CO2 Transport Infrastructure Workshop

October 12, 2022

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Great Plains Institute

Background on Great Plains Institute

An independent nongovernmental organization focused on energy policy and technology.

Mission

- *Transforming the energy system to benefit the economy and the environment.*

Objectives

- *Increase energy efficiency and productivity.*
- *Decarbonize electricity production.*
- *Electrify the economy and adopt zero and low-carbon fuels.*
- *Capture carbon for beneficial use and permanent storage.*

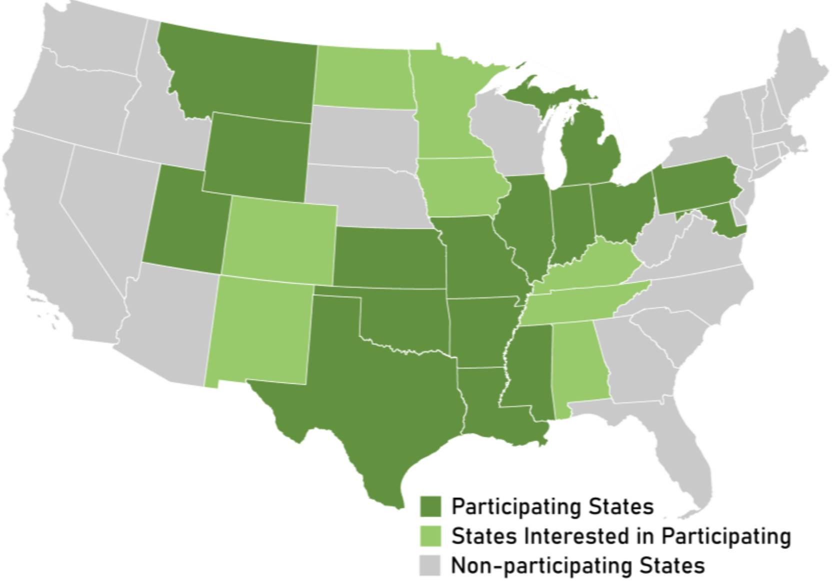
Key GPI Carbon Management Objectives

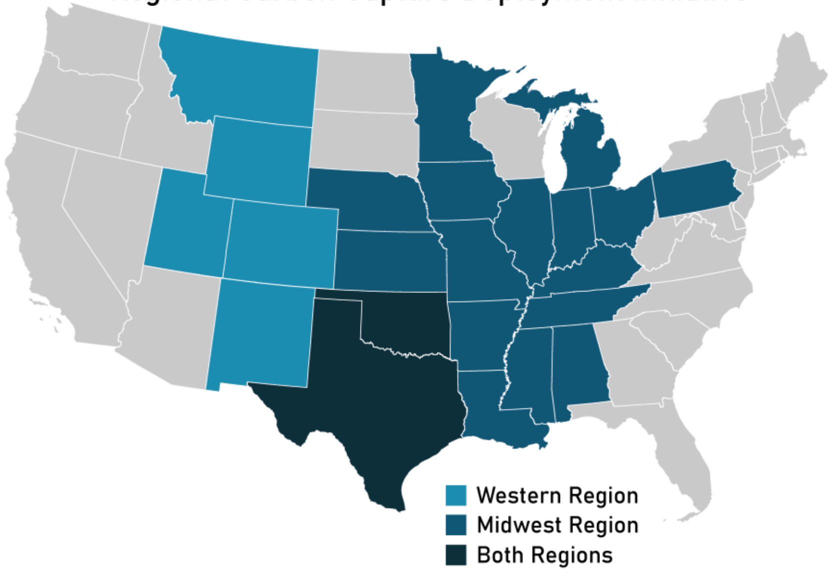
- ***Elevate carbon capture as a national priority for achieving midcentury climate goals, creating high-wage jobs and sustaining our domestic energy and industrial base.***

- ***Provide comprehensive policy support for carbon capture equivalent to support already provided to other low and zero-emission technologies.***

- ***Foster economywide deployment of carbon capture and the national buildout of critical CO_2 pipeline infrastructure.***

Helping States Become Carbon Capture Ready



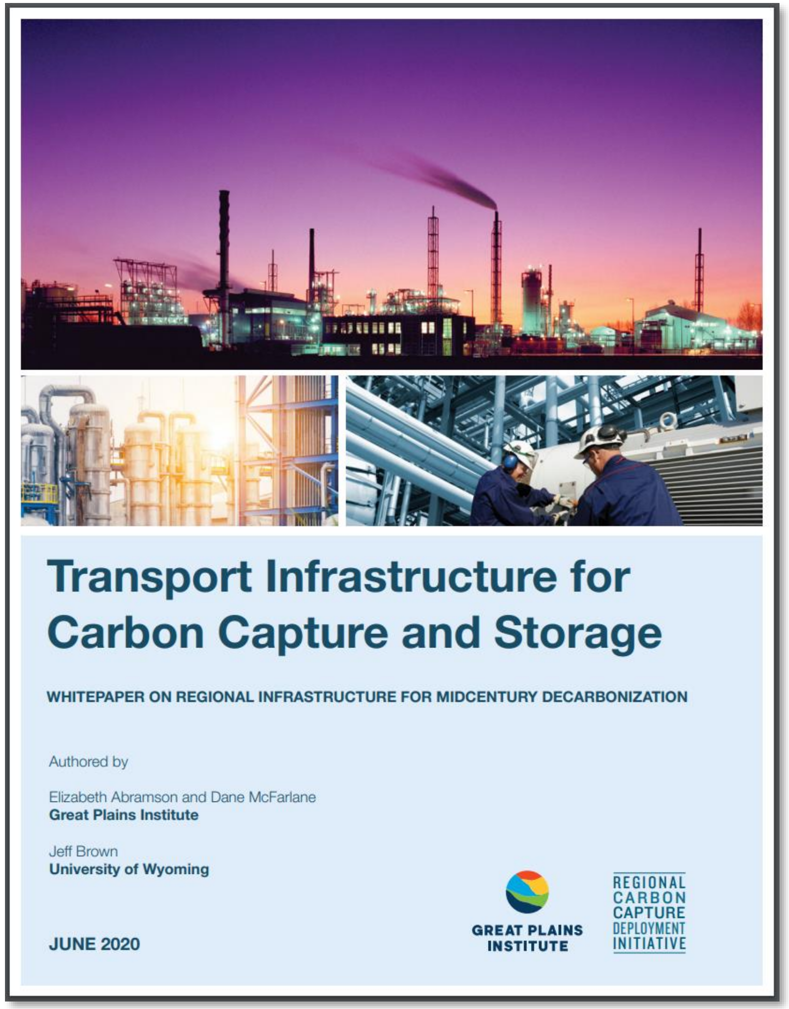


- **State Carbon Capture Work Group**: Established in 2015, with state officials representing 16 states.
- **Regional Deployment Initiative**: Over 800 state officials, companies, NGOs, and unions from two dozen states interested in supporting state and federal policy development
- Work Group and RDI coordinating state policymaker and stakeholder engagement, development of policy recommendations, and regional deployment modeling and jobs analysis.

