CUSP

Carbon Solutions

Richard Middleton

Carbon Solutions LLC

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CUSP State Status Updates

Background

Overview

- Low-carbon energy startup focusing on energy infrastructure, the energy transition, and society.
- 21 employees, ~25 consultants.
- ~30 projects in first year: DOE | Industry | NGOs.

Energy applications

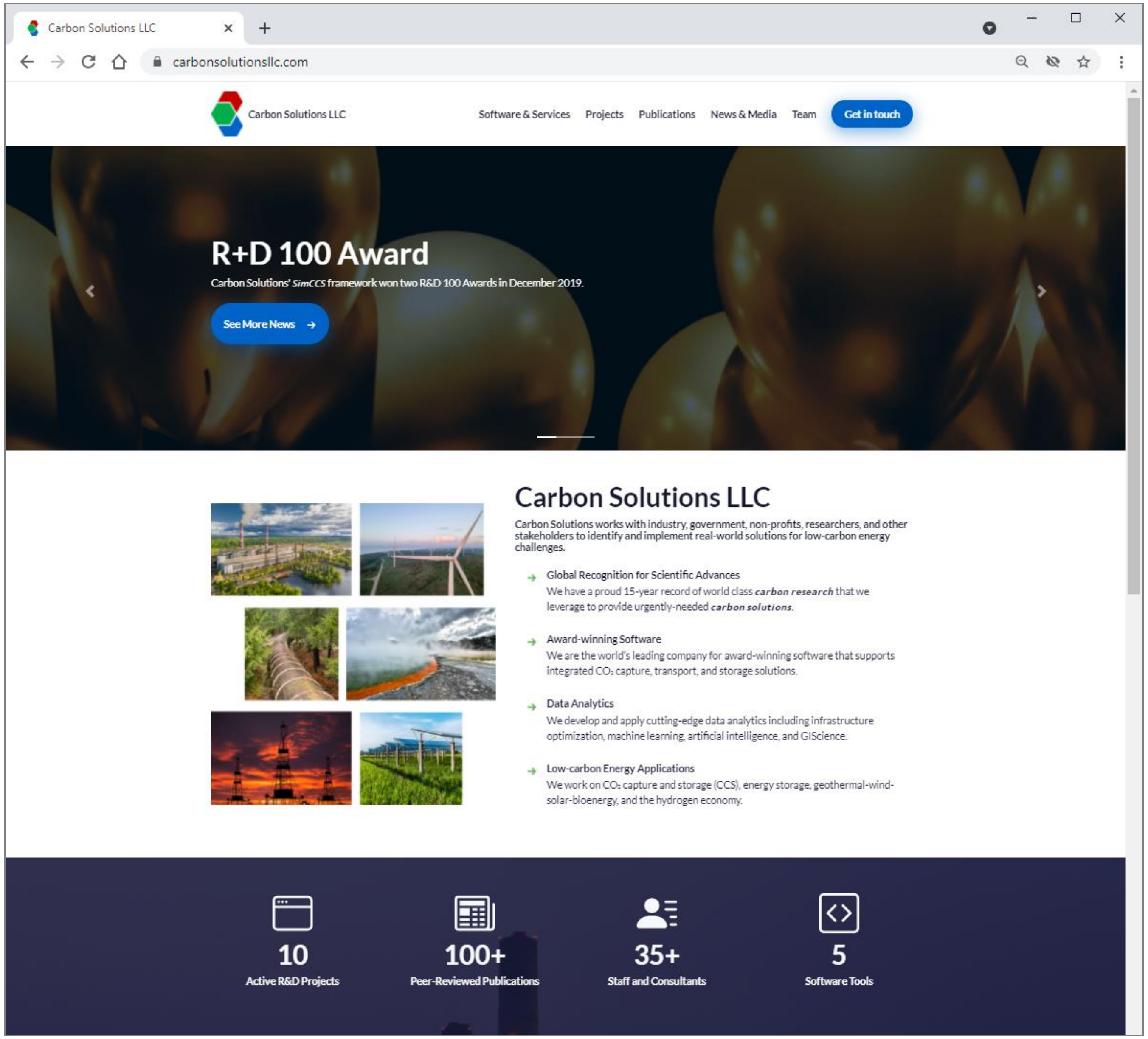
- CCS, energy storage, geothermal, wind, DAC, hydrogen, grid modeling, energy equity…

Data analytics

- Optimization, reservoir simulation, LCA, TEA, machine learning, GIScience…

Approach: Three Pillars

1. **R&D:** Applied R&D to support science-based decision making.
2. **SOFTWARE:** Science-based software solutions backed by publications.
3. **SERVICES:** Client support with unique science, data, & software.



Background

Foundation

- Award-winning CCS science & software.

SimCCS[PRO]

- Decision-support framework for designing CO_2 capture, transportation, & storage (CCS) infrastructure.
- Industry- & research-leading CCS infrastructure tool.
- Dozens of scientific papers, thousands of citations.
- Two R&D 100 Awards (2019).

Decision discovery & support

- Integrated capture, transport, & storage economics.
- End-to-end techno-economic assessment (TEA).
- Policy analysis.
- System-wide life cycle assessment (LCA).

CARBON SOLUTIONS LLC

- Leveraging decades of carbon *research* to help industry, stake-holders, and the Nation develop carbon *solutions*.

General Support & Focused Projects

Project support

- **WORKING GROUPS:** Lead/key roles in Data, Analytics, Economics, & Outreach.
- **CROSS-CUTTING SUPPORT WITH *SIMCCS*^{PRO}:**
  - CCS analysis: ***SimCCS***^{PRO}.
  - CO_2 capture: ***NICO$_2$LE***^{PRO}.
  - CO_2 transport : ***CostMAP***^{PRO}.
  - CO_2 storage : ***SCO$_2$T***^{PRO}.
- **TEAM *SIMCCS*:** Internal CARBON SOLUTIONS team, support *SimCCS* studies across the CUSP.
- **EXPERTISE:** Integrated CCS assessment, LCA, TEA, hydrogeology, geology.
- **FOCUSED PROJECTS:** Supporting six focused projects with *SimCCS*, reservoir simulation, LCA, TEA, machine learning, GIScience…

California | Stanford University

- Integrated *SimCCS*, LCA, environmental justice.

Kansas | Kansas Geological Survey

- Reservoir simulation, infrastructure assessment.

Montana | Montana State University

- Machine learning, *SimCCS* model development.

Nevada | Desert Research Institute

- Geothermal plant LCA/TEA, geothermal/CO_2 storage.

Oklahoma | University of Oklahoma

- Reservoir simulation, *SimCCS*, OK CCS road map.

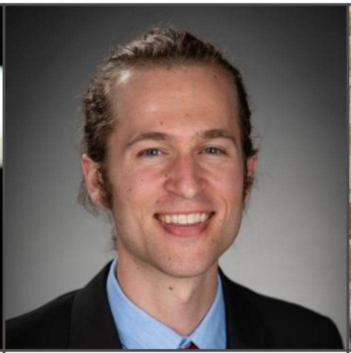
Utah | University of Utah

- LCA, *SimCCS*.

