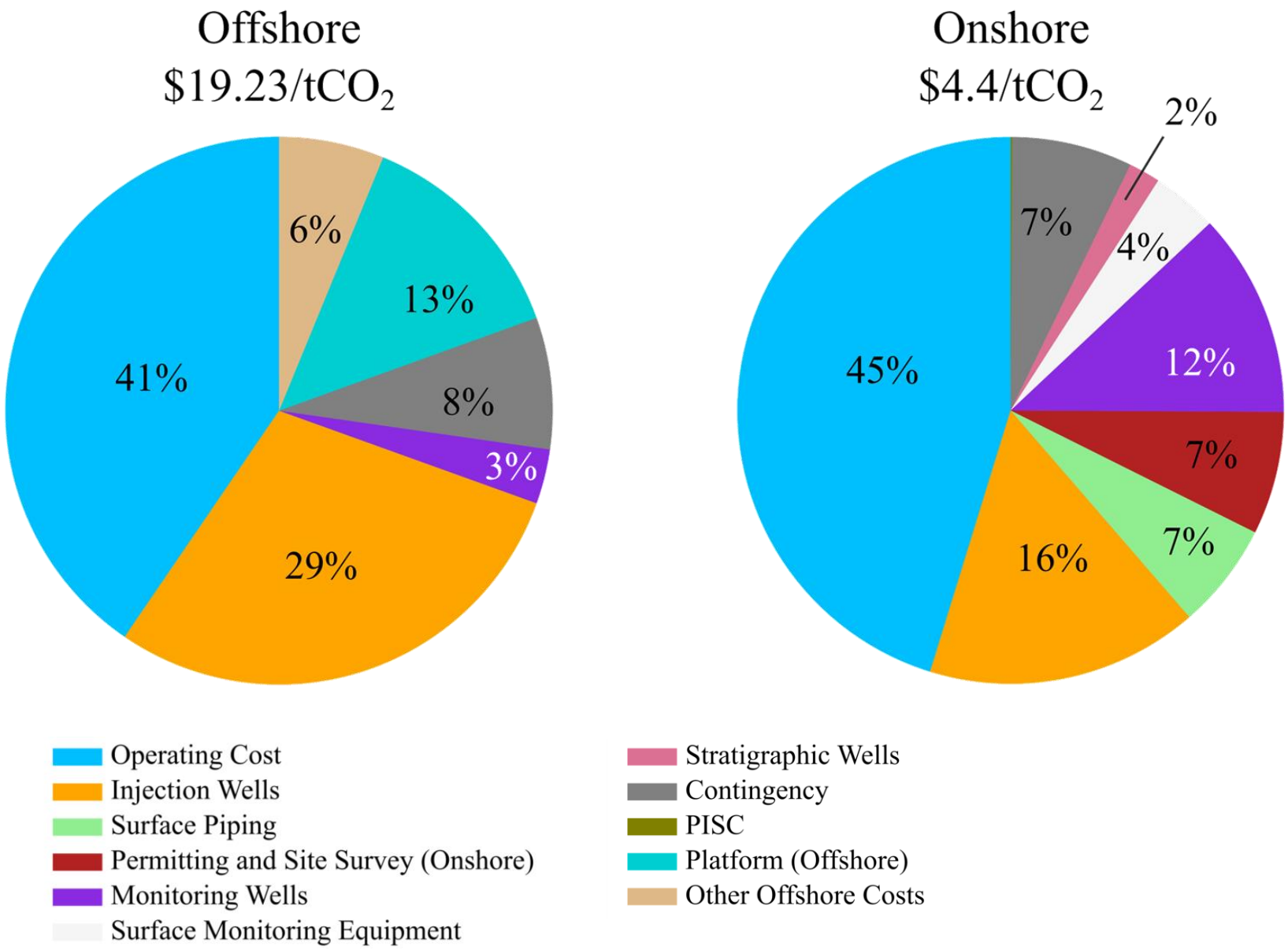
Costs

- Post-injection site care (PISC) is low because it's so far into the future.
- Cost breakdown doesn't change much with geology.
- OPEX is 36–41% of total costs.
- Costs drop significantly once CAPEX is cleared.

