

Geospatial analysis of near-term potential for carbon-negative bioenergy in the U.S.

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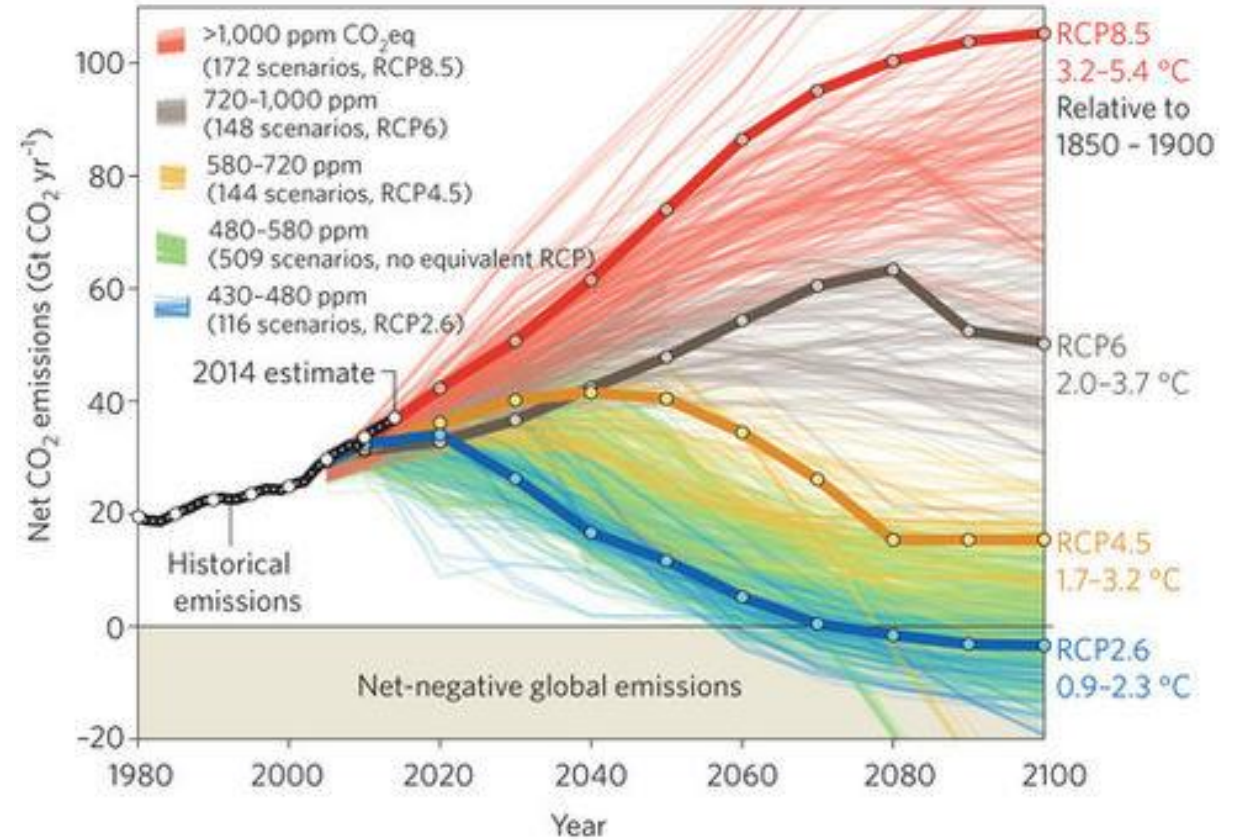
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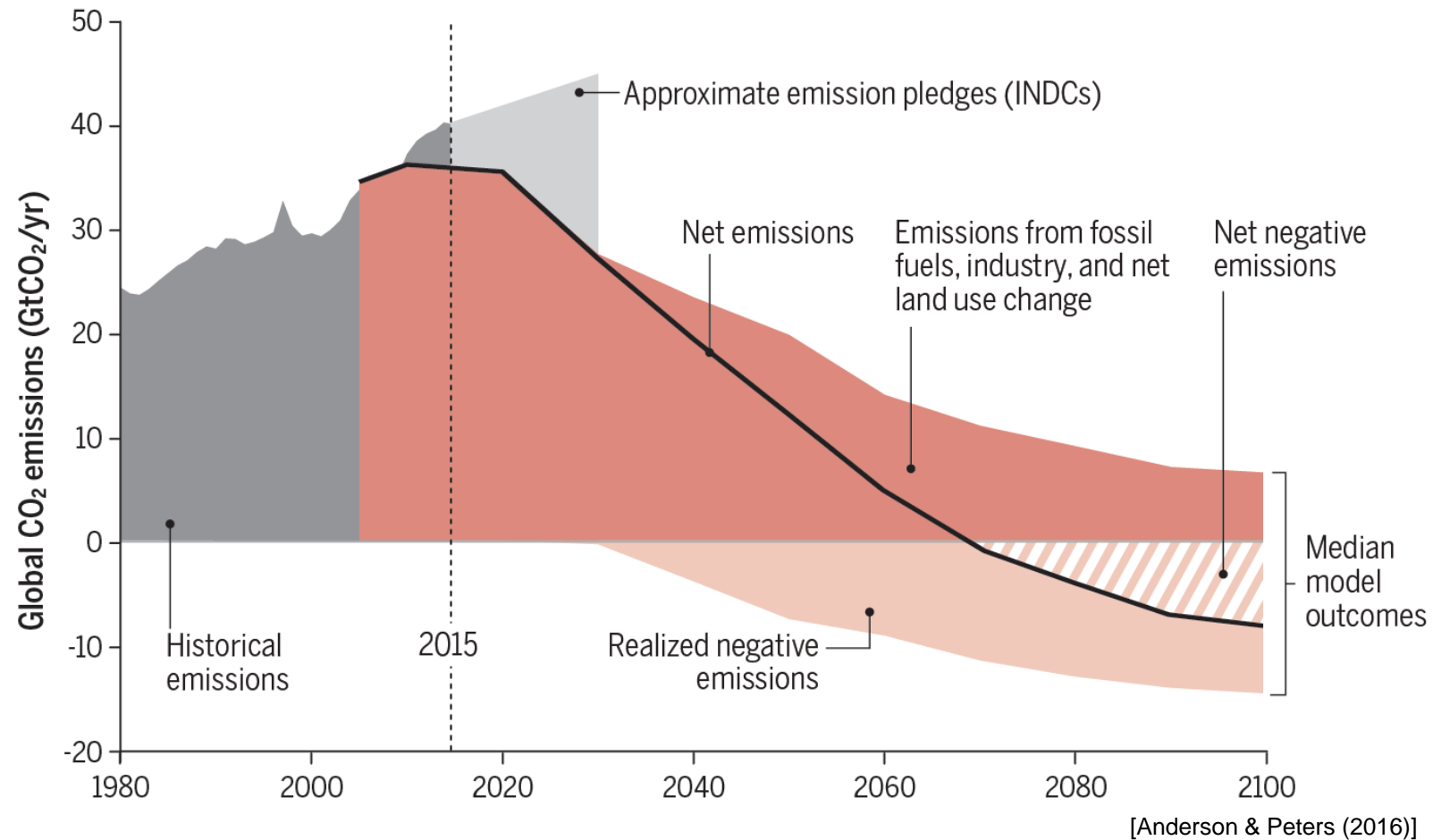
The Paris Agreement and integrated assessment models

THE PARIS AGREEMENT:
HOLD WARMING “TO
WELL BELOW 2 °C ...
AND TO PURSUE
EFFORTS TO LIMIT THE
TEMPERATURE
INCREASE TO **1.5 °C**”



[Fuss et al. (2016)]

The scale of carbon dioxide removal needed



Rightsizing carbon dioxide removal expectations

- Based on Field and Mach (2017)
 - Feasible at scale? Game changing?
 - Development of technology and policy?
 - Limits to deployment? (Land, water, reservoirs, energy)
 - Does overshoot limit impacts? Moral hazard and inequity?
 - Chances of failure



CLIMATE

Rightsizing carbon dioxide removal

Betting the future on planetary-scale carbon dioxide removal from the atmosphere is risky

By Christopher B. Field¹ and Katharine J. Mach²

Proven approaches for limiting climate change include enhancing energy efficiency, capturing wind and solar energy, decreasing deforestation, and reducing industrial and agricultural emissions. These approaches are increasingly cost-competitive, consistent with large-scale use, and largely supported by public sentiment. Yet, the current pace of their deployment is far from sufficient for holding warming well below 2°C above preindustrial levels with high probability, the goal of the Paris Agreement. Two ap-

proved in ecosystems through reforestation and afforestation, conservation agriculture, or coastal restoration. In many locations, improved stewardship can enhance carbon storage at low cost while also improving habitat quality or increasing agricultural yields. However, important questions remain about maximum feasible scales, effective carbon monitoring, and risks of losing stored carbon through disturbances or climate change effects.