CARBON SOLUTIONS CUSP Team/People

Richard Middleton
Role: Leadership, *SimCCS*

Elizabeth Abramson
Role: Visualization, Communication



Jeff Bennett
Role: LCA

Kyle Cox
Role: *SCO_2T* database

Kevin Ellett
Role: Leadership, Geoscience

Mike Ford
Role: Leadership, Economics

Peter Johnson
Role: Reservoir Simulation

Dane McFarlane
Role: Policy Analysis

Erin Middleton
Role: Environmental Justice

Marco Miranda
Role: *SimCCS*

Jonathan Ogland-Hand
Role: TEA

Kelsey Seals
Role: Reservoir Simulation

Carl Talsma
Role: *SimCCS*

Monty Vesselinov
Role: Machine Learning

$NICO_2LE^{PRO}$

Why?

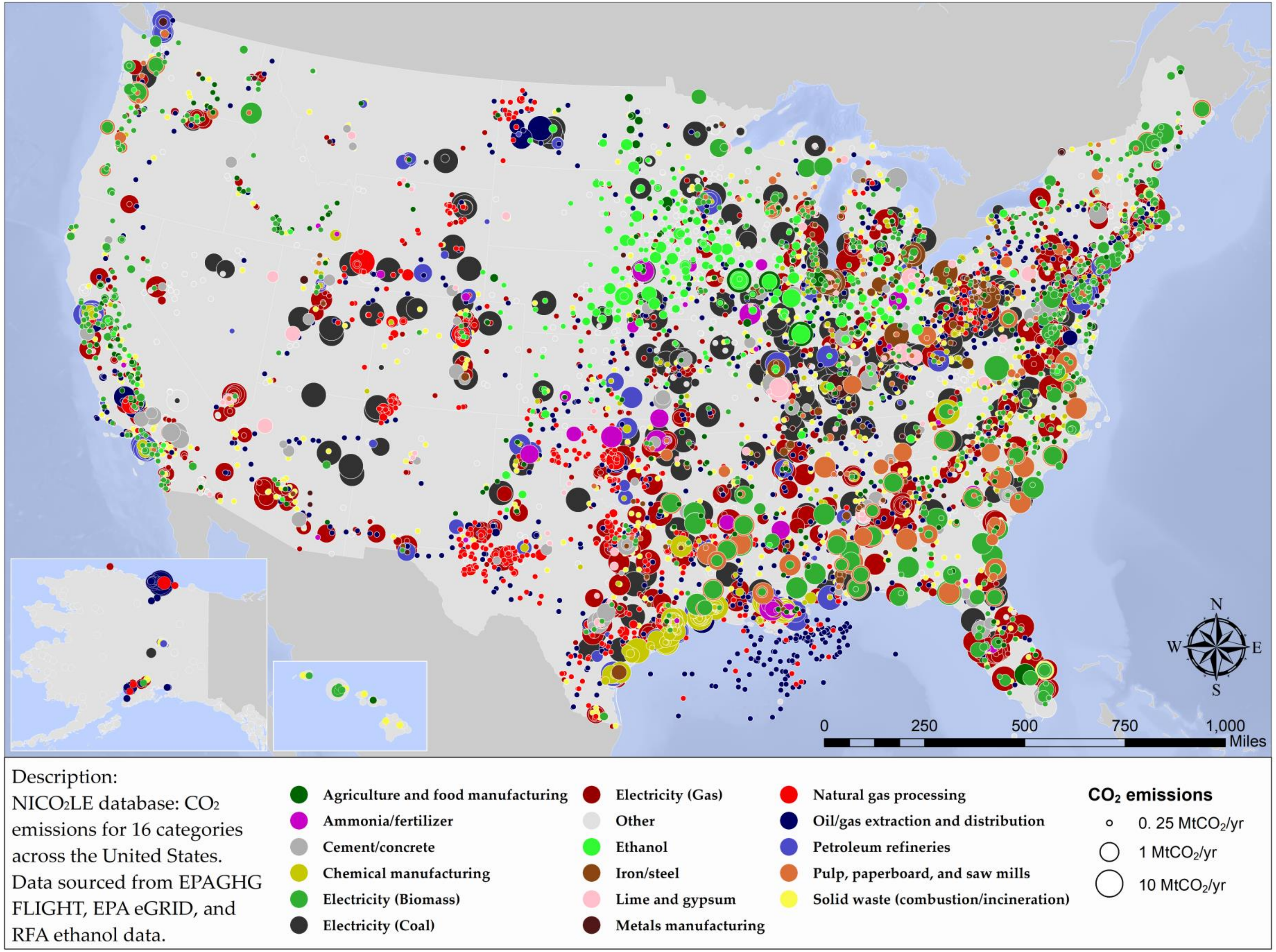
- Commercial-scale CO_2 capture opportunities.

How?

- **Fuse:** emissions data from EPA GHGRP/FLIGHT, EPA eGRID, RFA (ethanol)…
- **Fuse:** capture cost & stream data from 15+ lit. sources.
- **Expertise:** industry-leading experience with CO_2 capture.

What?

- **Geodatabase:** source locations, CO_2 streams (quantity & purity), & capture costs.
- **Supply curves:** Identify economic opportunities.
- Market Assessment.



Middleton et al. (2017) Industrial CO_2 and carbon capture: near-term benefit, long-term necessity, *Energy Procedia*.

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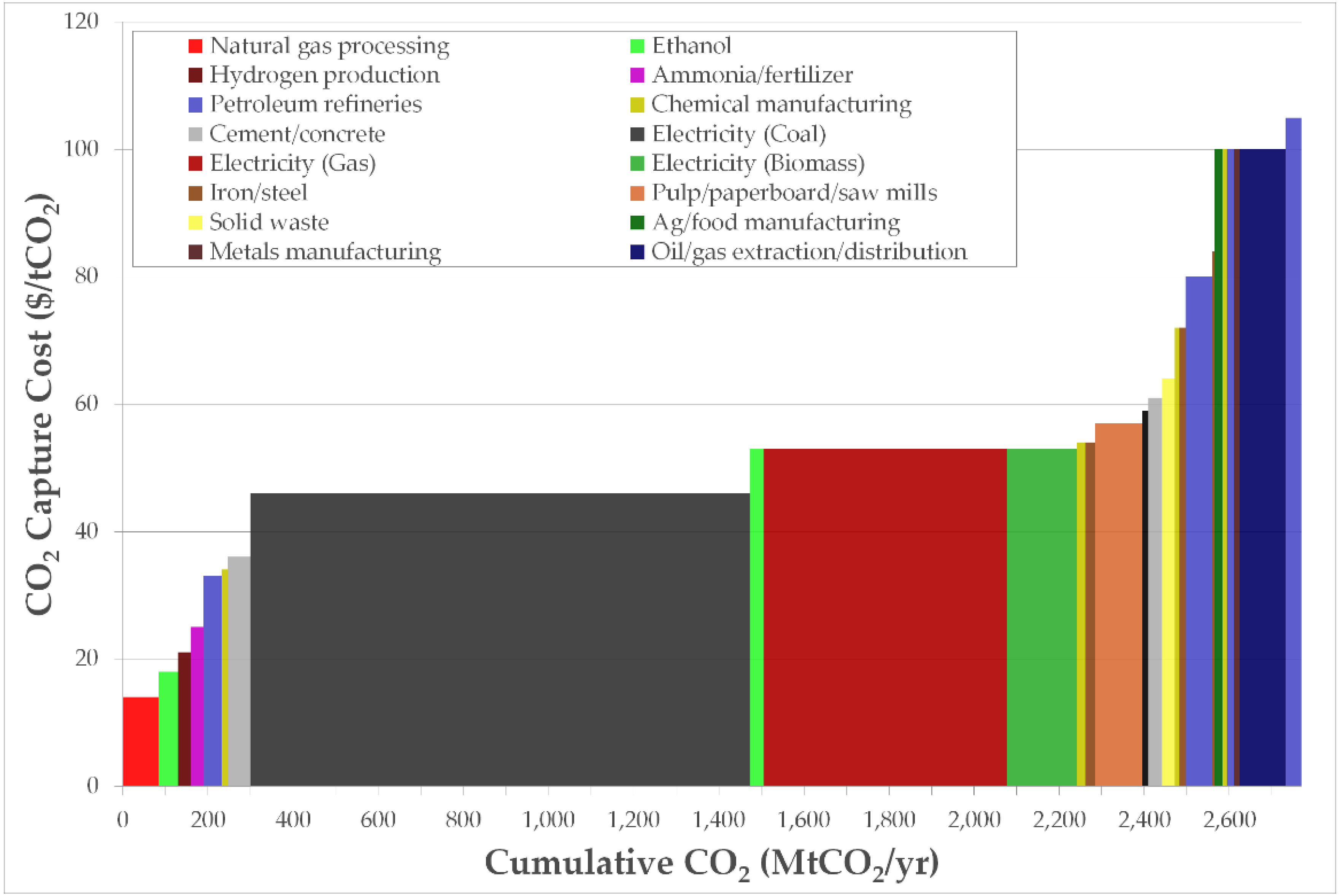