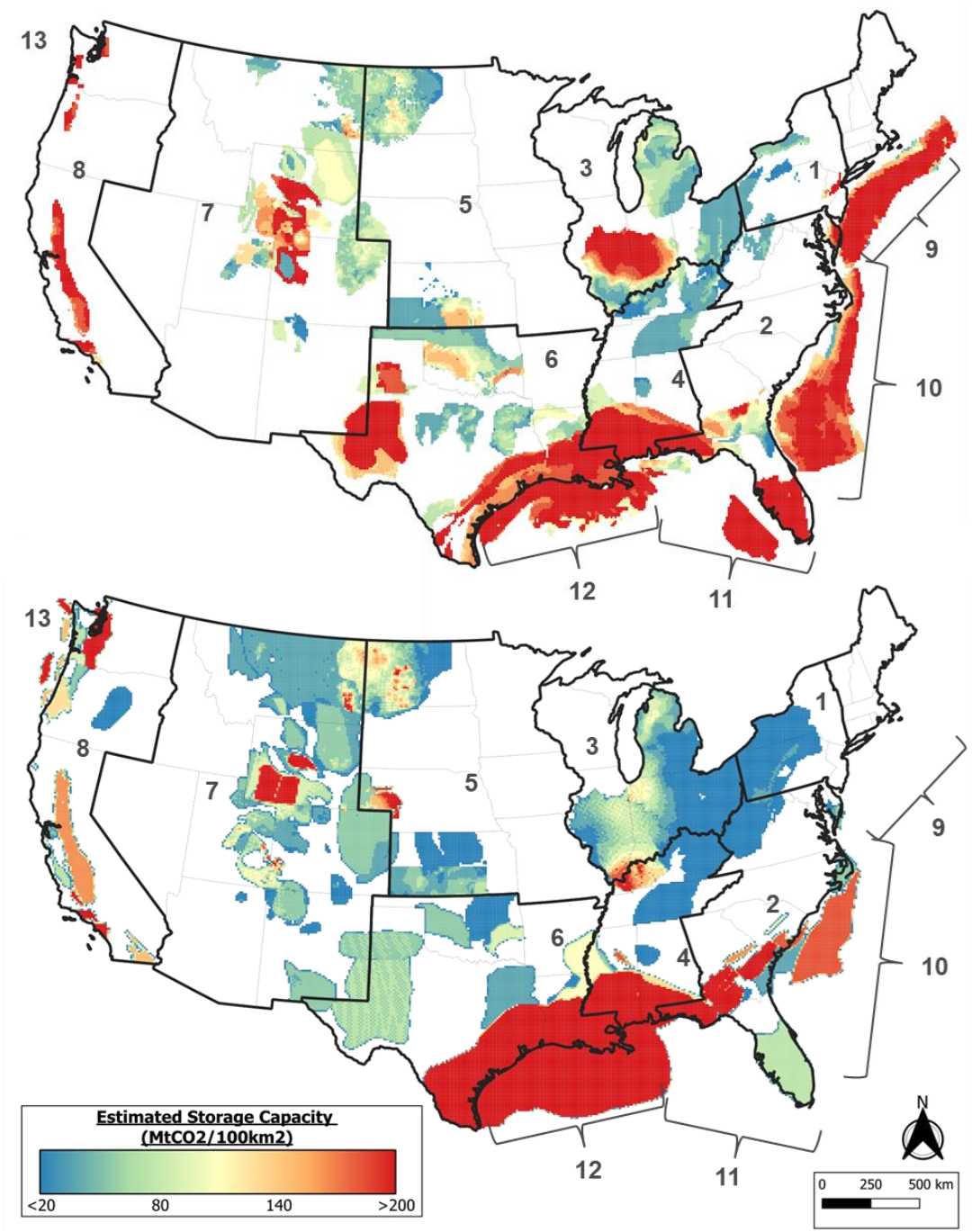
Comparing Onshore vs Offshore Cost

Comparison

- Lowest-cost 2 $GtCO_2$.
- Offshore requires fewer monitoring wells based on UK study (1 per 5–10 injection wells).
- Offshore platform can host up to 9 injection wells.
- Offshore wells are longer, more complex, often horizontal.