A second group of much less mature strategies is also biomass-based but involves more engineering and more environmental or social trade-offs. Leading options include biochar additions to soil, increased use of

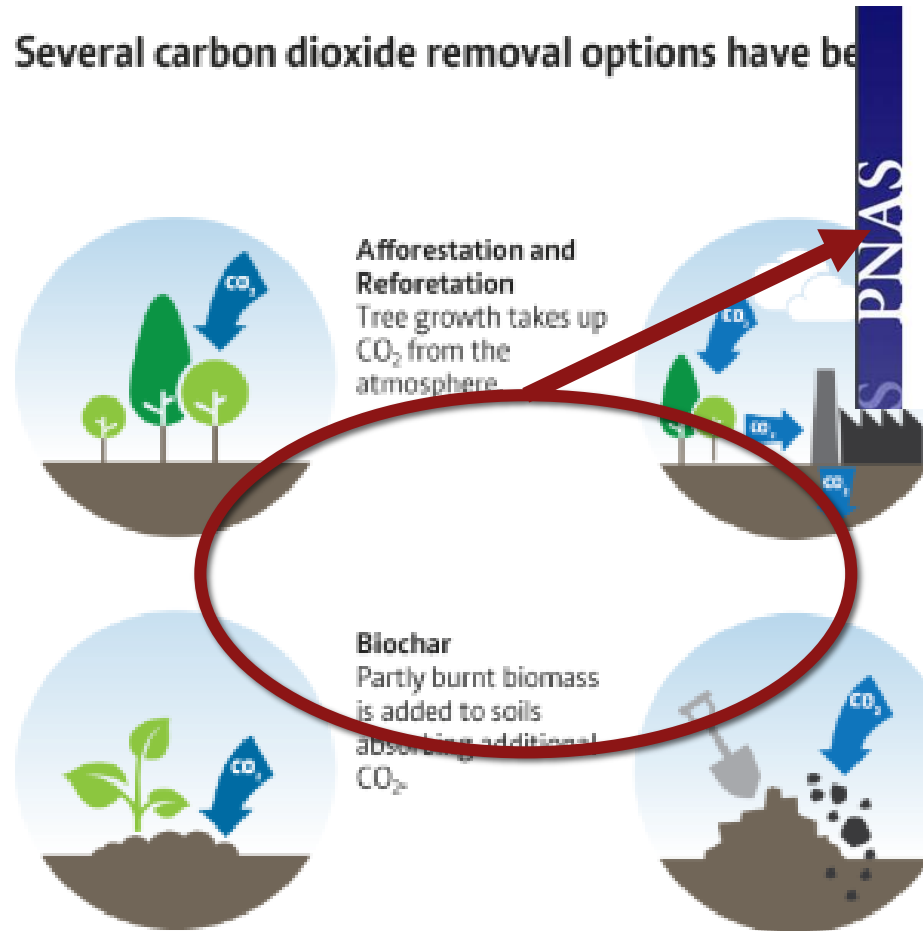
persive, they may eventually provide useful options for CDR at scale. At this point, however, their technological immaturity means that estimates of future costs, performance, and scalability are speculative.

OPPORTUNITIES AND CONSTRAINTS

With CDR, changes in the atmosphere and climate unfold as if emissions reductions were actually more rapid and extensive. As humanity moves toward decarbonized societies, CDR could counterbalance difficult-to-control sources such as carbon dioxide from aircraft and methane from cattle. It could also, in theory, justify delaying near-term action, based on the expect-

Different negative emissions technologies

Several carbon dioxide removal options have been



Geospatial analysis of near-term potential for carbon-negative bioenergy in the United States

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Edited by William H. Schlesinger, Earth and Ocean Sciences, Nicholas School of the Environment, Duke University, Durham, NC, and approved February 12, 2018 (received for review November 21, 2017)

Bioenergy with carbon capture and storage (BECCS) is a negative-emissions technology that may play a crucial role in climate change mitigation. BECCS relies on the capture and sequestration of power plants. CO₂ captured and stored underground.

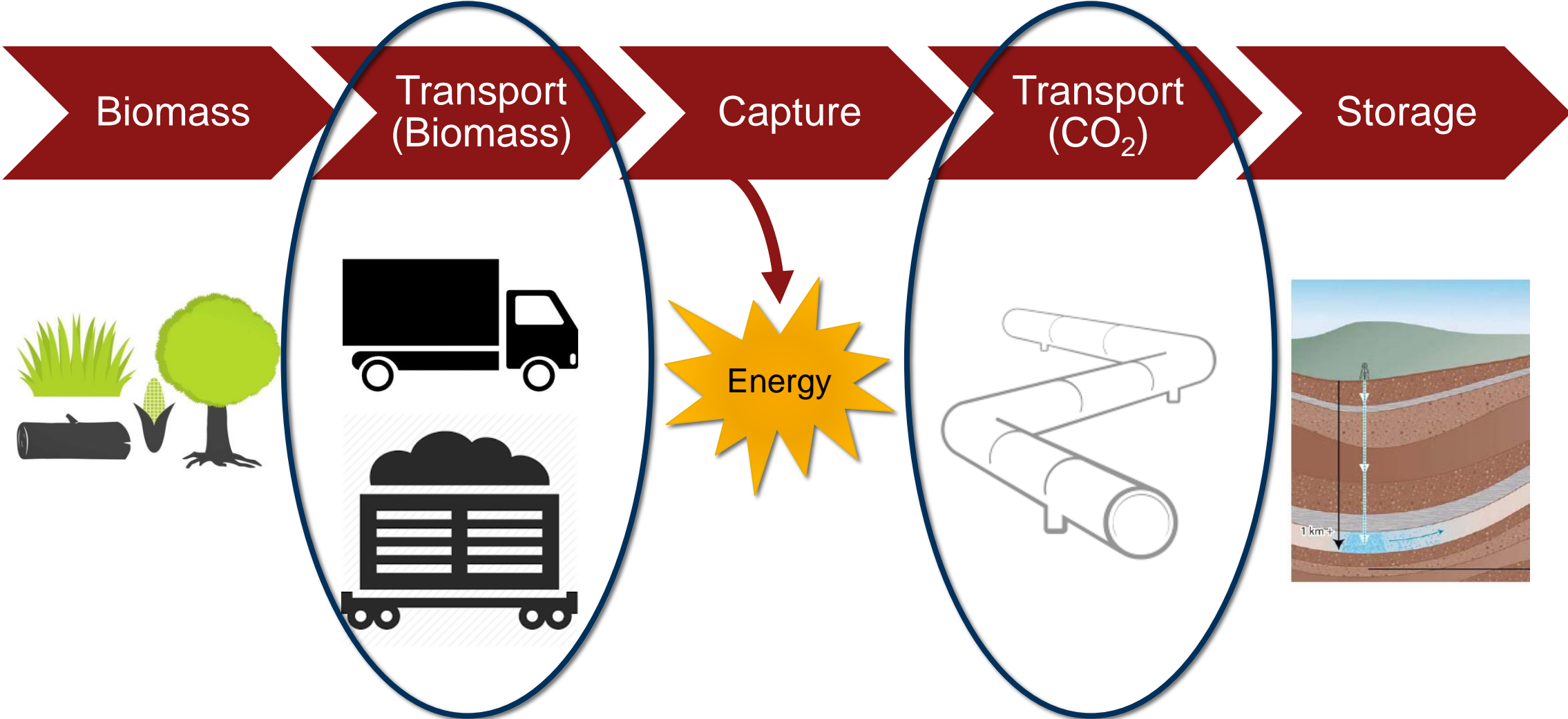
biomass potential (9–13) but has often neglected to consider the availability and characteristics of suitable storage sites for sequestration. Studies that have considered storage and injection increasing CO₂ content of BECCS (6, 14, 15) have consid absorption.

Enhanced weathering
Crushed minerals are applied to soil for chemical CO₂ absorption.

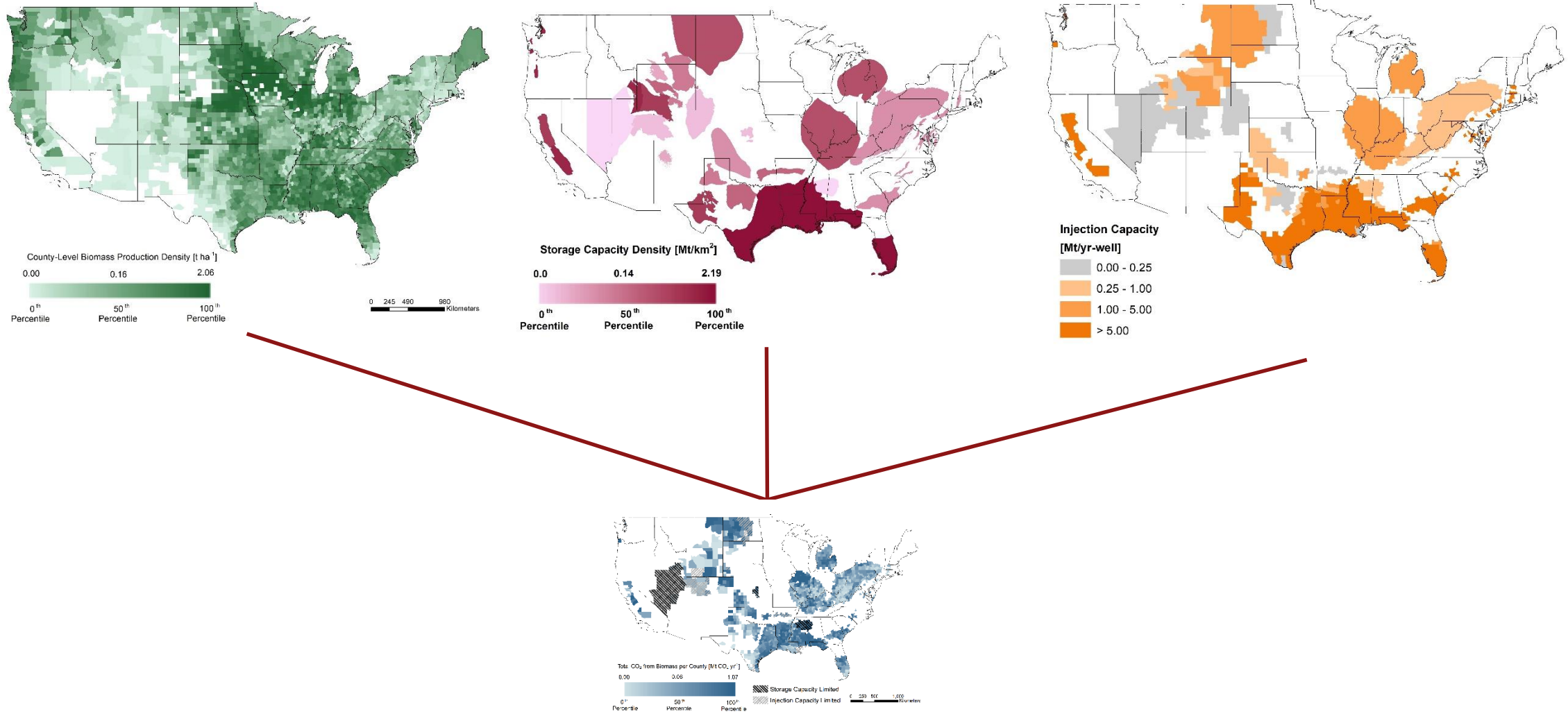
Direct Air Capture
CO₂ is removed from ambient air through chemical processes and stored underground.