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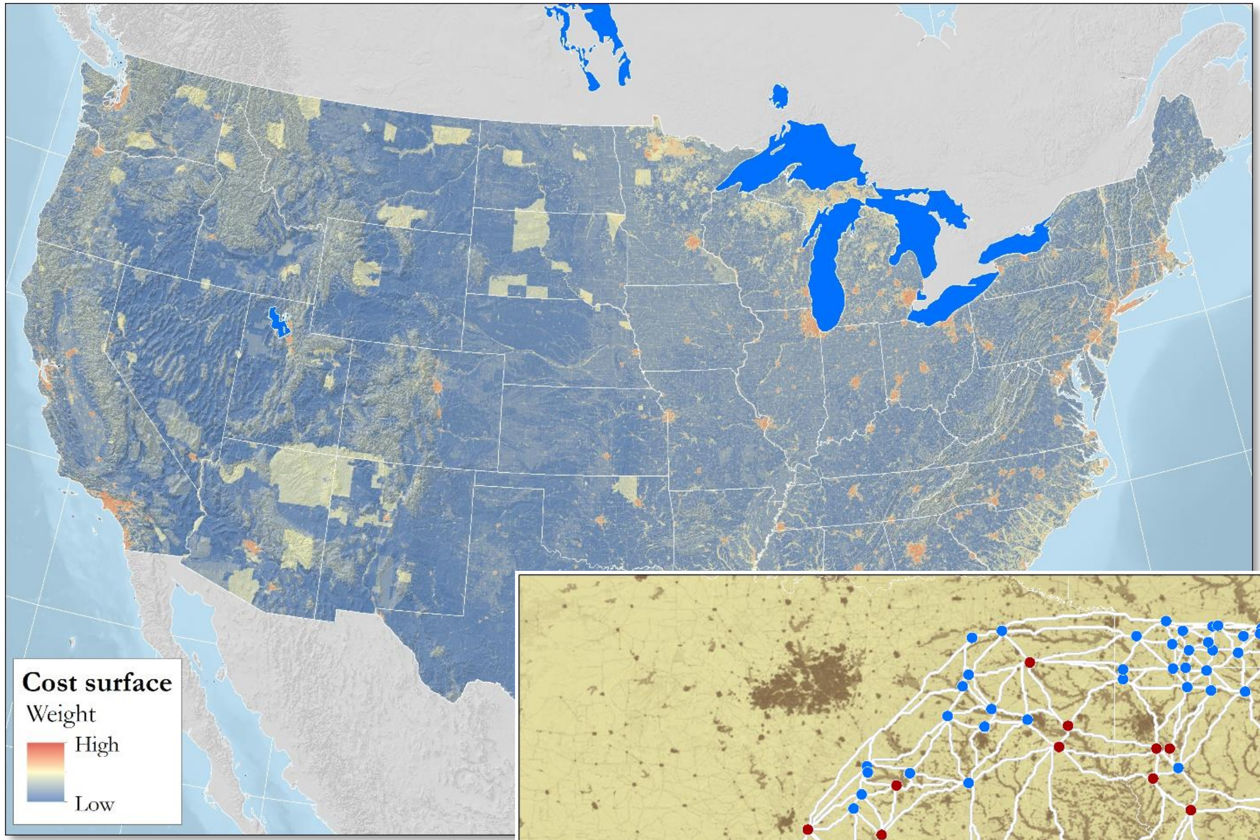
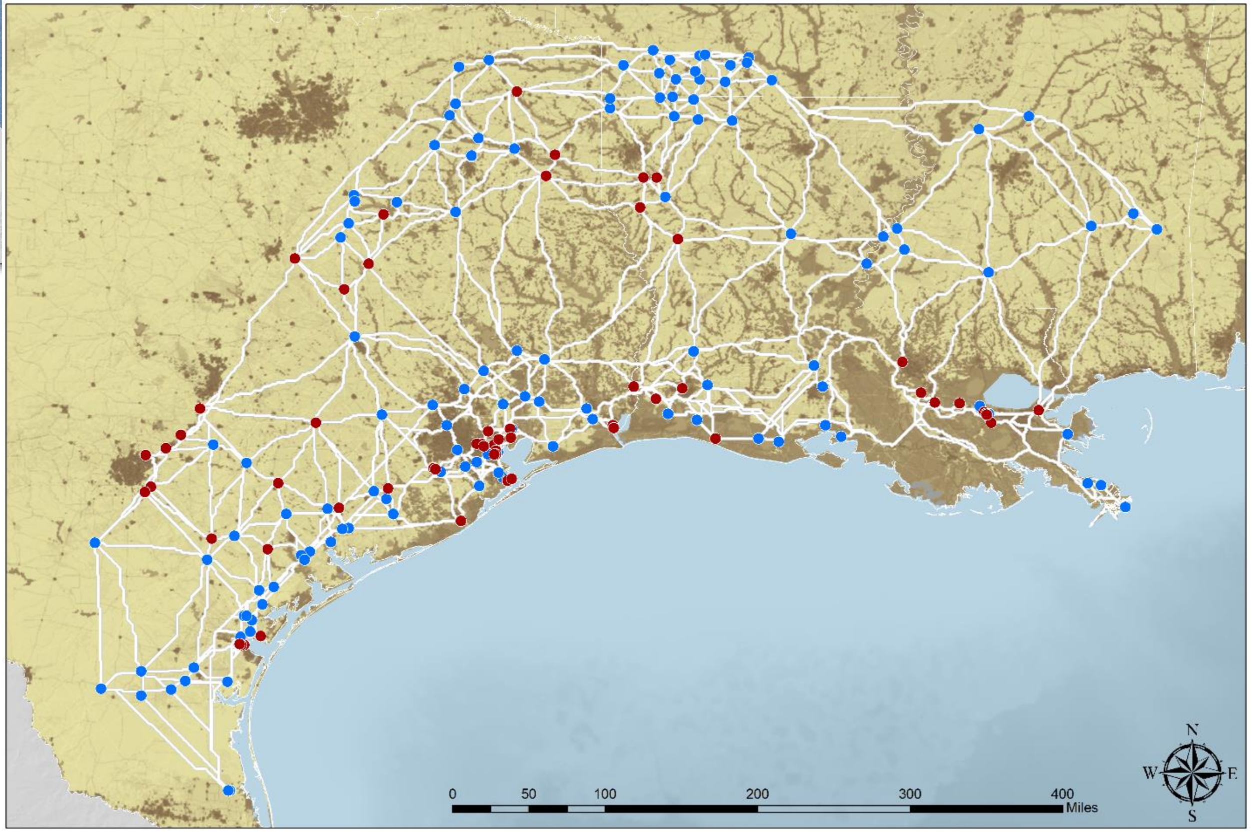




Hoover et al. (2020) *CostMAP*: an open-source software package for developing cost surfaces using a multi-scale search kernel, *International Journal of Geographical Information Science.*

SimCCS^{PRO} CostMAP^{PRO}

Why?