www.carboncaptureready.org

Analytical Report

Published June 30, 2020



Transport Infrastructure for Carbon Capture and Storage

WHITEPAPER ON REGIONAL INFRASTRUCTURE FOR MIDCENTURY DECARBONIZATION

Authored by

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Great Plains Institute

Jeff Brown
University of Wyoming

JUNE 2020

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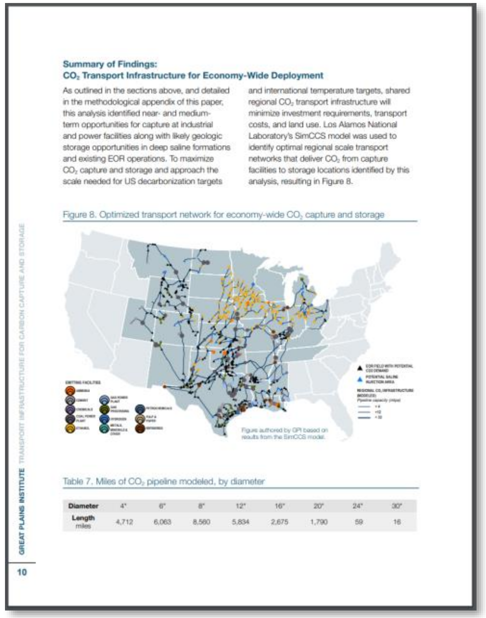
REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE



Summary of Findings:
CO_2 Transport Infrastructure for Economy-Wide Deployment

As outlined in the sections above, and detailed in the methodological appendix of this paper, this analysis identified near- and medium-term opportunities for capture at industrial and power facilities along with likely geologic storage opportunities in deep saline formations and existing EOR operations. To maximize CO_2 capture and storage and approach the scale needed for US decarbonization targets and international temperature targets, shared regional CO_2 transport infrastructure will minimize investment requirements, transport costs, and land use. Los Alamos National Laboratory's SimCCS model was used to identify optimal regional scale transport networks that deliver CO_2 from capture facilities to storage locations identified by this analysis, resulting in Figure 8.

Figure 8. Optimized transport network for economy-wide CO_2 capture and storage

Figure authored by GPI based on results from the SimCCS model.

Table 7. Miles of CO_2 pipeline modeled, by diameter

Diameter	4"	6"	8"	12"	16"	20"	24"	30"
Length miles	4,712	6,063	8,560	5,834	2,675	1,790	59	16

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The difference in build-out of CO_2 transport infrastructure in the Near- to Medium-Term Scenario and the High-Cost Sensitivity Scenario shows that there is still a gap in pure break-even economic equilibrium: a regional scale CO_2 transport network will require capital investment that will not necessarily be paid simply through the sale of CO_2 at $20 per ton combined with the value of tax credits in the current 45Q program. The transport networks modeled here maximize the rate of CO_2 capture and storage across the power and industrial sectors while minimizing the cost and land use of transport infrastructure. In reality, CO_2 transport infrastructure may more likely be built out in a piecemeal fashion, linking single facilities or a small group of projects to a single storage location. This may result in CO_2 infrastructure that is not of sufficient capacity to meet the scale of CO_2 capture and storage required by midcentury decarbonization targets. This infrastructure would need to be replaced in the future or an abundance of additional infrastructure would need to be built, costing more and having a greater land use impact than a regional system built through coordinated planning.

This study has shown clear opportunities for wide-spread capture at low costs throughout the Midwest, Midcontinent, Rockies, Northern Plains, Gulf Coast, and Texas.

If the US is to significantly decarbonize the industrial and power sectors, as well as create a marketplace that allows for direct air capture facilities to help achieve net-zero or negative carbon emissions, then planning and coordination must occur in the near term to begin building regional-scale transport

Near-term planning and coordination of regional-scale infrastructure will enable significant decarbonization of the industrial and power sectors while creating a marketplace for direct air capture of CO_2 will require.

Economy-wide deployment of carbon capture and storage will help achieve net-zero or negative carbon emissions in the US.

networks for economy-wide deployment of carbon capture and storage. By midcentury, local, national, and international climate action and the need to drive down the societal costs of carbon emissions will likely create natural economic incentives that enable CO_2 capture at industrial and power facilities, in addition to direct air capture facilities, that today seem relatively expensive.

Developing solutions in the near term to address logistical issues such as inter-state CO_2 transportation corridors, interconnected pipeline networks operated or shared by multiple private entities, and state and federal support for future-proofing pipeline capacity through "super-sizing" will drastically reduce costs as well as land use and environmental impact of CO_2 transport infrastructure. Achieving national goals will require broad scale coordinated vision and action. This analysis provides a framework for coordinated regional infrastructure that can help define that vision.

TRANSPORT INFRASTRUCTURE FOR CARBON CAPTURE AND STORAGE GREAT PLAINS INSTITUTE

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Download the paper at:

carboncaptureready.org/analysis

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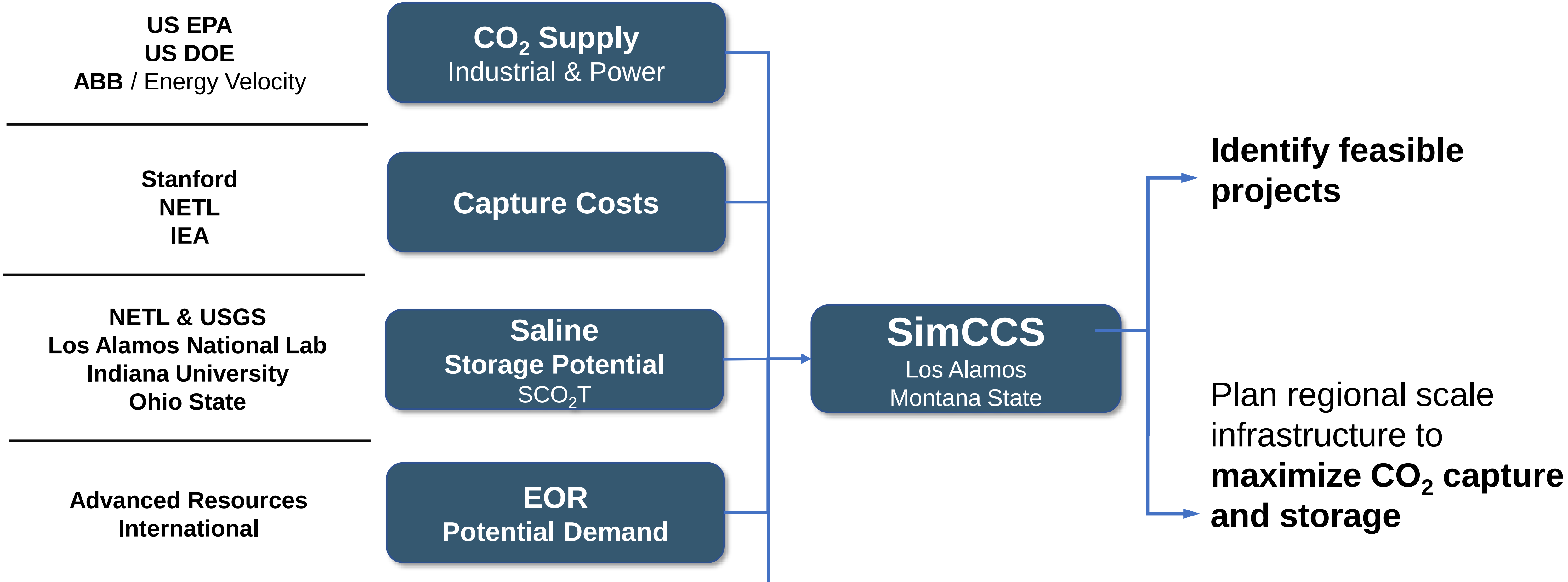
Regional CO_2 Transport Infrastructure Study