[Mercator Research Institute on Global Commons and Climate Change (MCC) (2016)]

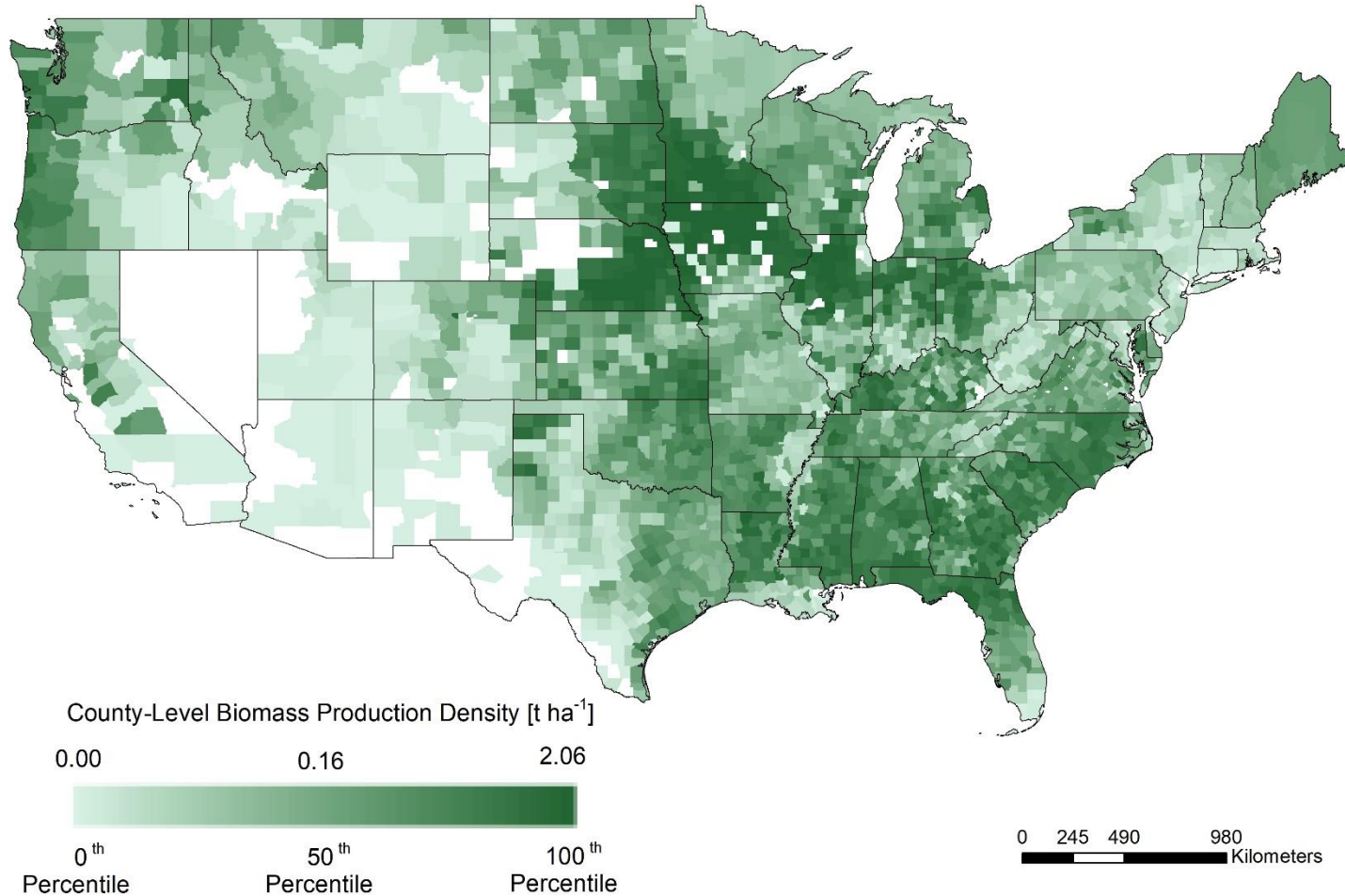
Components of BECCS



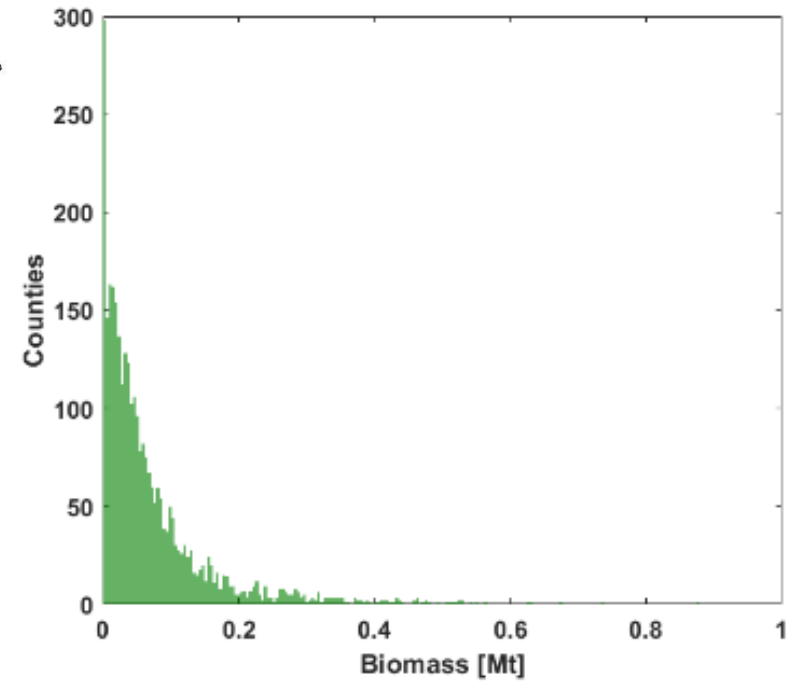
This study



1. Biomass availability

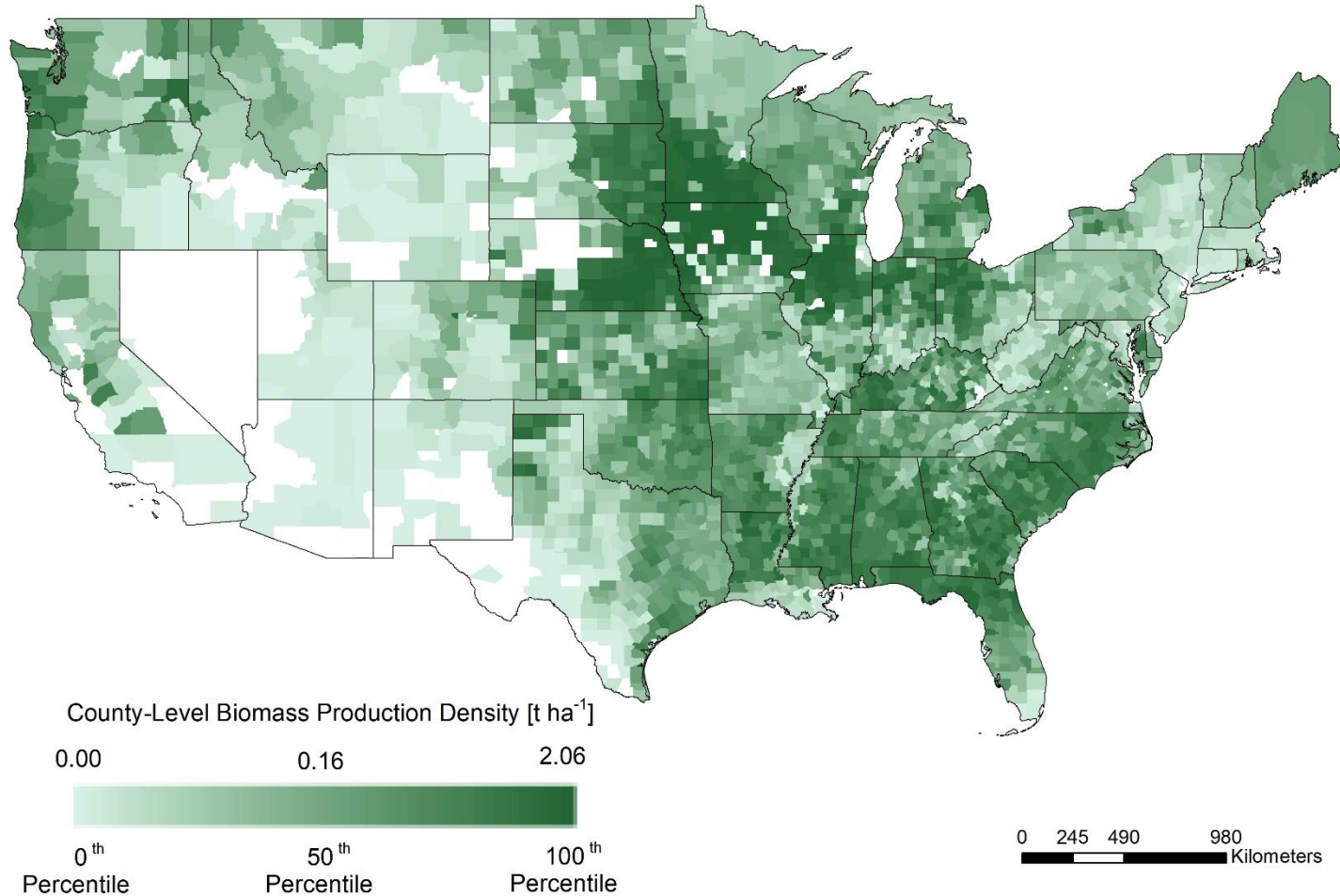


Distribution of biomass production per county in 2020

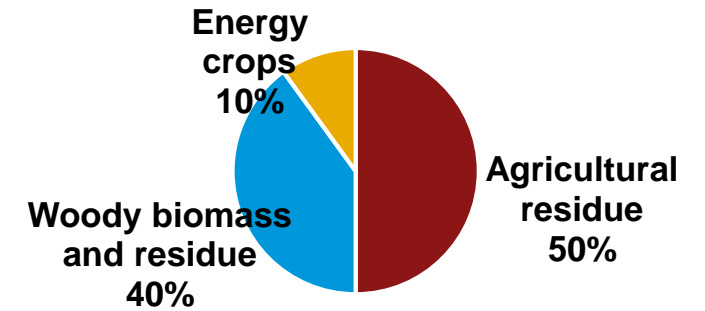