Region	SCO_2T^{PRO} ($GtCO_2$)	NATCARB ($GtCO_2$)	Difference
1. Middle Atlantic	25	11	56%
2. South Atlantic	374	367	2%
3. East North Central	322	170	47%
4. East South Central	441	440	0%
5. West North Central	140	164	-17%
6. West North Central	936	1239	-32%
7. Mountain	509	452	11%
8. Pacific	153	351	-129%
9. Offshore Mid-Atlantic	502	0	100%
10. Offshore South Atlantic	468	191	59%
11. Offshore EGOM	142	47	67%
12. Offshore WGOM	397	1601	-303%
13. Offshore PNW	0	41	-
TOTAL	**4409**	**5074**	**-15%**



SCO_2T - NATCARB

SCO_2T approach

- **Database:** Improved geology data, removed many areas (marginal quality, depth, salinity, etc.).
- **Tool:** Dynamic injection.

Differences

- SCO_2T^{PRO} excluded marginal areas & added new areas leading to largest differences.
- Broad regional agreements.

Screening

Complexity

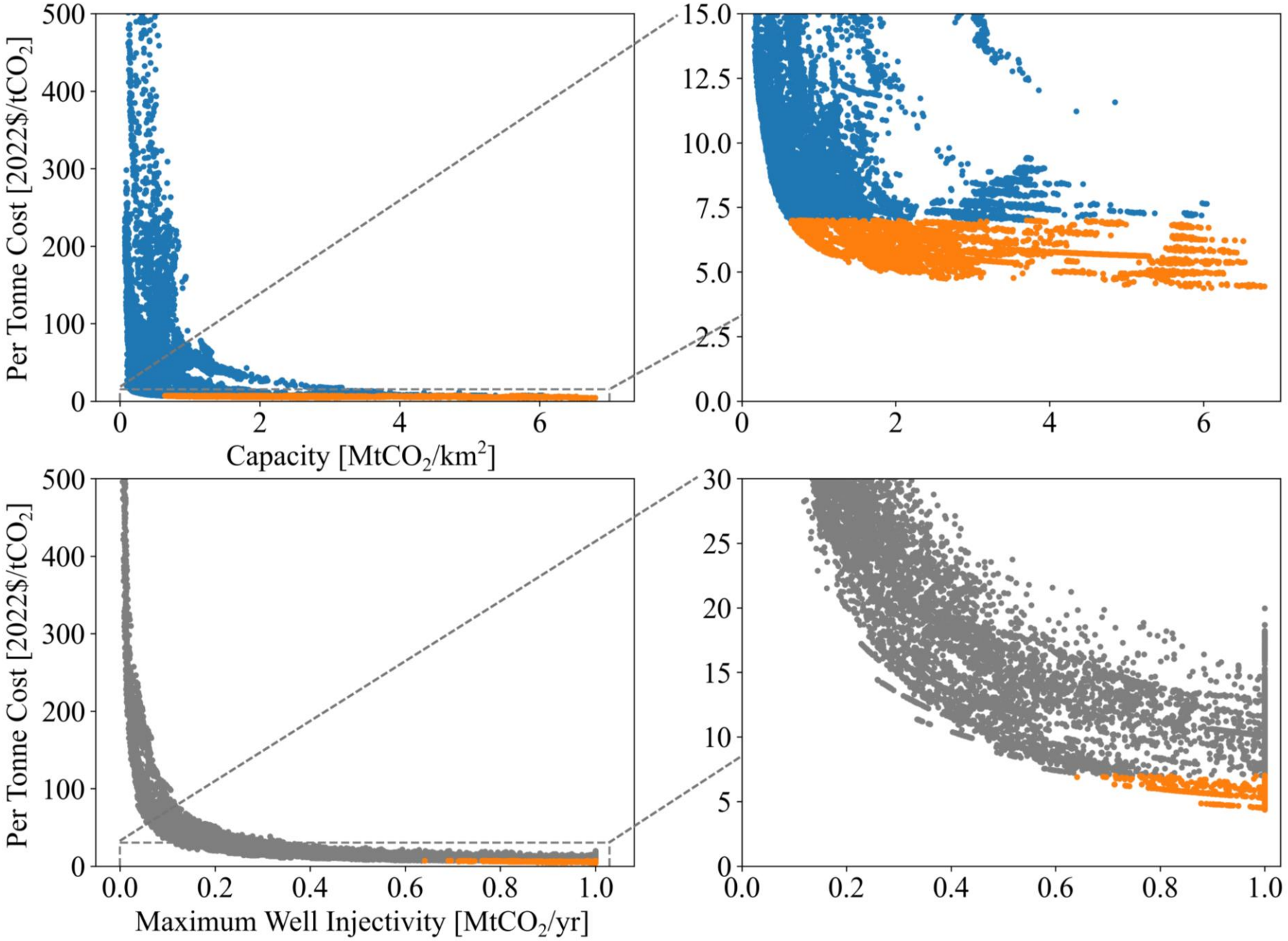
- Capacity & injectivity are alone insufficient for identifying low-cost CO_2 storage.