- Understand where, how, & cost of CO_2 transportation.

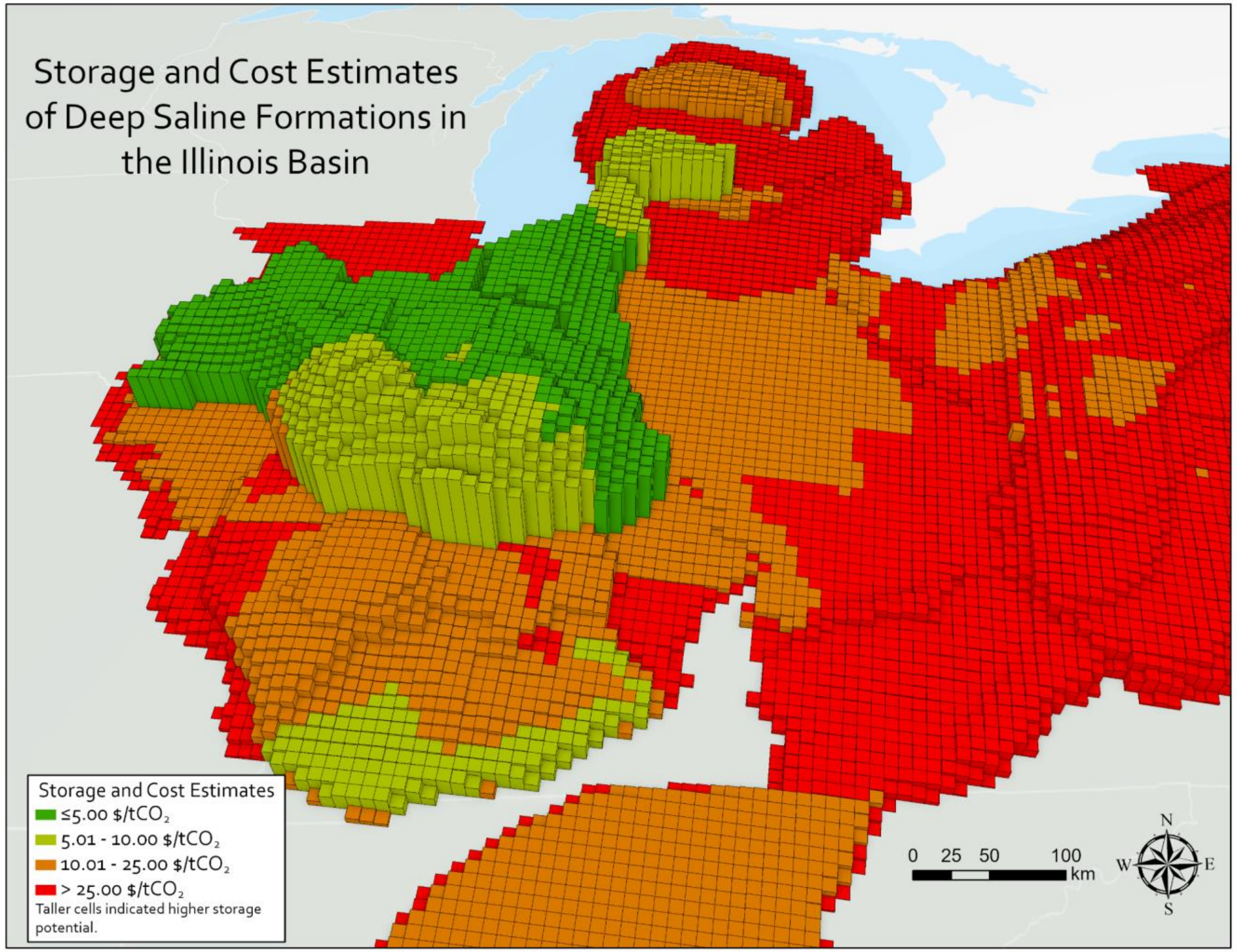
How?

- Nonlinear integration of ROWs (e.g., pipelines), barriers (e.g., rivers), population, topography, land use, ownership, environmental justice…
- *SimCCS* cost model.

What?

- Next-generation software for pipeline costs & routing.
- Cost & routing surfaces, grid cells 10 m to ~1,000 m.
- Multiple pipeline routes, avoid sensitive areas.
- Pipeline route robustness.

Background



Pronunciation

- **"Great SCO_2T"** | Doc Brown (1885/1955/1985).
- **"Beam me up SCO_2T"*** | James T. Kirk (2265–2269).

* **Disclaimer:** This was never actually said in any Star Trek film or episode or CARBON SOLUTIONS publication to date.

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: **Electricity Planning** (2022): *link*.
- Application: **Plume Geothermal** (2022): *link*.