Biomass Data: U.S. DOE Billion Ton Study

1. Biomass availability

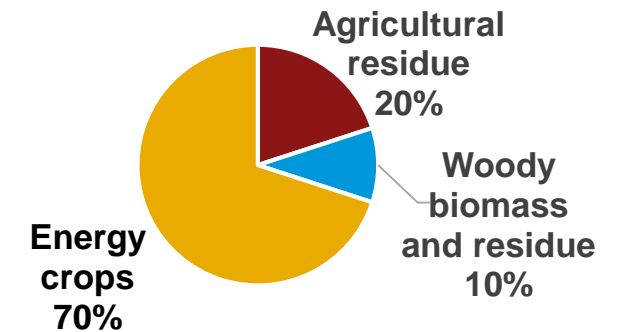


2020 Projection



Biomass (~370-400 Mt CO₂/yr)

2040 Projection

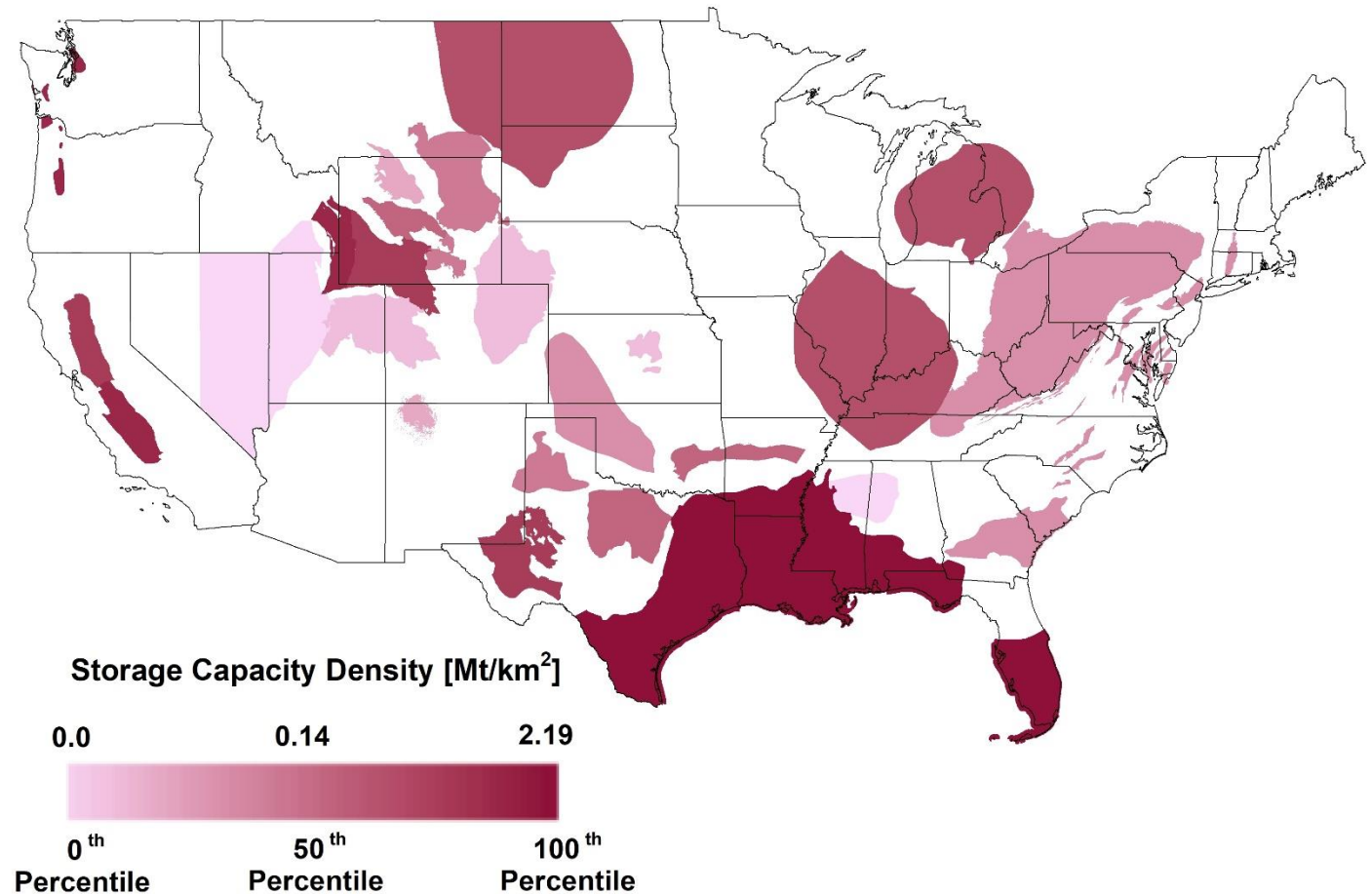


Biomass (~1040-1780 Mt CO₂/yr)

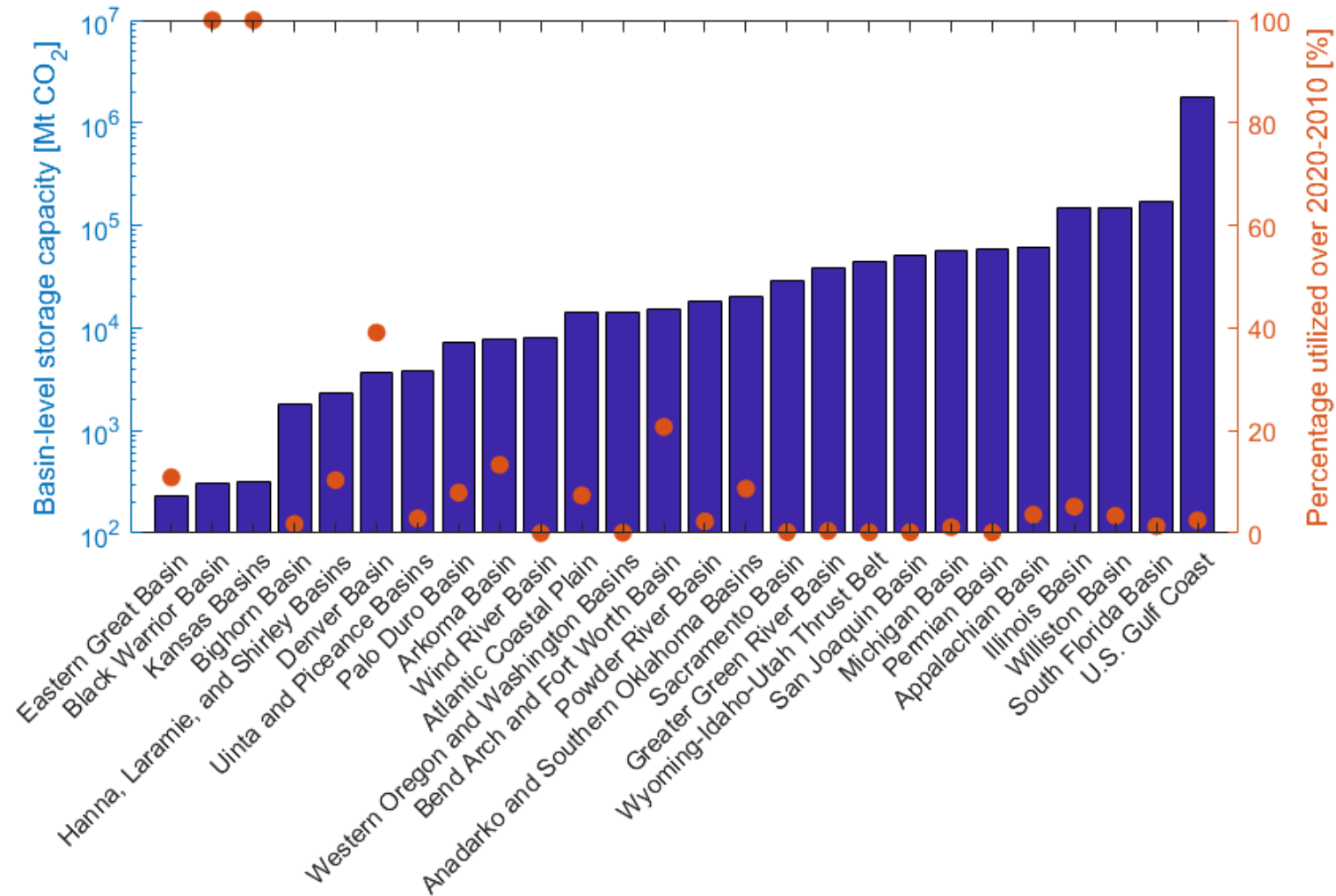
2. Storage sites characteristics: storage capacity varies widely