Study coordinated by GPI & RDI, and lead by GPI analysts

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CO_2 Capture Opportunities: Industrial and Power Facilities

Section 45Q
Tax Credit for CO_2 Storage

Geologic Saline:	\$50 / ton
EOR Storage:	\$35 / ton

Minimum Capture Thresholds

Industrial Facility:	100 thousand tons CO_2
Power Plants:	500 thousand tons CO_2

Near- and Medium-Term Screening Criteria:

- 45Q Eligibility
- Operational patterns
- Expected life
- Right-size capture equipment to specific units within each facility

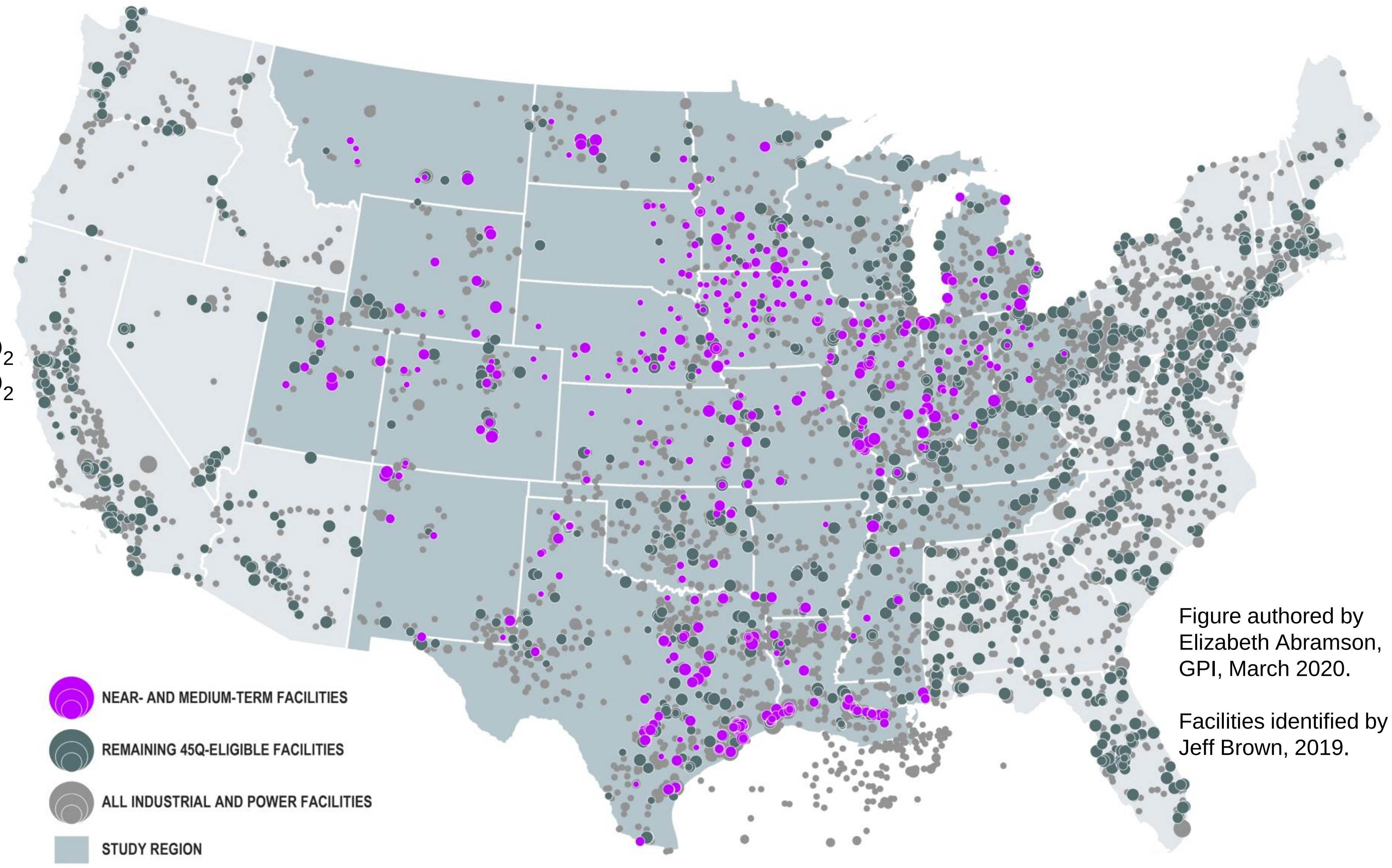

Figure authored by Elizabeth Abramson, GPI, March 2020.

Facilities identified by Jeff Brown, 2019.