Top charts

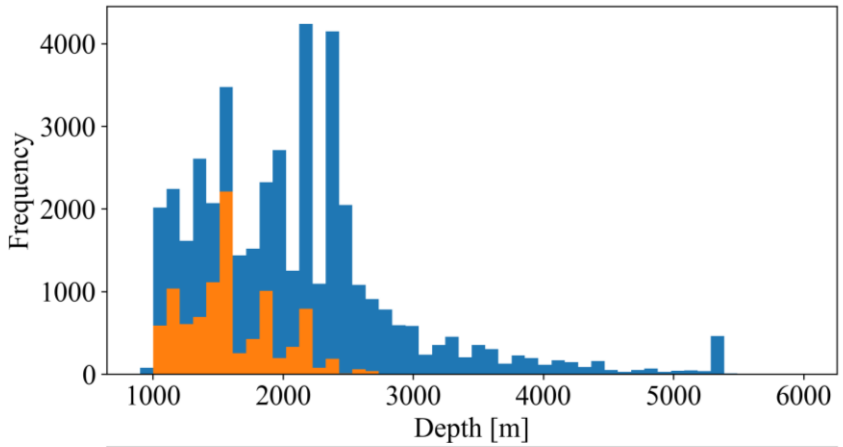
- High-capacity storage general means low cost.
- Low-capacity storage does not mean high cost.

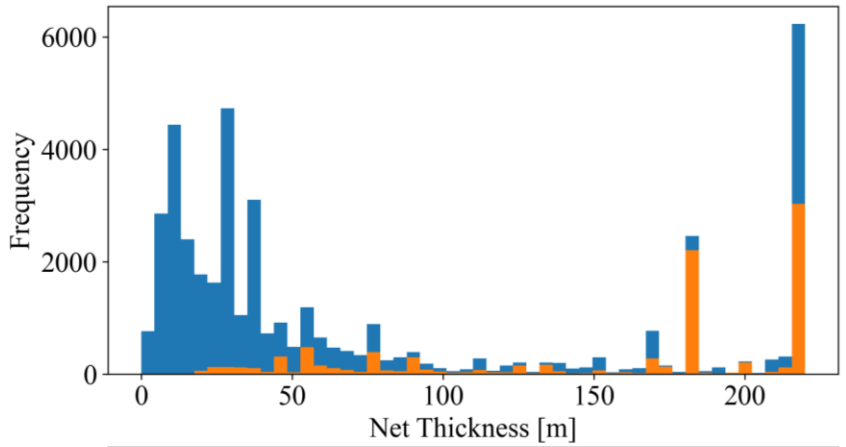
Bottom charts

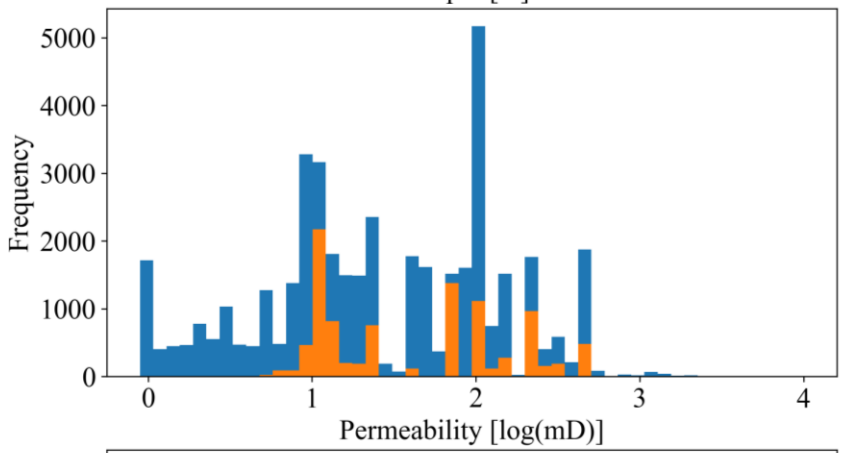
- Low injectivity means high cost.
- High injectivity does not mean low cost.