Storage Site Data: USGS National Assessment of Geologic Carbon Dioxide Storage Resources

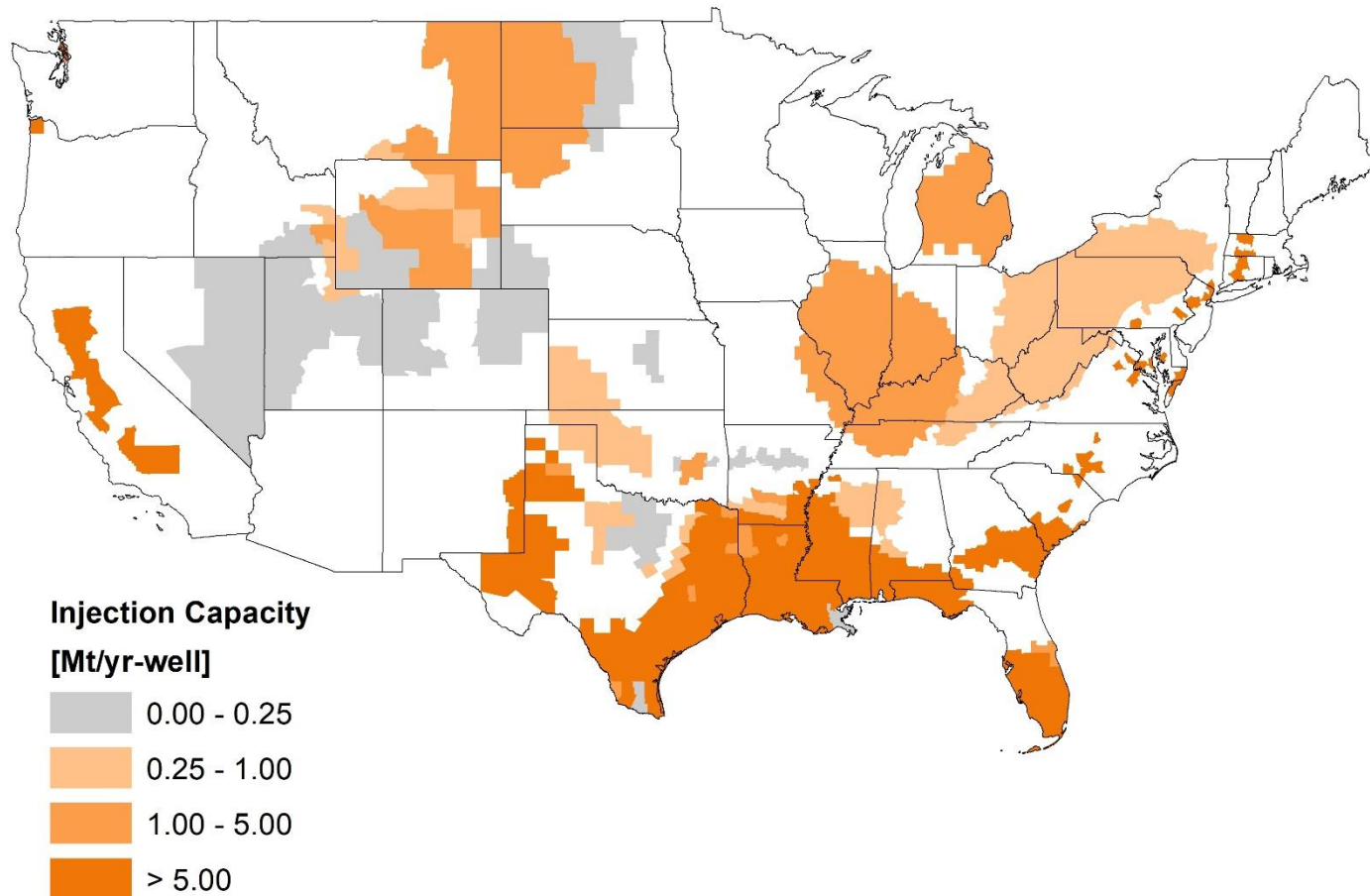
- **Estimated aggregate storage capacity: ~3,000 Gt CO₂**
- **Aggregate storage capacity is not likely a limiting factor for BECCS deployment**
- **Regional storage capacities vary widely**