Sequestration Science

Approach

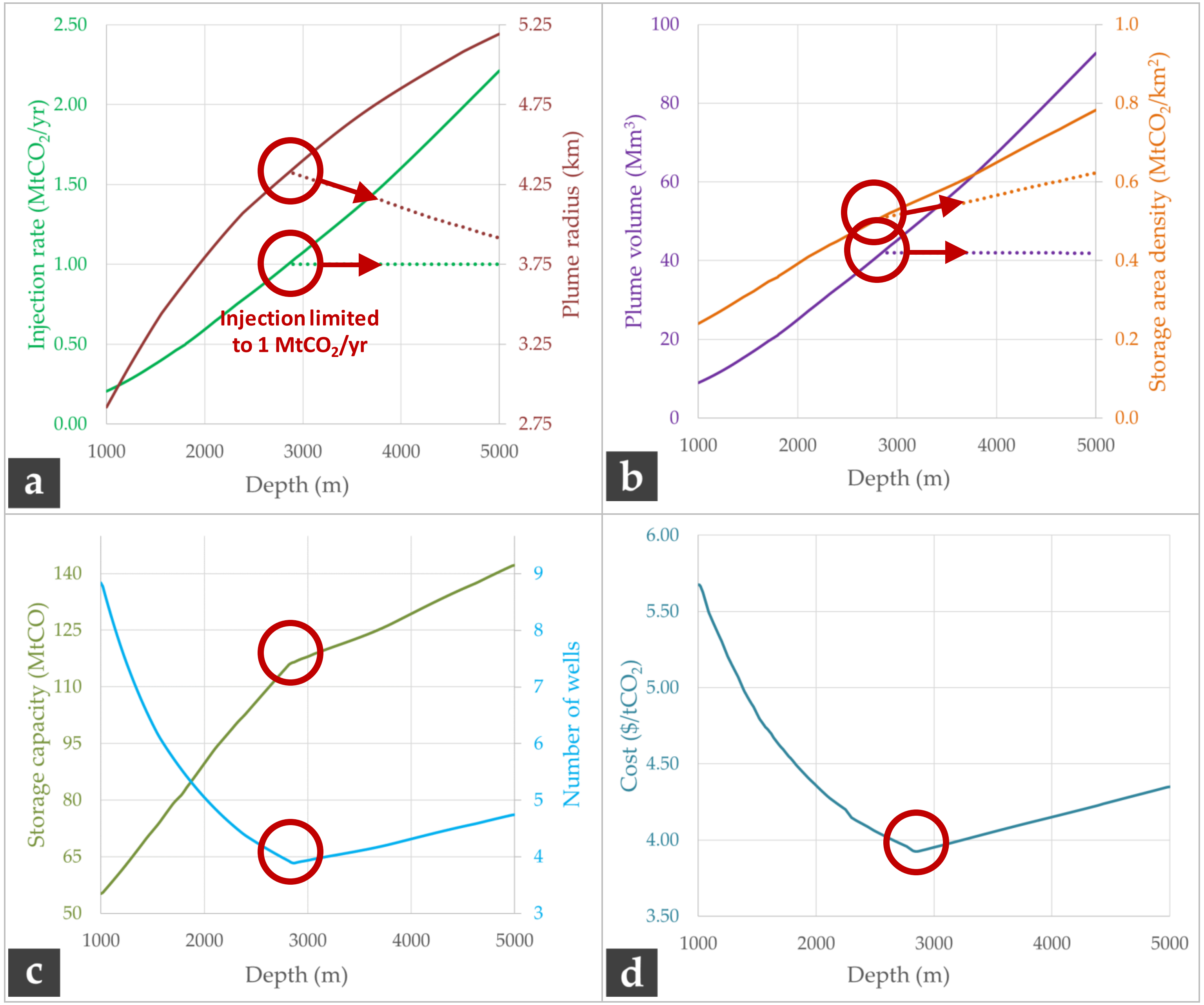
- Sensitivity analysis for reservoir depth, thickness, permeability, porosity, & temperature.

Example: depth

- Injection rate and plume radius increase.
- Plume volume and storage area density increase.
- Traditional understanding: costs go down.

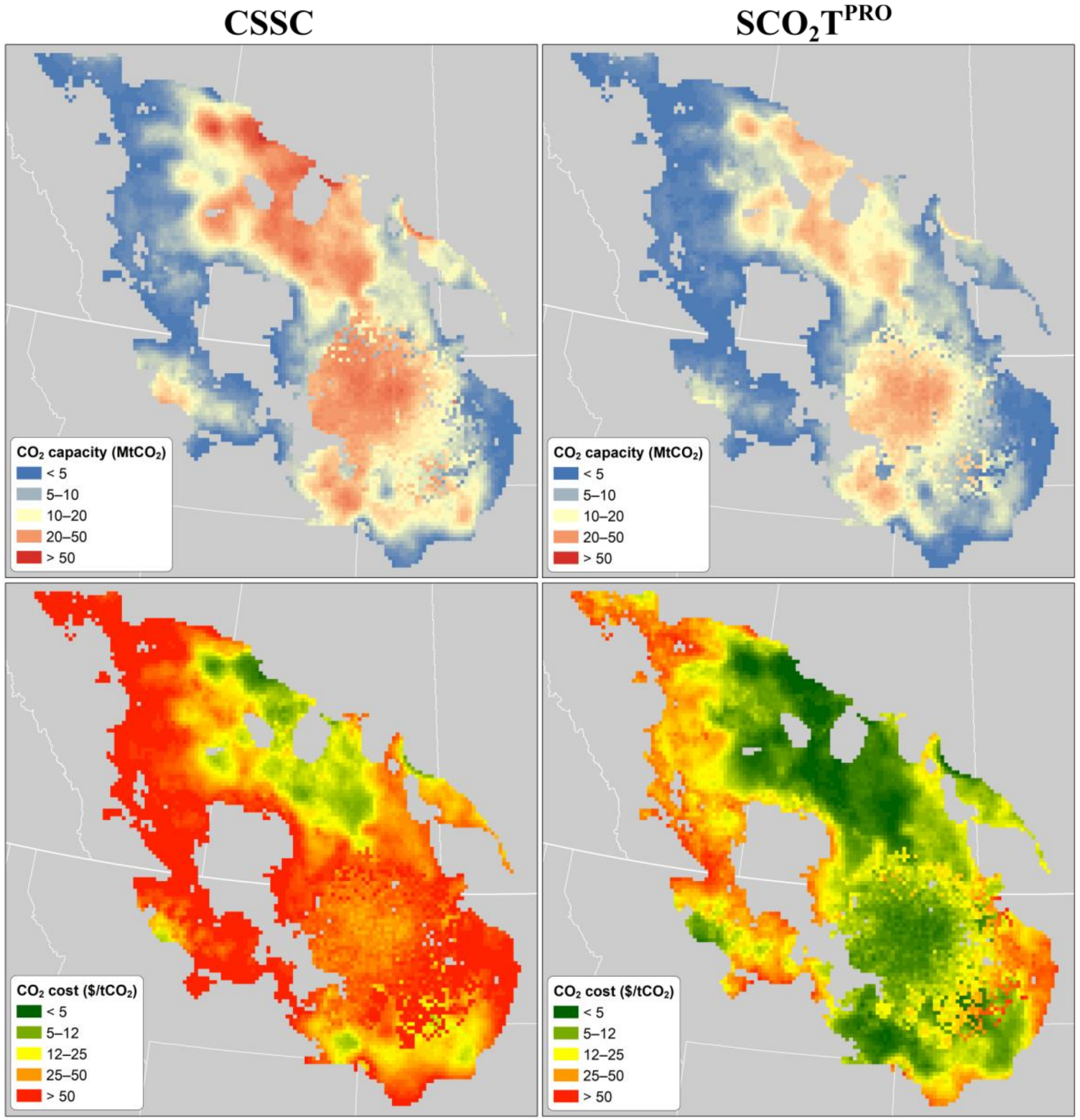
Well limitations

- Limit injection to 1 $MtCO_2$/yr.
- Plume radius decreases.
- Changes in storage rate.
- Costs rise once well capacity is reached.



Middleton et al. (2020) Identifying geologic characteristics and operational decisions to meet global carbon sequestration goals, *Energy & Environmental Science.*

Comparison with State of the Art



Ogland-Hand et al. (2022) Screening for Geologic Sequestration of CO_2: A Comparison Between *SCO_2T^{PRO}* and the FE/NETL CO_2 Saline Storage Cost Model, *International Journal of Greenhouse Gas Control.*

Peer-reviewed paper

- Screening for Geologic Sequestration of CO_2: A Comparison Between *SCO_2T^{PRO}* and the FE/NETL CO_2 Saline Storage Cost model (CSSC).
- Compared *SCO_2T* with the “leading” competitor.

Primary takeaways:

- Cost and capacity estimates from FE/NETL tool (CSSC) were at least twice as large as those of *SCO_2T^{PRO}*.
- *SCO_2T^{PRO}* can execute screening thousands of times faster than CSSC.