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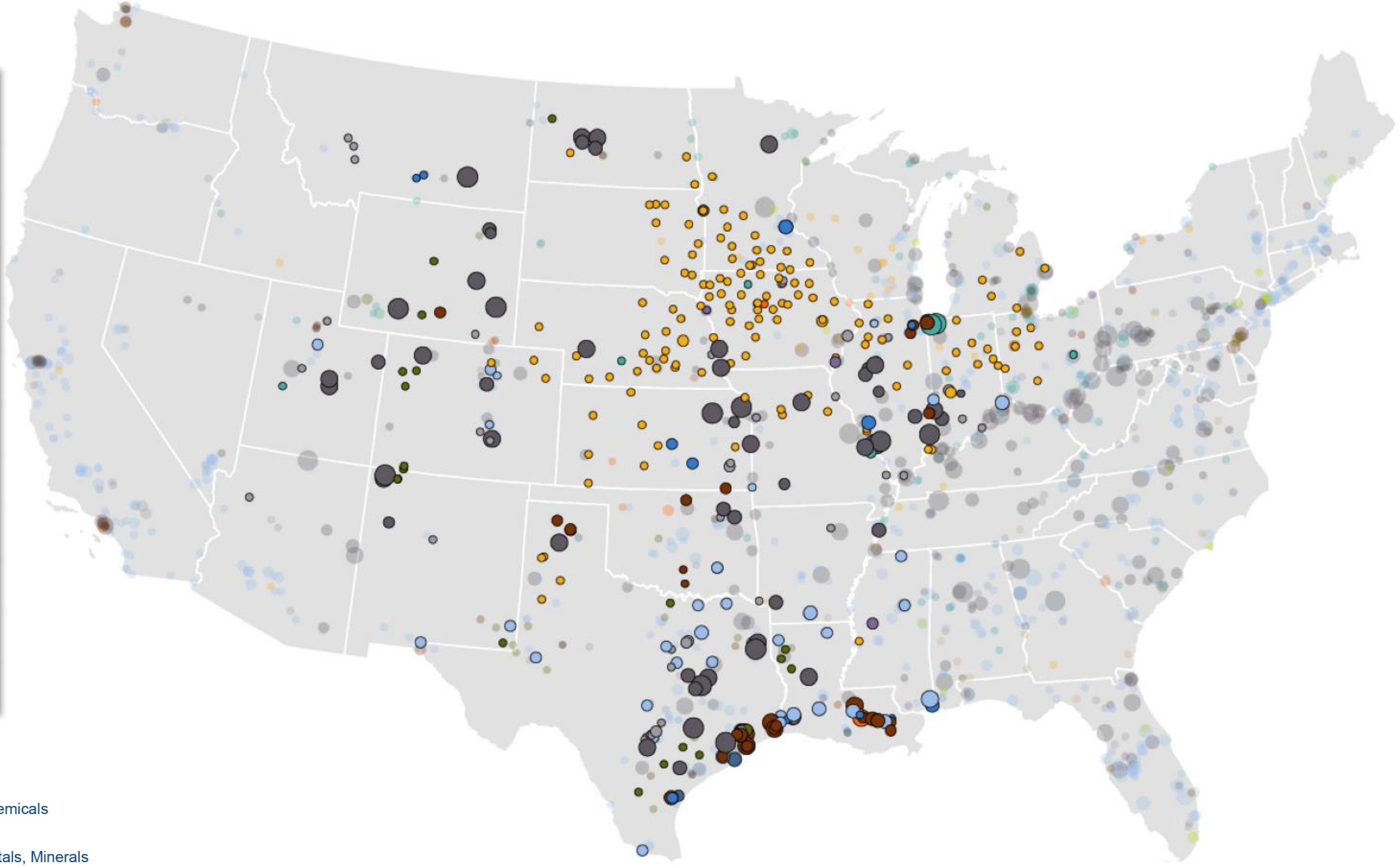
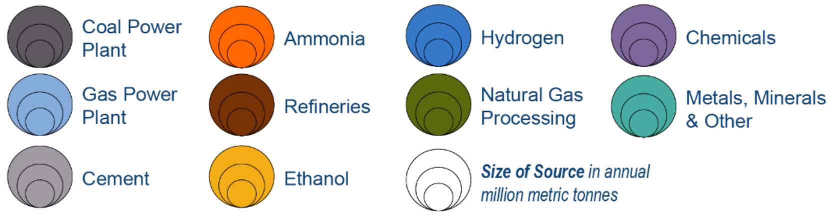
Economically Feasible Capture Retrofit with 45Q

Facilities identified by Regional Deployment screening

Industry	Capture Target (million MT/yr)
Steel (Blast Furnace)	12.5
Cement	29.5
NG Processing	4.5
Ethanol	36.2
Refineries (FCC)	25.4
Hydrogen	14.7
Lime	0.9
NG Power Plants	65.9
Ammonia	0.7
Coal Power Plants	132.6
Total	**322.9**





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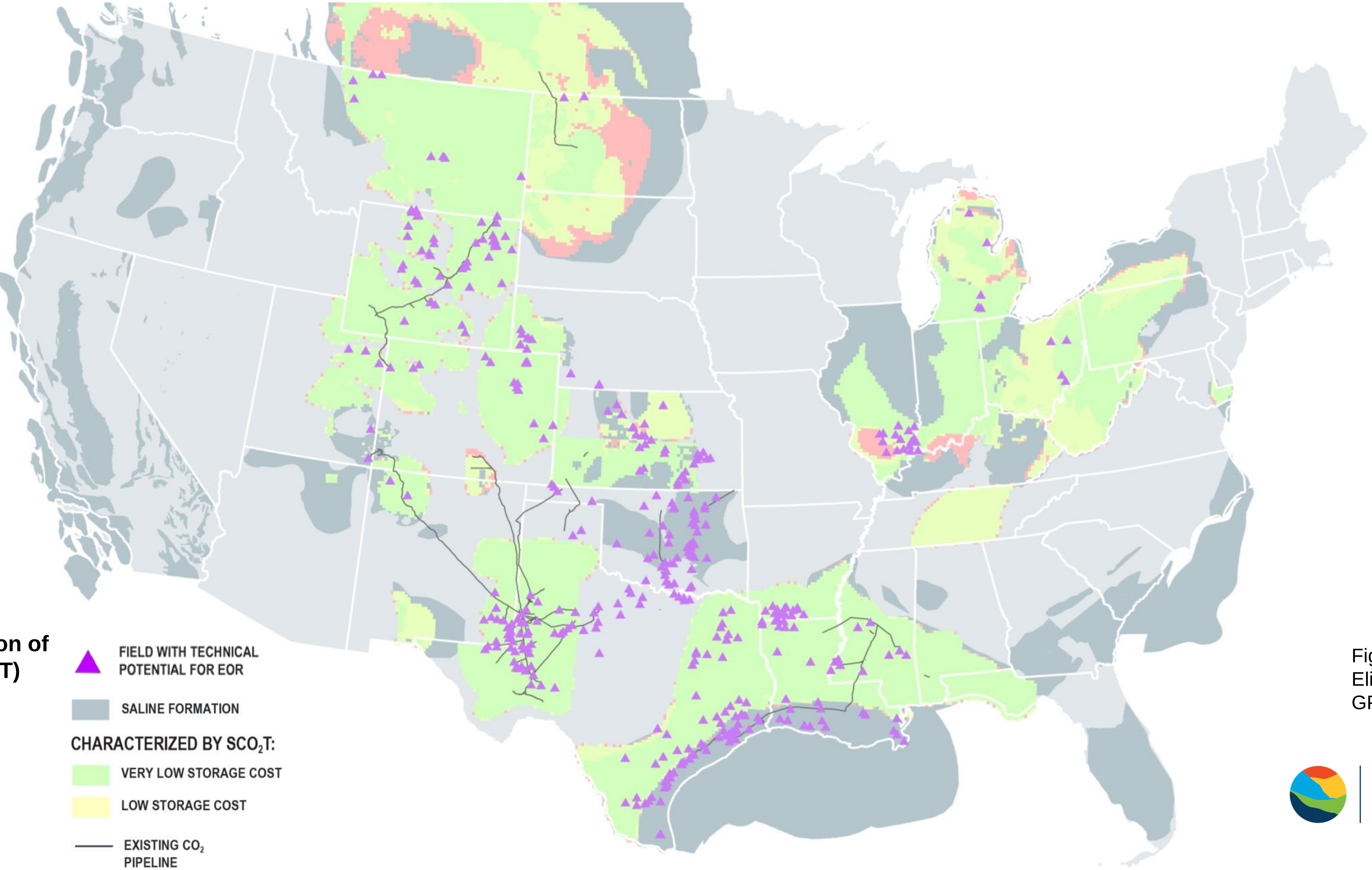
Saline: SCO2T & NATCARB 10km Grid Cells



Saline data via
The Sequestration of CO2 Tool (SCO2T)