2. Storage sites characteristics: storage capacity analysis

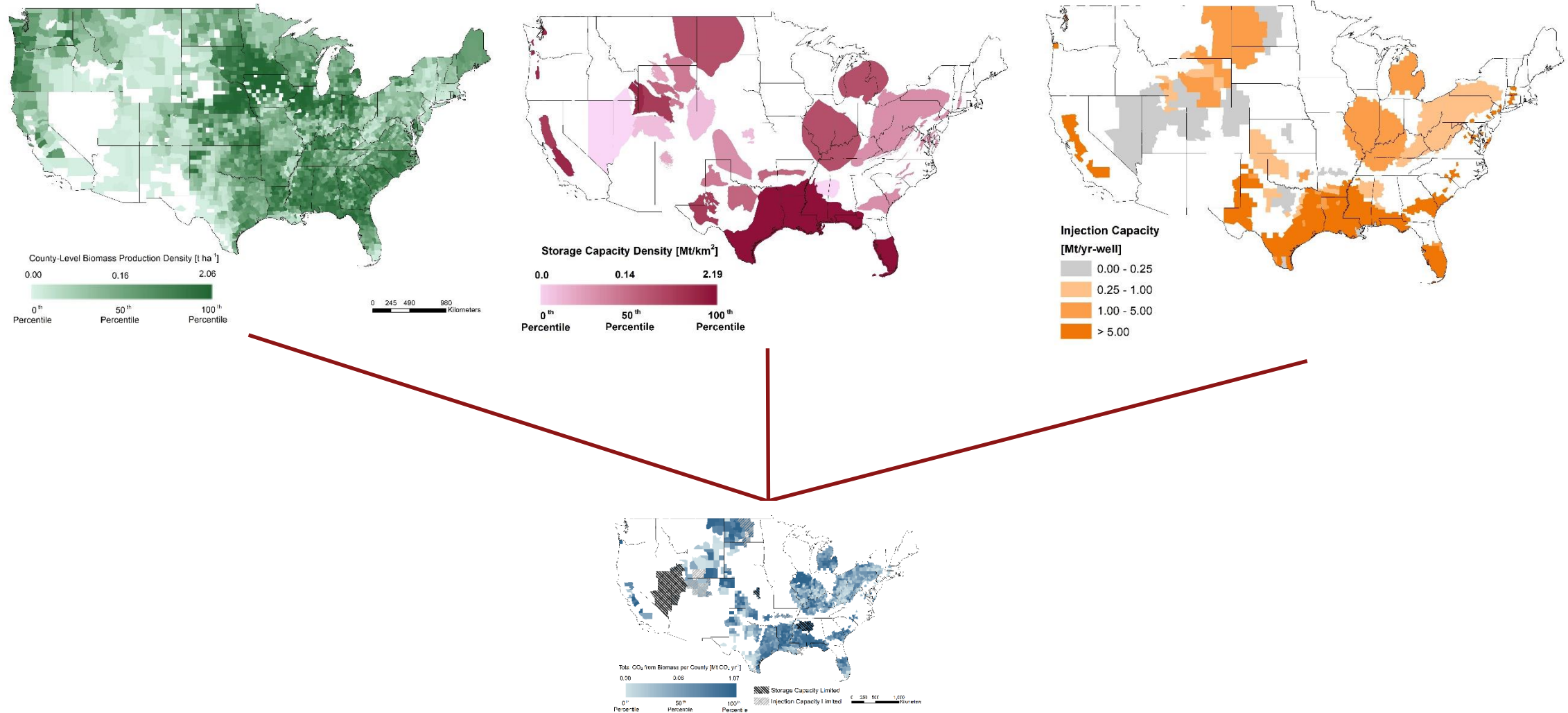


3. Storage sites characteristics: injectivity varies widely

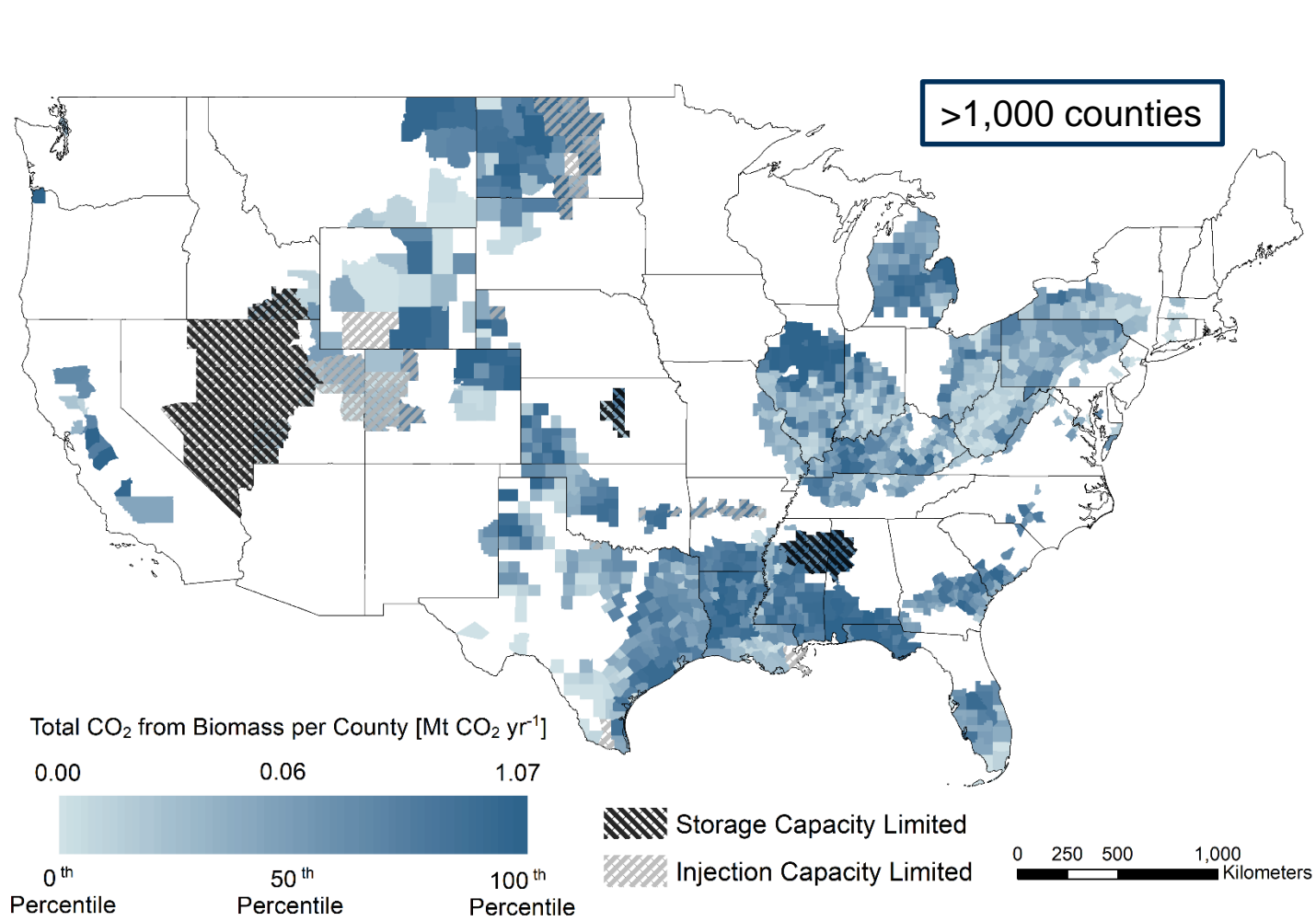


- **Low injectivity indicates higher risks of pressure buildup and leakage**
- **Calculate storage injectivity given porosity, permeability, and depth of each storage site**
- **Regional injectivity widely varies**

Combine components



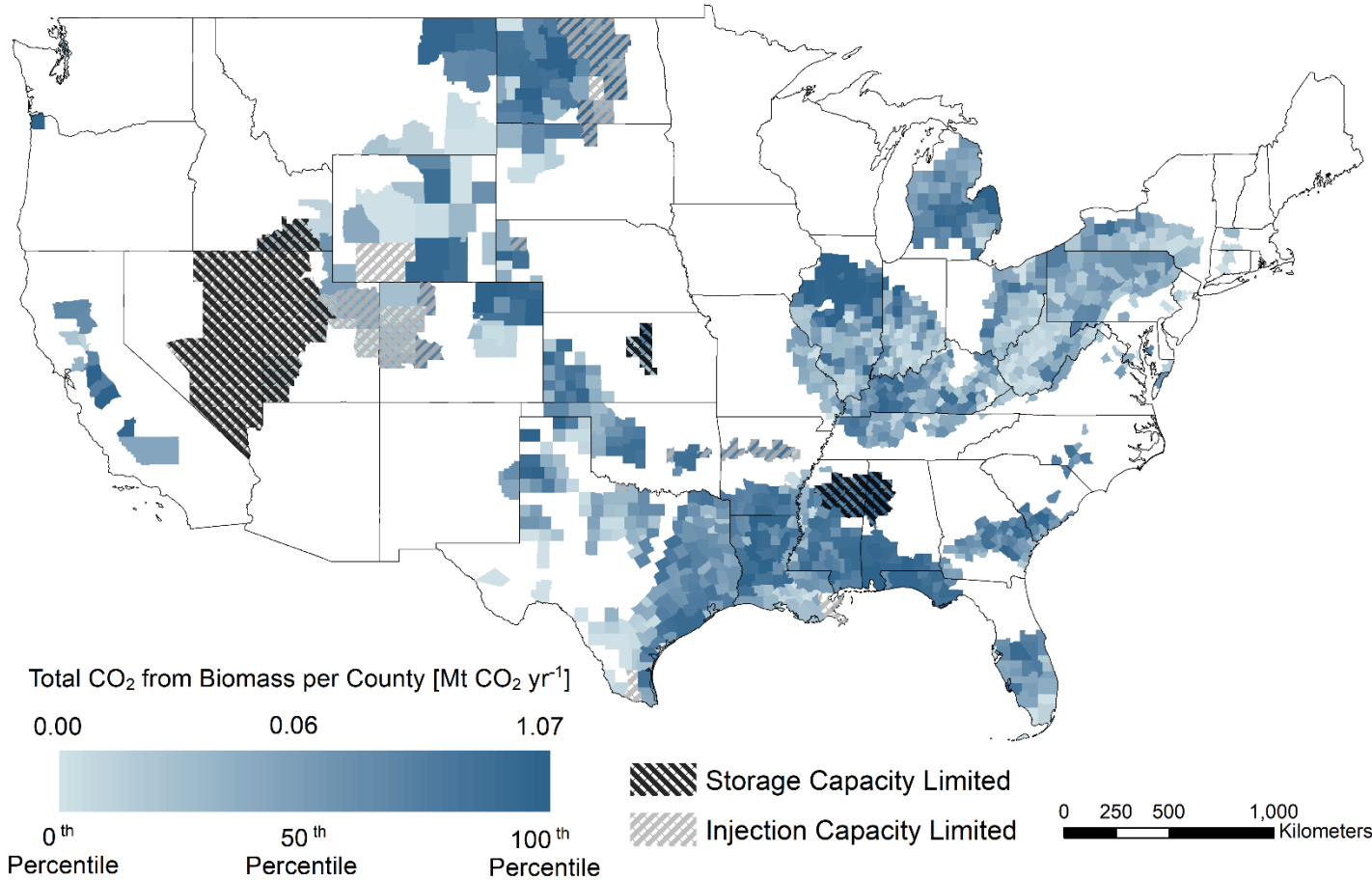
Resulting negative emissions potential in the U.S.