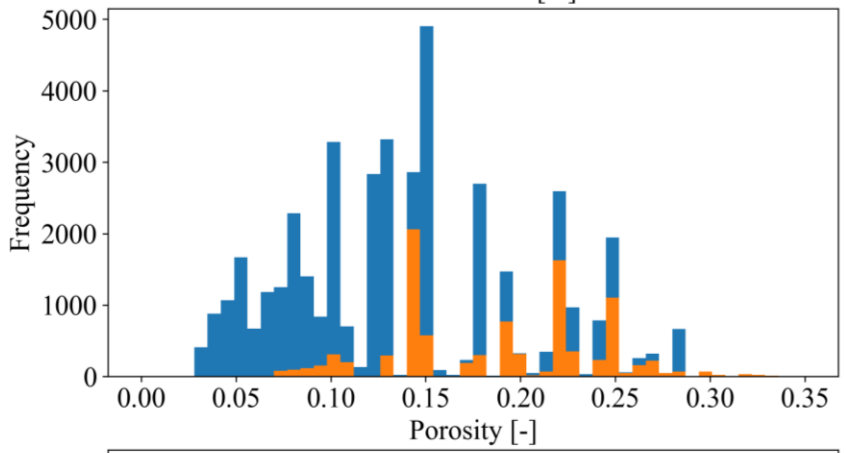


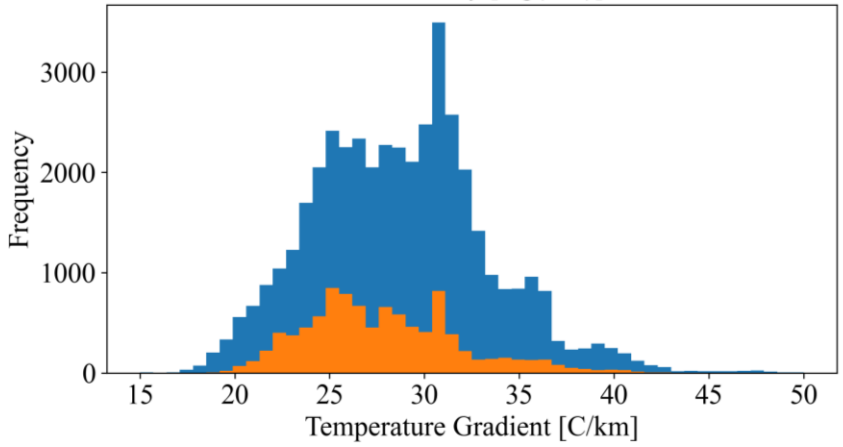
Screening

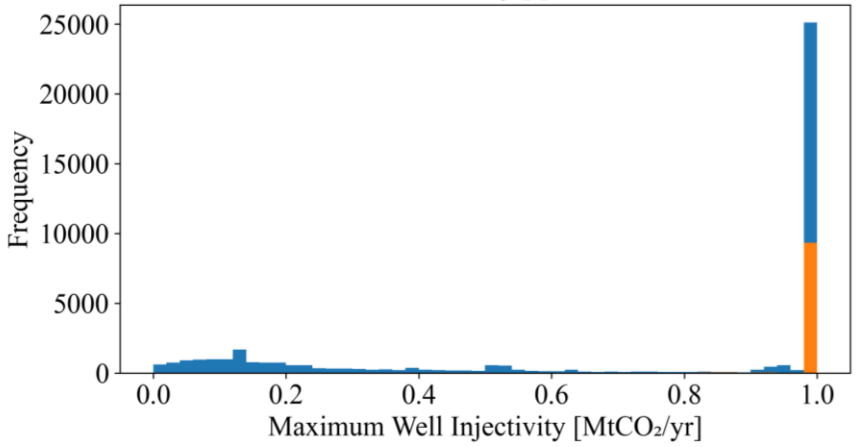












Results

- Even screening-level analysis is complicated.
- No single geologic variable can be used as a proxy for cost.

Take Home Message

Net Zero America

- 1,000s of CO_2 injection wells across the US.
- A first-step is nationwide site screening, but it is difficult.