Los Alamos National Laboratory EST. 1943

Indiana University

Figure authored by Elizabeth Abramson, GPI, March 2020

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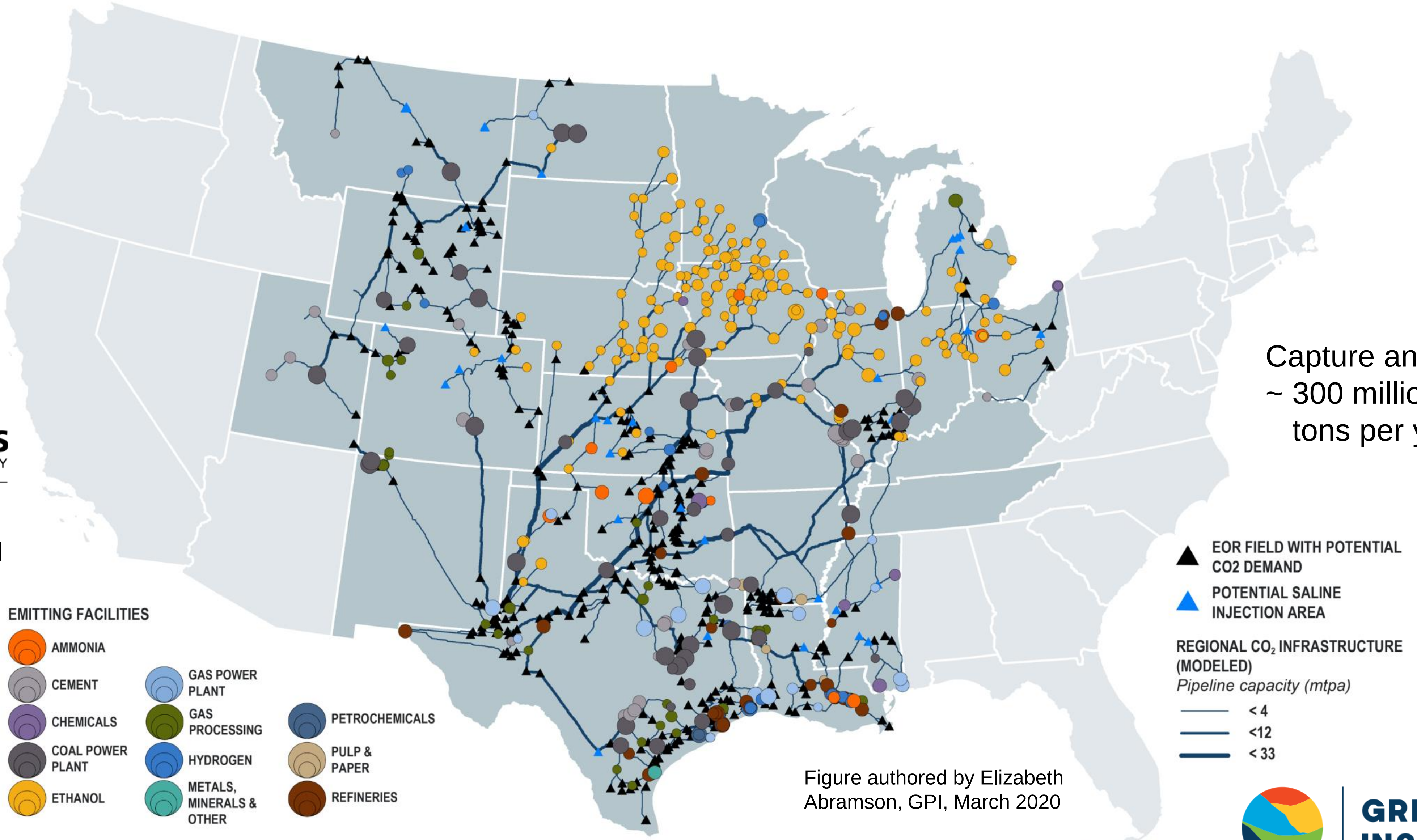
Near- and Medium-Term Scenario:
Optimized transport network for CO_2 capture and storage under 45Q

Los Alamos NATIONAL LABORATORY EST.1943

SimCCS CO_2 transport model



Capture and storage: ~ 300 million metric tons per year

Figure authored by Elizabeth Abramson, GPI, March 2020

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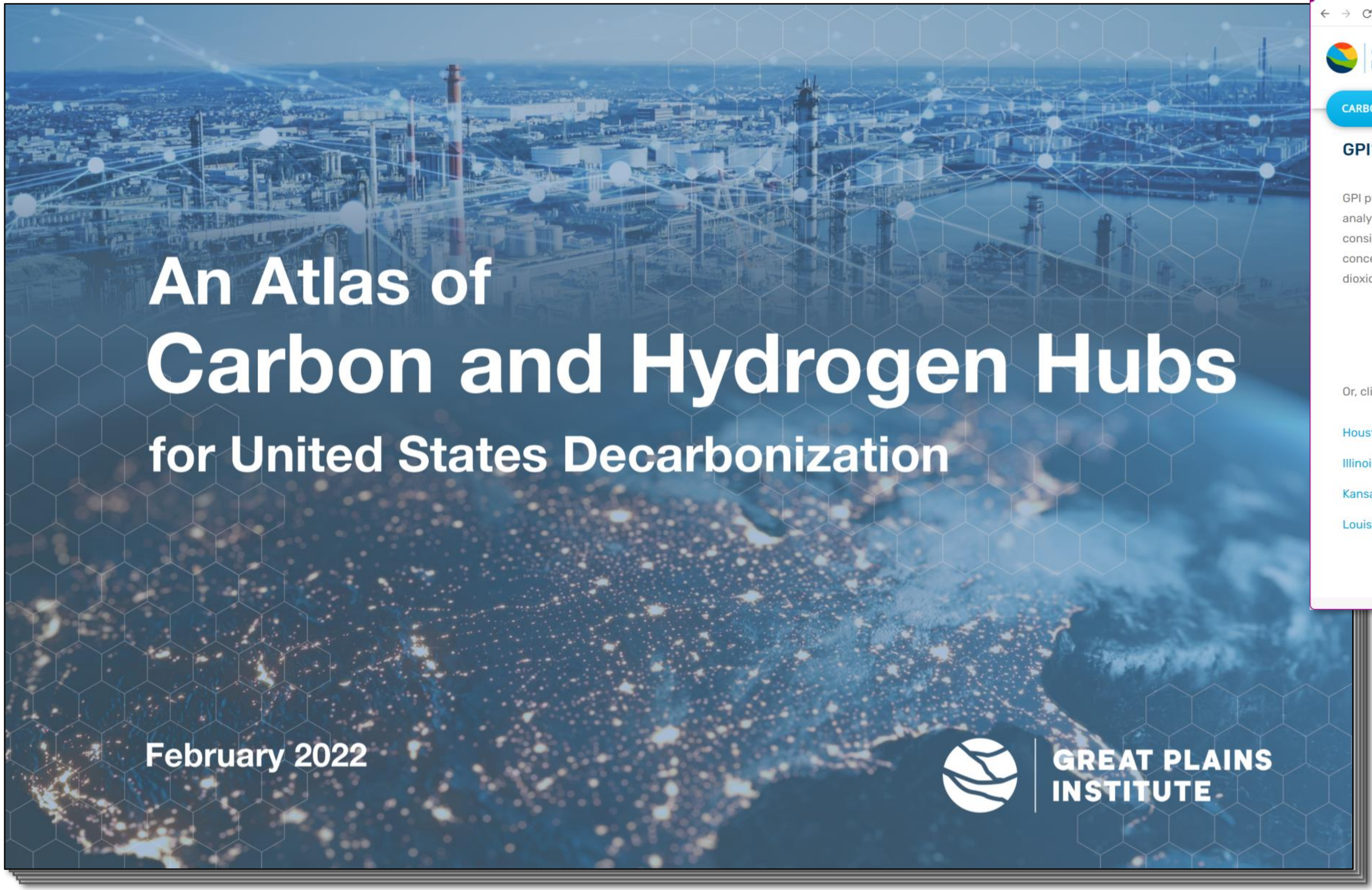