CO$_2$-Geothermal

In-review paper

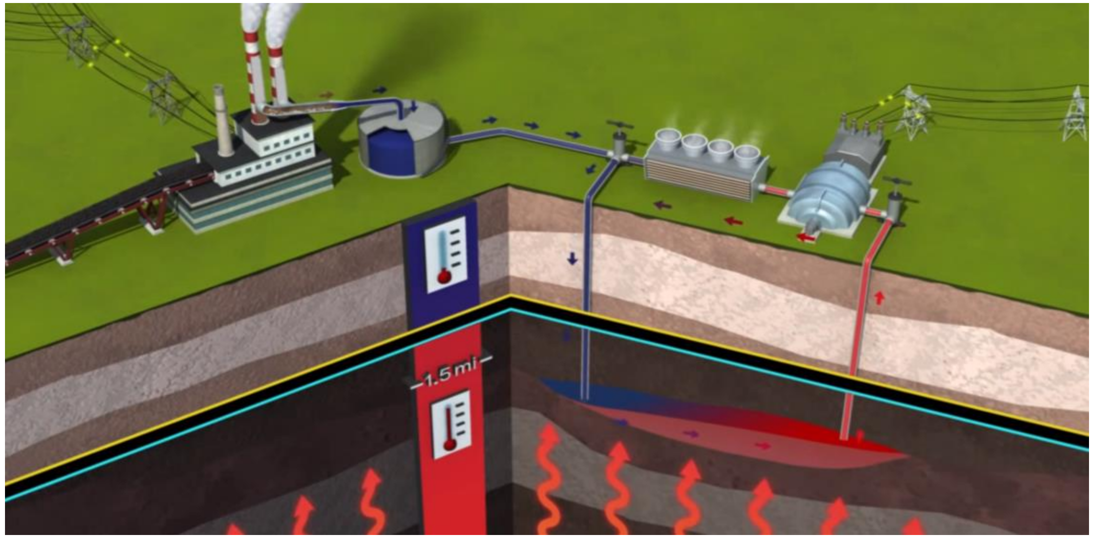
- A Geospatial Cost Comparison of CO_2 Plume Geothermal (CPG) and Geologic CO_2 Storage.
- Journal: *Frontiers in Energy Research Carbon Capture, Utilization and Storage.*

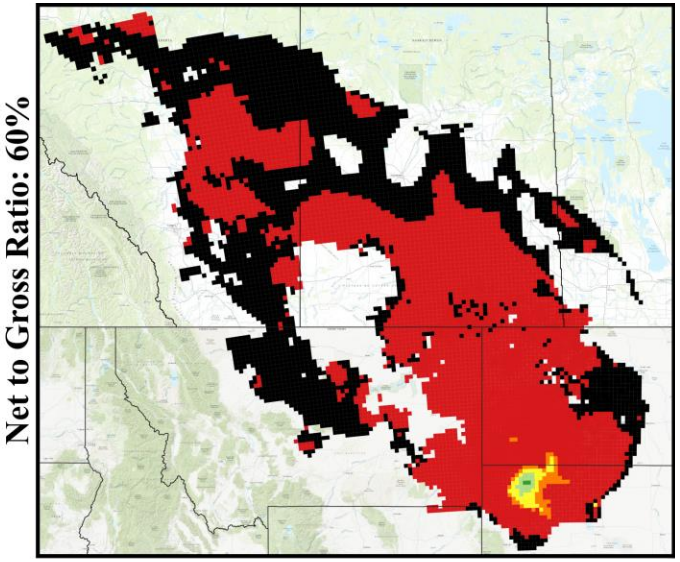
Primary Takeaways

- Lowest cost locations are different than locations with lowest cost CPG.
- Drilling new wells specific for CPG can lower the breakeven price of electricity required instead of using only CCS injection wells.
- Sequestered CO_2 could be used to triple the US geothermal capacity via single South Dakota CPG “sweet spot” (7 GWe, current US capacity ~3.8 GWe).

CO_2 Plume Geothermal (CPG)

Using Geologically Stored CO_2 to Generate Electricity





$LCOE_{CCS}$	$LCOE_{Ormat}$	$LCOE_{Lazard}$
Brownfield [2017$/MWh]		
Low Power Generation (< 1 kW_e)		
< 77	< 84	< 120
77-80	84-87	120-125
80-100	87-109	125-156
100-150	109-164	156-234
> 150	> 164	> 234

Ogland-Hand et al. (2022) A Geospatial Cost Comparison of CO_2 Plume Geothermal (CPG) Power and Geologic CO_2 Storage, *Frontiers in Energy Research* (in review).

Nationwide Database

Industry

- Class VI site selection & pre-characterization.

National map

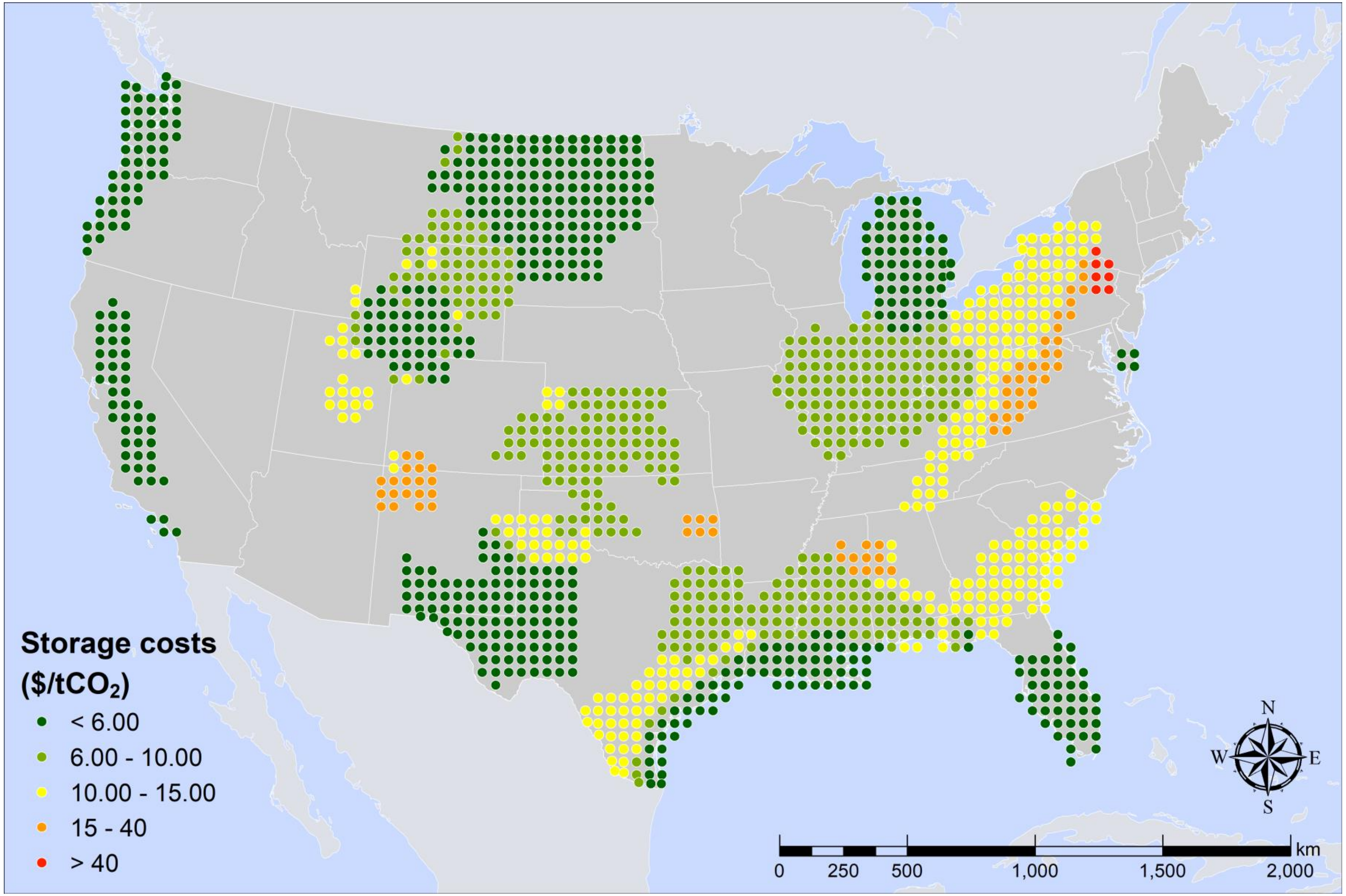
- Integrate best-available geology & deploy SCO_2T^{PRO}.
- First-generation nationwide capacity & map (~March '22).