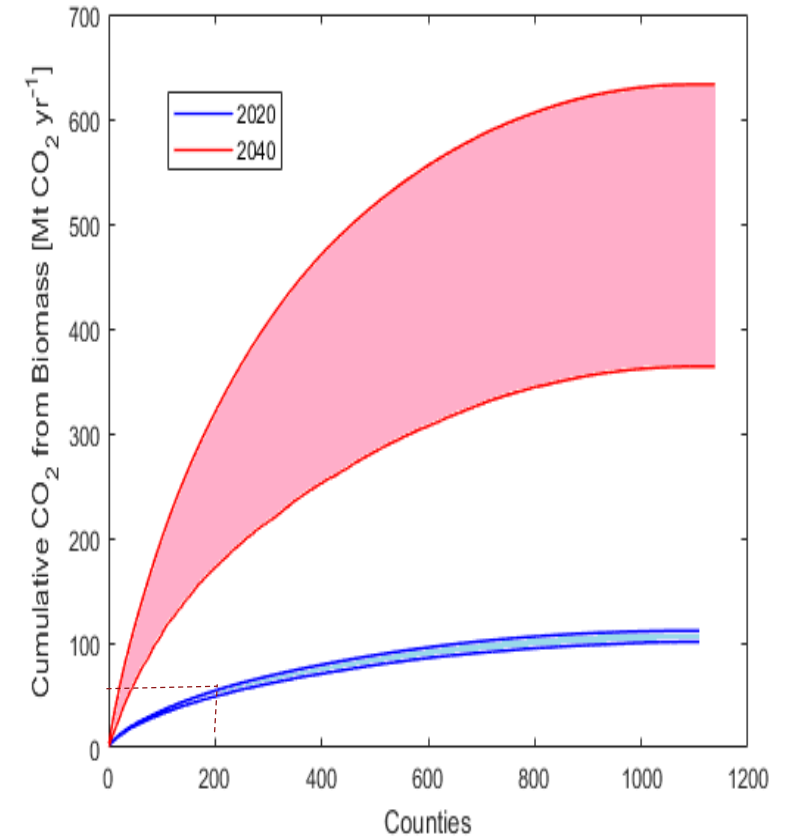
Current U.S. CO₂ emissions: ~5,000 Mt

Negative Emissions Potential [Mt CO ₂ /yr]	2020	2040
Total	370-400	1,040-1,780
with co-located storage	110-120	400-680
with co-located storage with sufficient storage capacity and injectivity	100-110	360-630

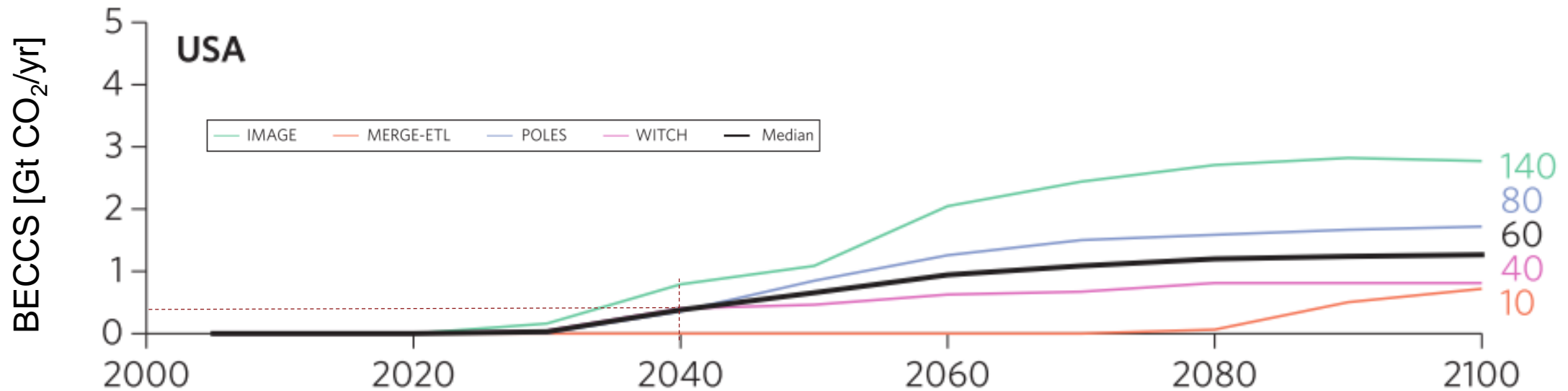
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Cumulative CO₂ from biomass from counties in 2020 and 2040

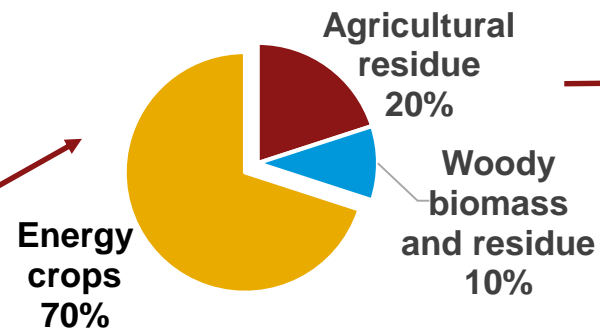


Comparison with integrated assessment model



[Peters and Geden (2017)]

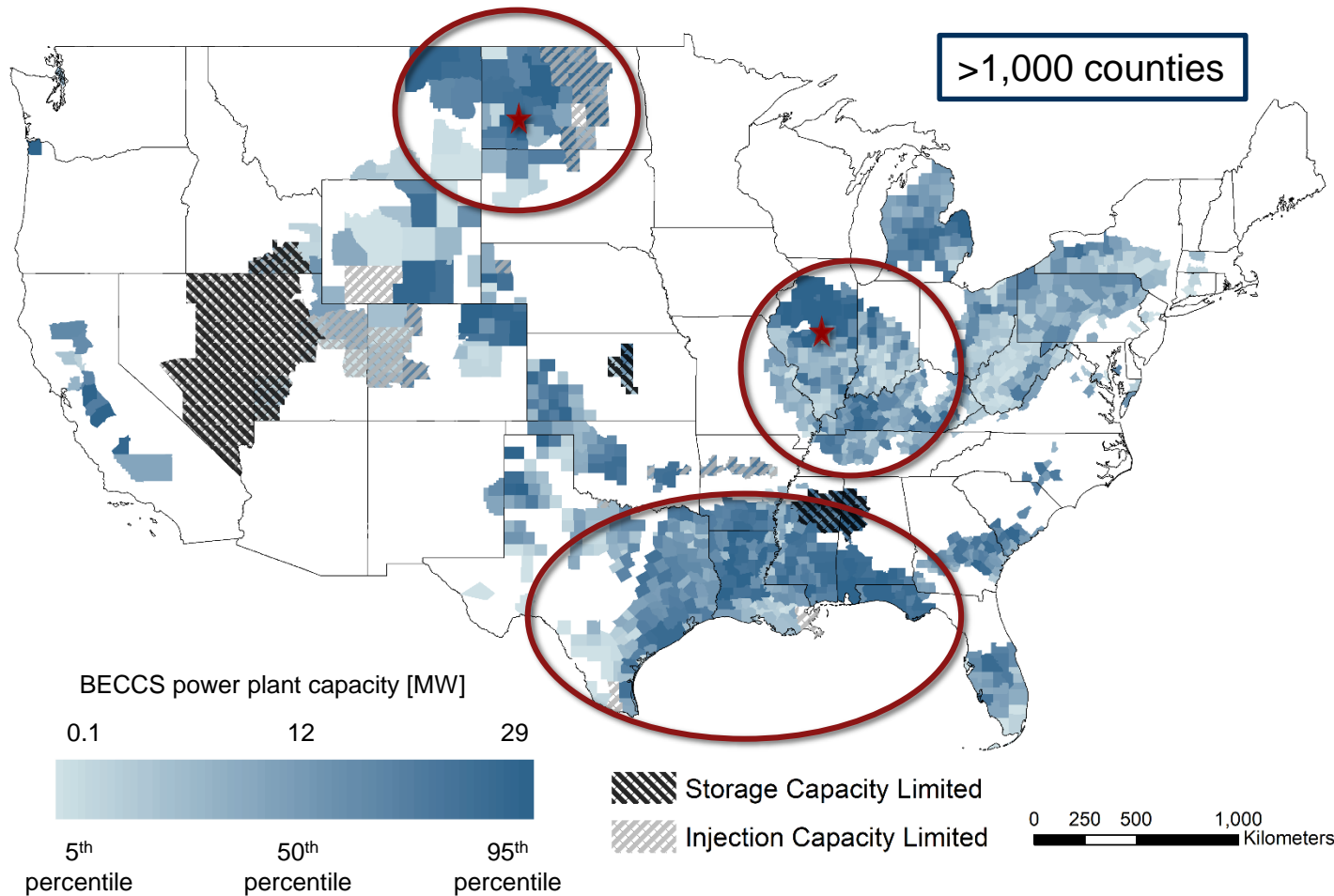
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Without Energy Crops