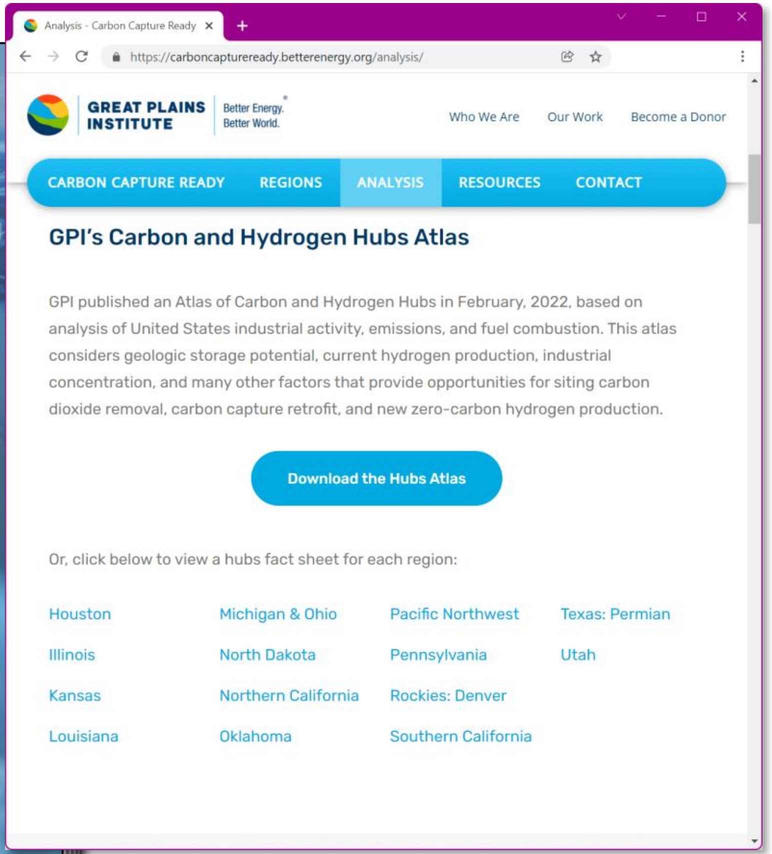

Download the atlas at:
carboncaptureready.org

Identified near- and medium-term carbon capture retrofit opportunities

Sector	45Q Eligible Facilities	Near- and Medium-Term Retrofit Opportunities
Ammonia	24	9
Cement & Lime	130	89
Chemicals	17	2
Ethanol	173	170
Gas Processing	92	52
Metals & Minerals	29	3
Petrochemicals	35	4
Pulp and Paper	17	2
Refineries	94	65
Steel	45	8
Coal Power Plant	216	65
Gas Power Plant	325	73
Total	**1,197**	**542**

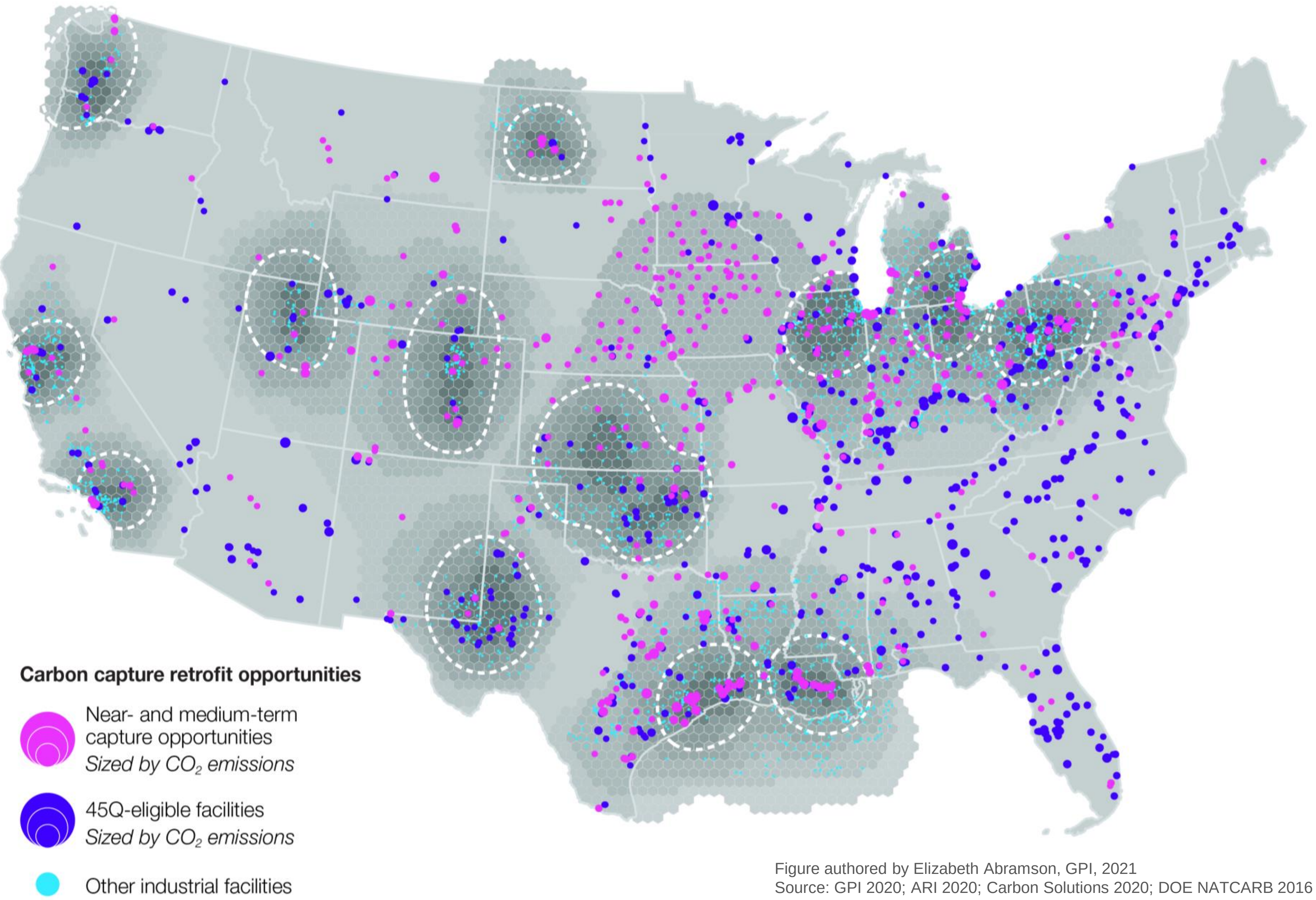

Figure authored by Elizabeth Abramson, GPI, 2021
Source: GPI 2020; ARI 2020; Carbon Solutions 2020; DOE NATCARB 2016