SCO_2T^{PRO} enables nationwide site screening

- Coupled software + database.
- Rapid-running: entire country in seconds, uncertainty analysis.

Storage capacity

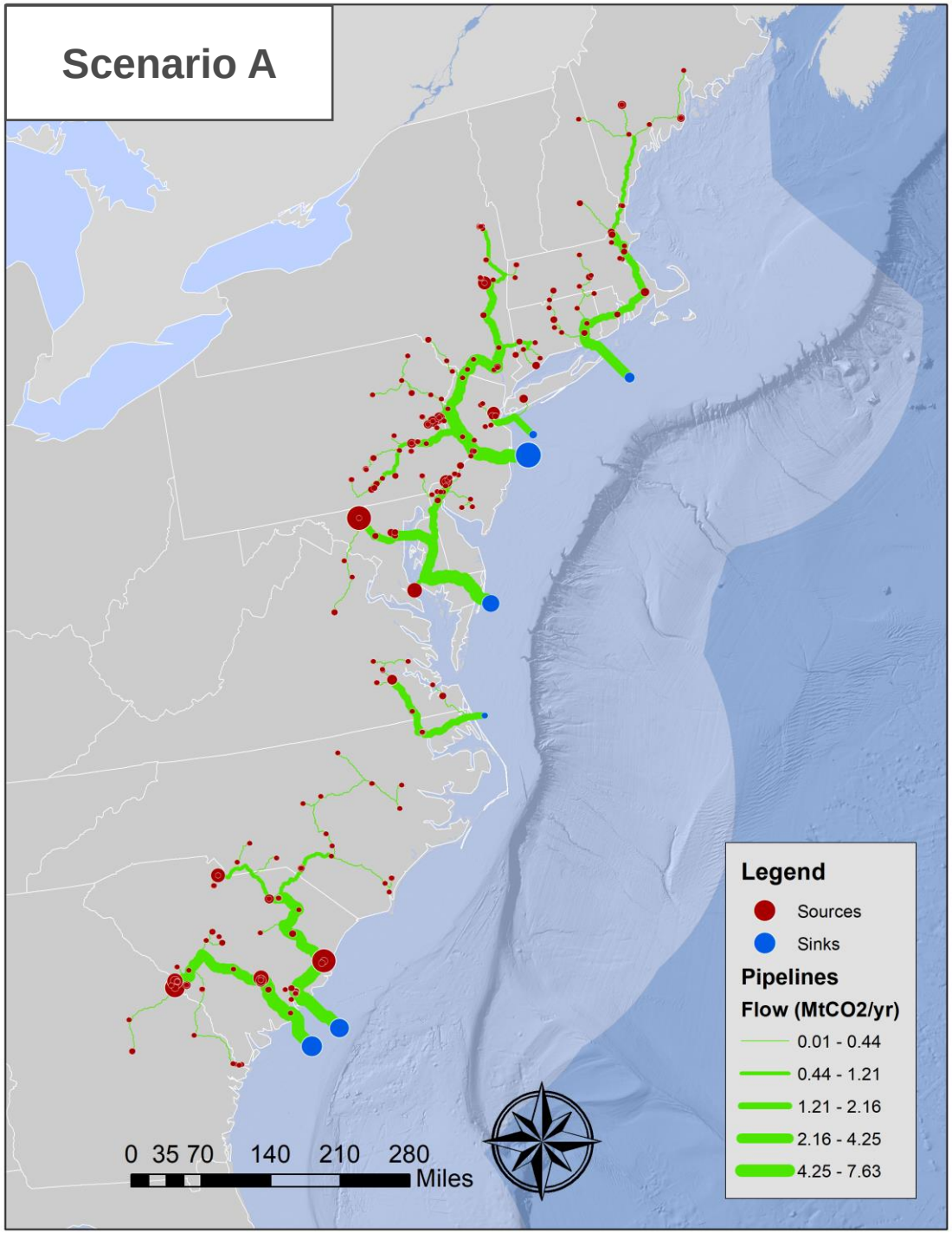
- Substantial… but not evenly geospatially distributed.
- Planning and coordination.

Storage costs

- Low-cost of onshore ~\$7/tCO_2, offshore is ~4x higher.
- Financing assumptions do matter.

Complexity

- No simple proxy for good sequestration.
- Rapid screening for down-selection & modeling.



richard.middleton@carbonsolutionsll.com