2040 Negative Emissions Potential:
104-111 Mt CO₂/yr

Meeting all the potential in the context of power generation

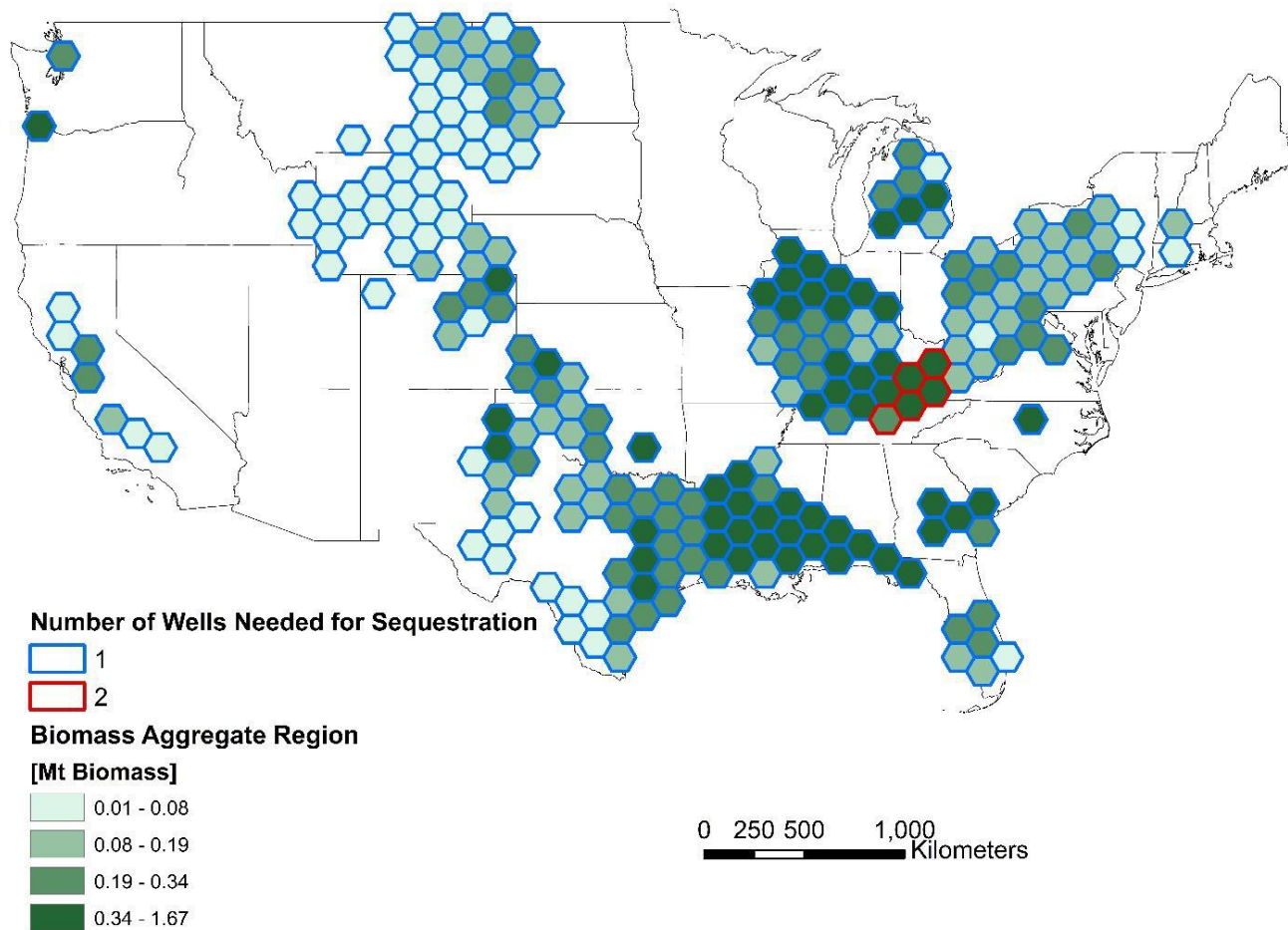


Current U.S.
biomass electricity
generation: ~**0.2 EJ**

	2020	2040
Negative Emissions Potential [Mt CO ₂ /yr]	100-110	360-630
Corresponding Energy [EJ]	0.3	1-2
Corresponding Capacity [GW]	10-12	40-70


- **Currently in the U.S.:**
 - **11 GW capacity of biomass electricity**
 - **approximately 300 biomass power plants with a median capacity of 23 MW**

Another possibility: 50 mile transportation of biomass



- **Number of Wells:**
>1,000 → ~230
- **Injection per Well (Median):**
0.06 Mt CO₂/yr → 0.5 Mt CO₂/yr
- **Power Plant Capacity (Median):**
12 MW → 108 MW
- **Additional prospective regions for potential near-term deployment**

Related Works



Near-term deployment of carbon capture and sequestration from biorefineries in the United States


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Edited by Donald J. DePaolo, Lawrence Berkeley National Laboratory, Berkeley, CA, and approved March 16, 2018 (received for review November 10, 2017)

Capture and permanent geologic sequestration of biogenic CO₂ emissions may provide critical flexibility in ambitious climate change mitigation. However, most bioenergy with carbon capture and sequestration (BECCS) technologies are technically immature or commercially unavailable. Here, we evaluate low-cost, commercially ready CO₂ capture opportunities for existing ethanol biorefineries in formations that allow for safe, reliable, and permanent CO₂ sequestration. Near-term opportunities to develop, demonstrate, and deploy BECCS technologies can reduce costs, improve performance, and clarify their sustainable scale (8). In particular, analysis that identifies opportunities to leverage existing infrastructure, tech-

“Unprecedented rates of land-use transformation in modeled climate change mitigation pathways” – Turner et al. *Nature Sustainability* (in press)




Climatic Change (2018) 148:1–10
<https://doi.org/10.1007/s10584-018-2189-z>

The global overlap of bioenergy and carbon sequestration potential

P. A. Turner¹ · K. J. Mach² · D. B. Lobell^{2,3} · S. M. Benson⁴ · E. Baik⁴ · D. L. Sanchez¹ · C. B. Field⁵

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Abstract Bioenergy with carbon capture and storage (BECCS) is a negative emissions technology that is a largely untested but prominent feature of ambitious climate change mitigation scenarios. This strategy involves capturing carbon dioxide (CO₂) from stationary bioenergy facilities and sequestering it in suitable geological formations, effectively removing CO₂ from the atmosphere. Many factors potentially limit BECCS



CLIMATE

Rightsizing carbon dioxide removal

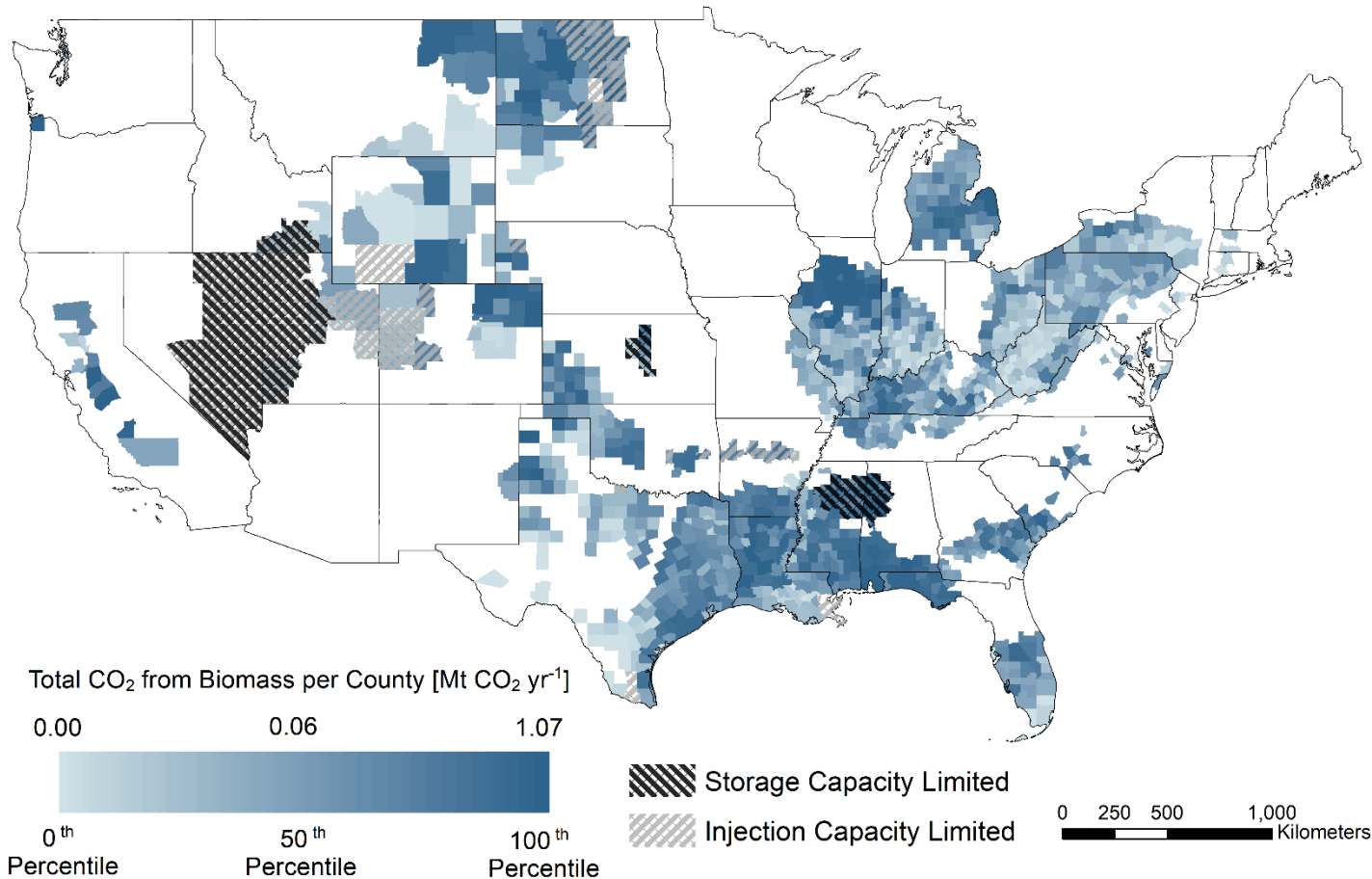
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OPPORTUNITIES AND CONSTRAINTS
 With CDR, changes in the atmosphere and

Conclusion



- Approximately 30% of the biomass potential in the U.S. is overlapping with a storage site
- Resulting negative emissions potential in the U.S.:
 - 100-110 Mt CO₂/yr in 2020
 - 360-630 Mt CO₂/yr in 2040
- BECCS potential is widespread
- Helps define the near-term opportunities that minimize social and economic barriers to BECCS deployment

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Thank you for listening. Questions?