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Permanent geologic storage in saline and fossil formations

DOE Estimated Storage Capacity

	Low	Med	High
Saline	2.2 trillion	8.1 trillion	21.2 trillion
Fossil	72 billion	159 billion	188 billion

metric tons CO2

- More than ample storage capacity for US annual emissions
- However, local characterization is needed. Access and cost are not guaranteed.
- Locating DAC and carbon capture hubs at storage formations can minimize transport costs, land use, and local impact
- Shared transport infrastructure between storage regions can achieve beneficial economies of scale, enabling investment break-even for industrial capture retrofit

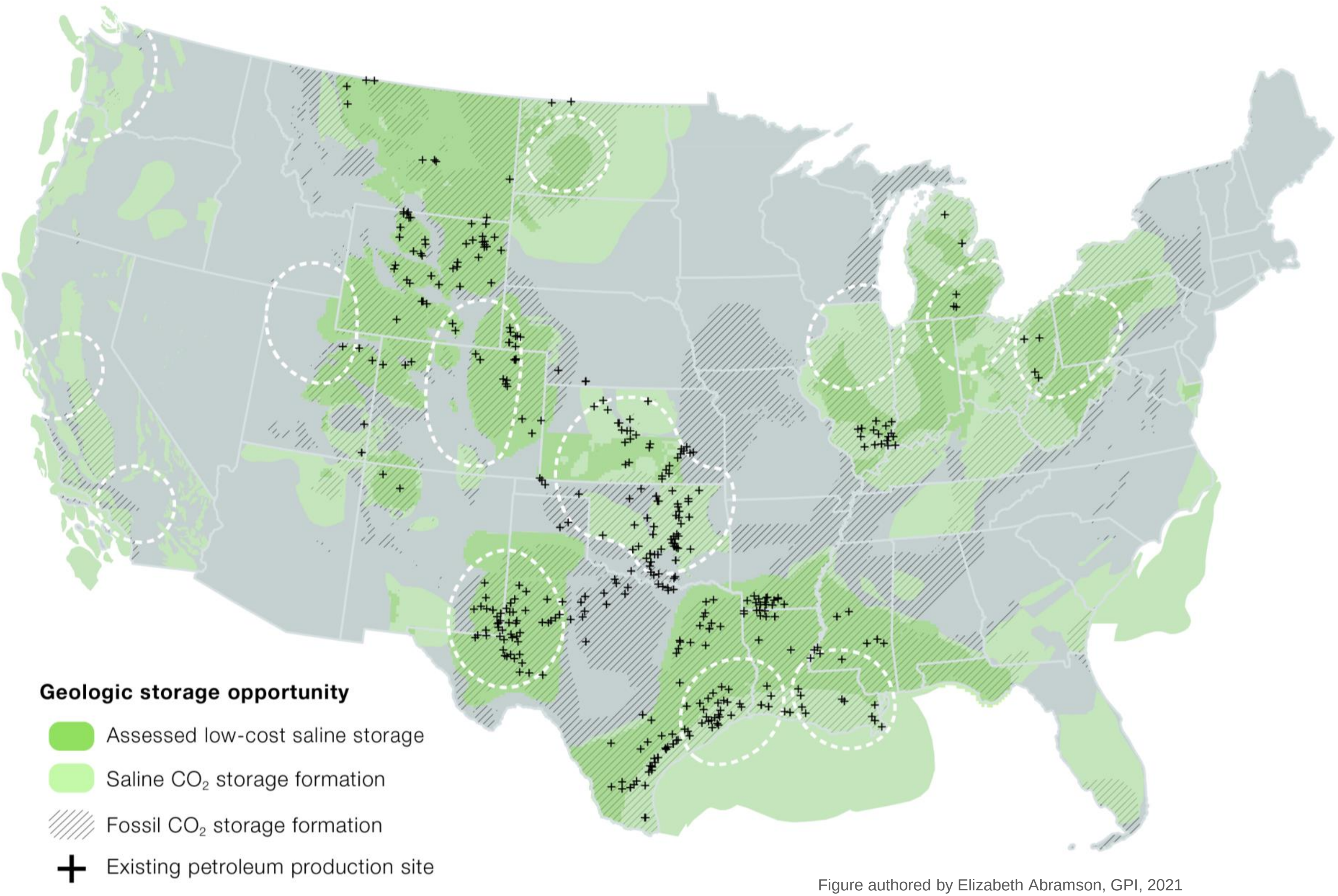

Figure authored by Elizabeth Abramson, GPI, 2021
Source: ARI 2020; Carbon Solutions 2020; DOE NATCARB 2016

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Existing hydrogen and ammonia production

- Hydrogen is a versatile fuel and energy carrier
- 13% of global energy demand is fueled by H_2 in IEA's Net-Zero 2050 scenario
- Today, 95% of hydrogen is produced from natural gas through SMR
- Low carbon hydrogen can be produced with biomass, renewable and zero carbon electricity (electrolysis), and SMR with CCS
- IEA Net Zero: 40% of hydrogen produced through SMR + CCS in 2050