Projects

- Nationwide CO_2-storage supply curves for energy.

DOE Office of Science

- Complete rebuild of SCO_2T using STOMP.
- Advanced sequestration capabilities for individual sites & regions.



0.5 $MtCO_2$/yr
1 $MtCO_2$/yr
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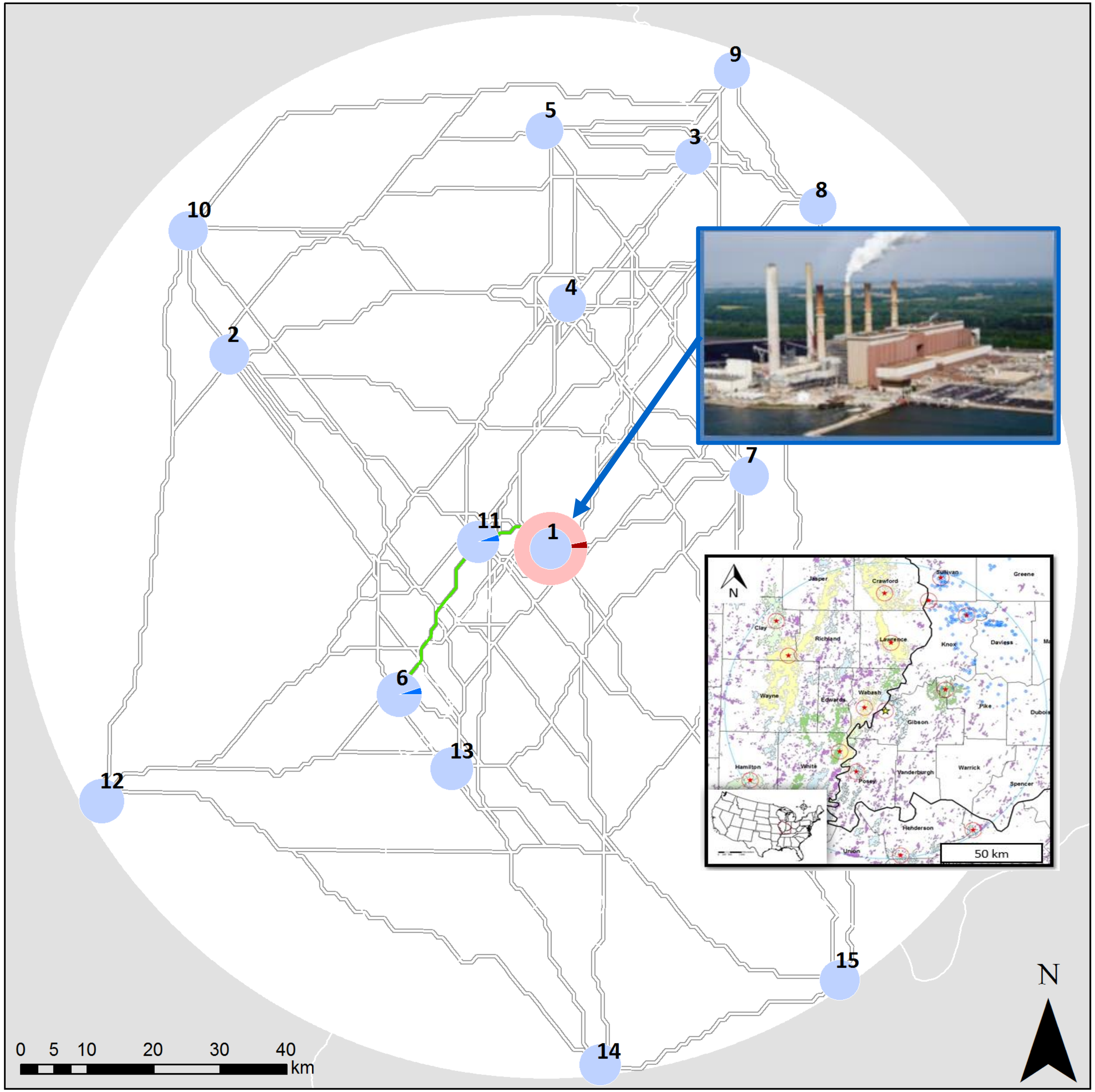


LOCAL CASE STUDY

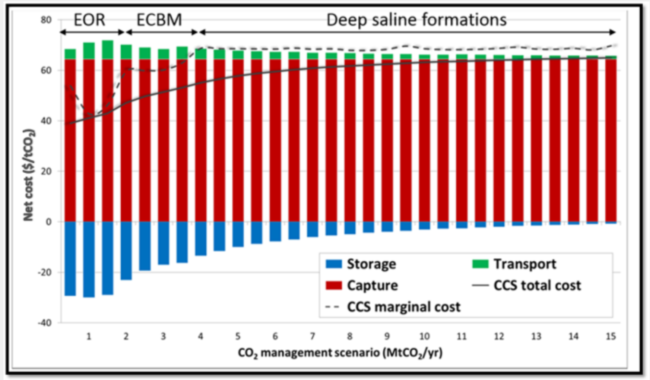
Duke Energy

Analysis

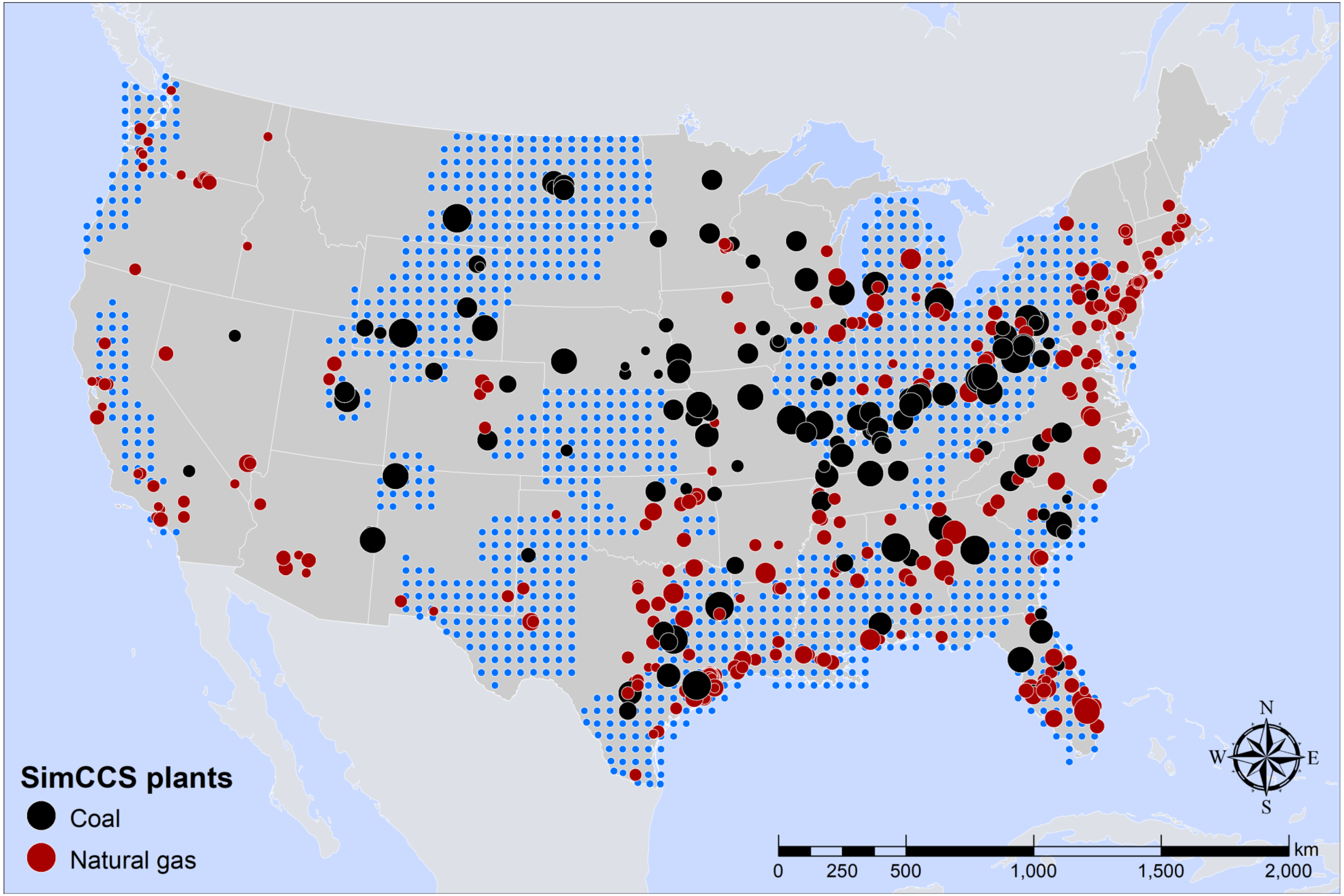
- Help Duke Energy understand options for capturing part to all of Gibson Station's CO_2.

Decisions

- **COSTS:** Infrastructure deployment & costs over.
- **REVENUE:** Oil (CO_2-EOR), methane (ECBM, depleted gas fields).
- **CCS BUSINESS PLAN:** Assess multiple business scenarios, carbon targets, uncertainty, de-risk investments.



Decarbonization of Fossil Electricity



Scenario

- Help guide policymaker plans for emissions rules for coal and gas plants.

Scenario

- Sources:
  - 429 plants | 1,044 $MtCO_2$/yr.
  - 137 coal | 603 $MtCO_2$/yr.
  - 293 NGCC | 444 $MtCO_2$/yr.
- Storage:
  - Saline-only, Medium-cost estimates from *SCO_2T^{PRO}*.
- Scenario:
  - *$SimCCS^{CAP}$* mode.
  - Increasing CO_2 capture (100–1,1044 $MtCO_2$/yr).

Analysis

- Distributed storage vs. major hubs?

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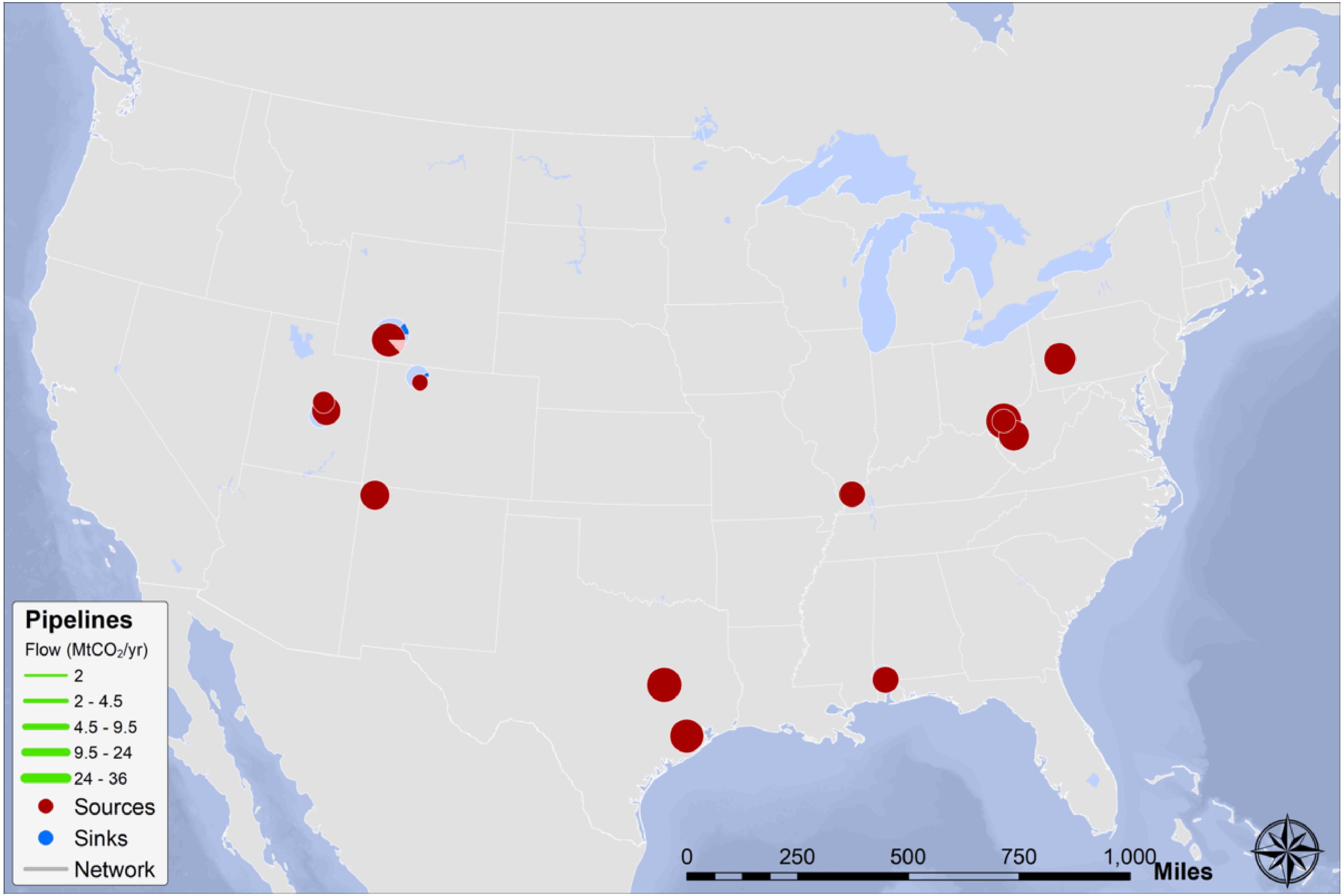

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