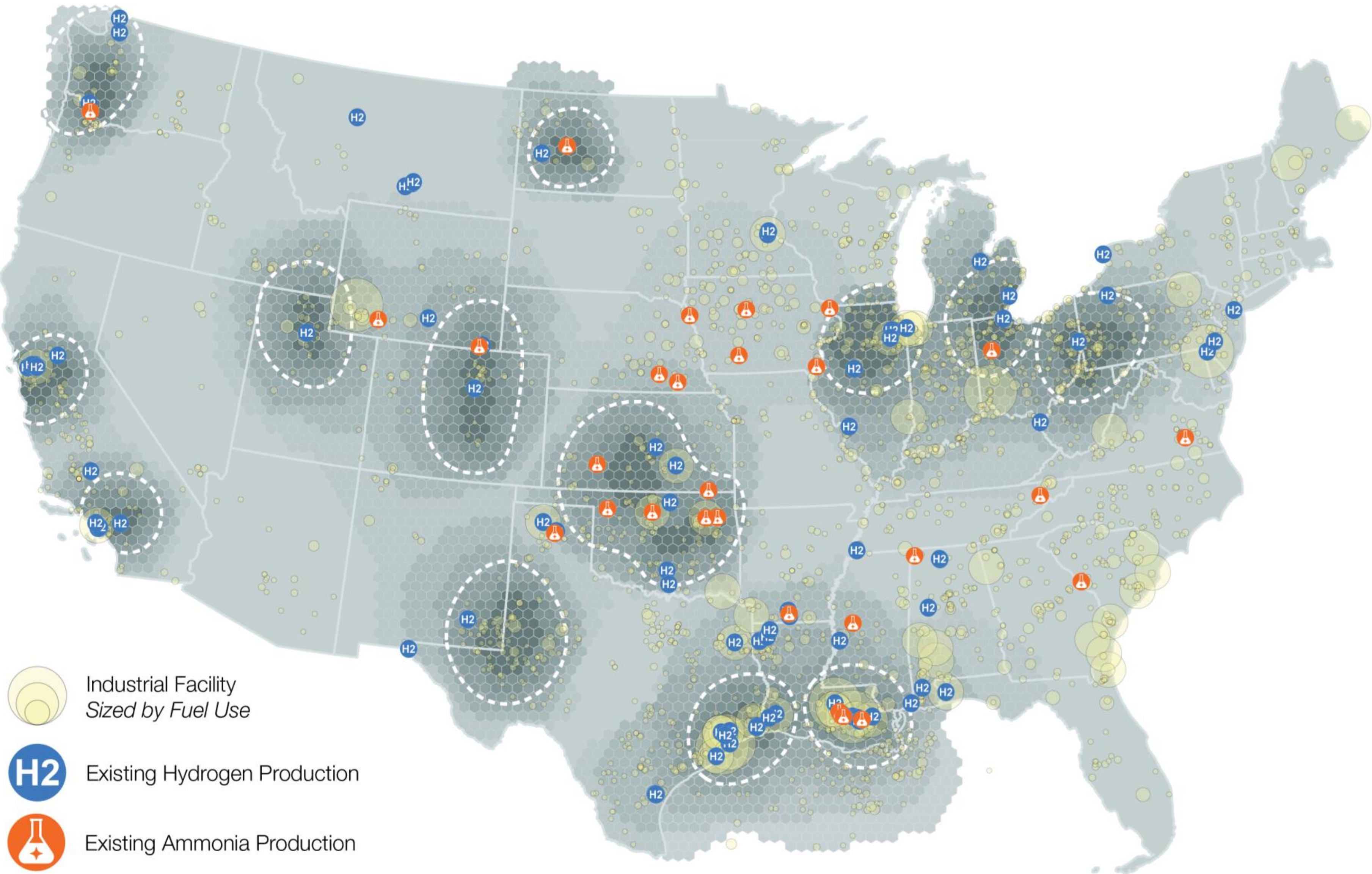

Figure authored by Elizabeth Abramson, GPI, 2021
Source: NREL 2018; EPA 2021

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Zero-carbon electricity for hydrogen electrolysis and direct air capture

Low carbon hydrogen can be produced with renewable and zero carbon electricity, which is also an important consideration for DAC

Must also consider:

- Projected load, especially with widespread electrification and EVs
- Capacity of regional balancing authority / dispatch market
- Projected retirement of nuclear and other baseload power plants
- Transmission constraints

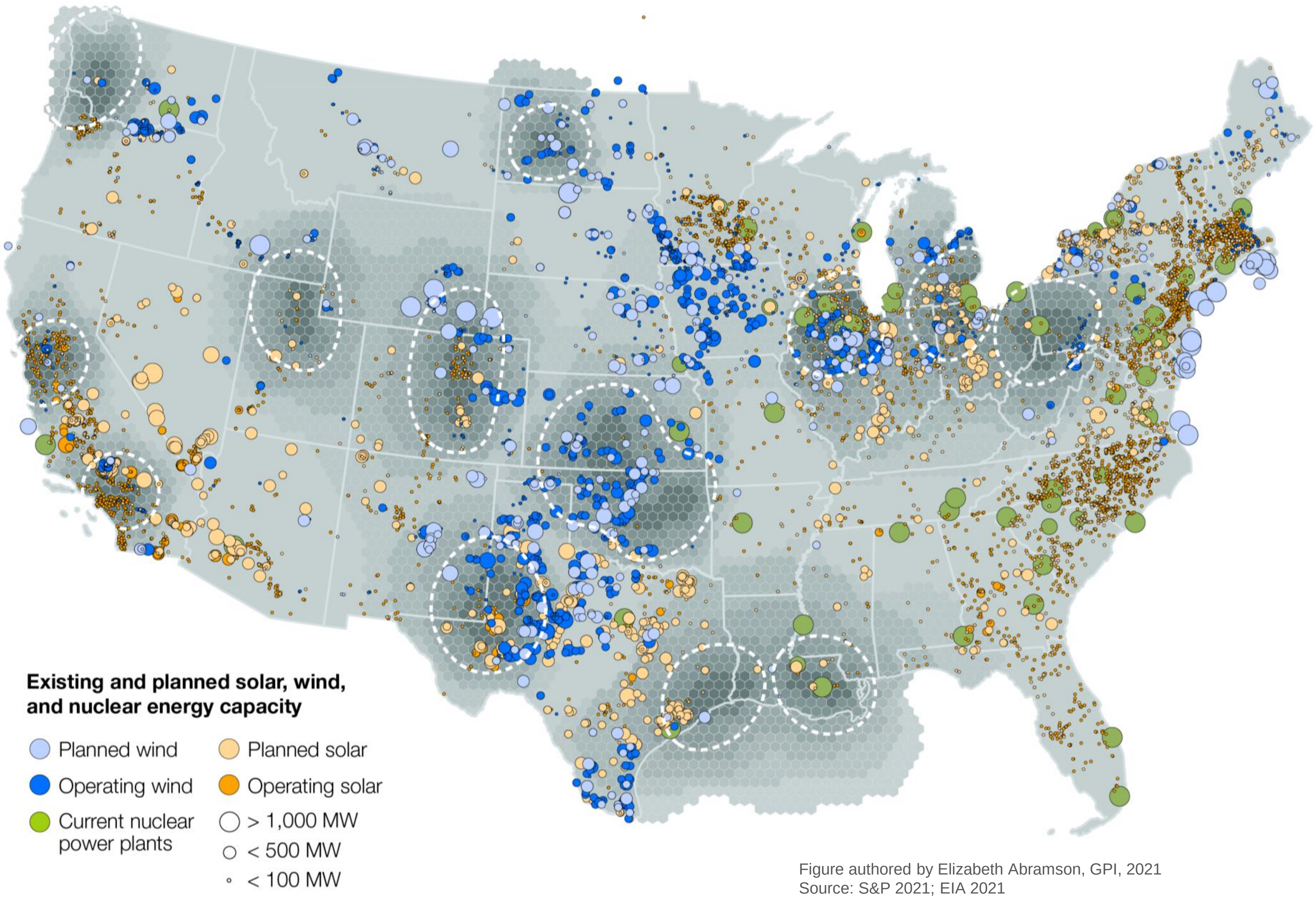

Figure authored by Elizabeth Abramson, GPI, 2021
Source: S&P 2021; EIA 2021

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Existing petroleum, crude oil, and HGL pipeline infrastructure

- Existing pipelines could provide an adjacent right-of-way that reduces land use, logistics, and planning costs for either CO_2 or H_2 infrastructure
- High correlation to hubs: these areas often already operate as a major interchange of petroleum, fossil fuel, and other chemicals transmission

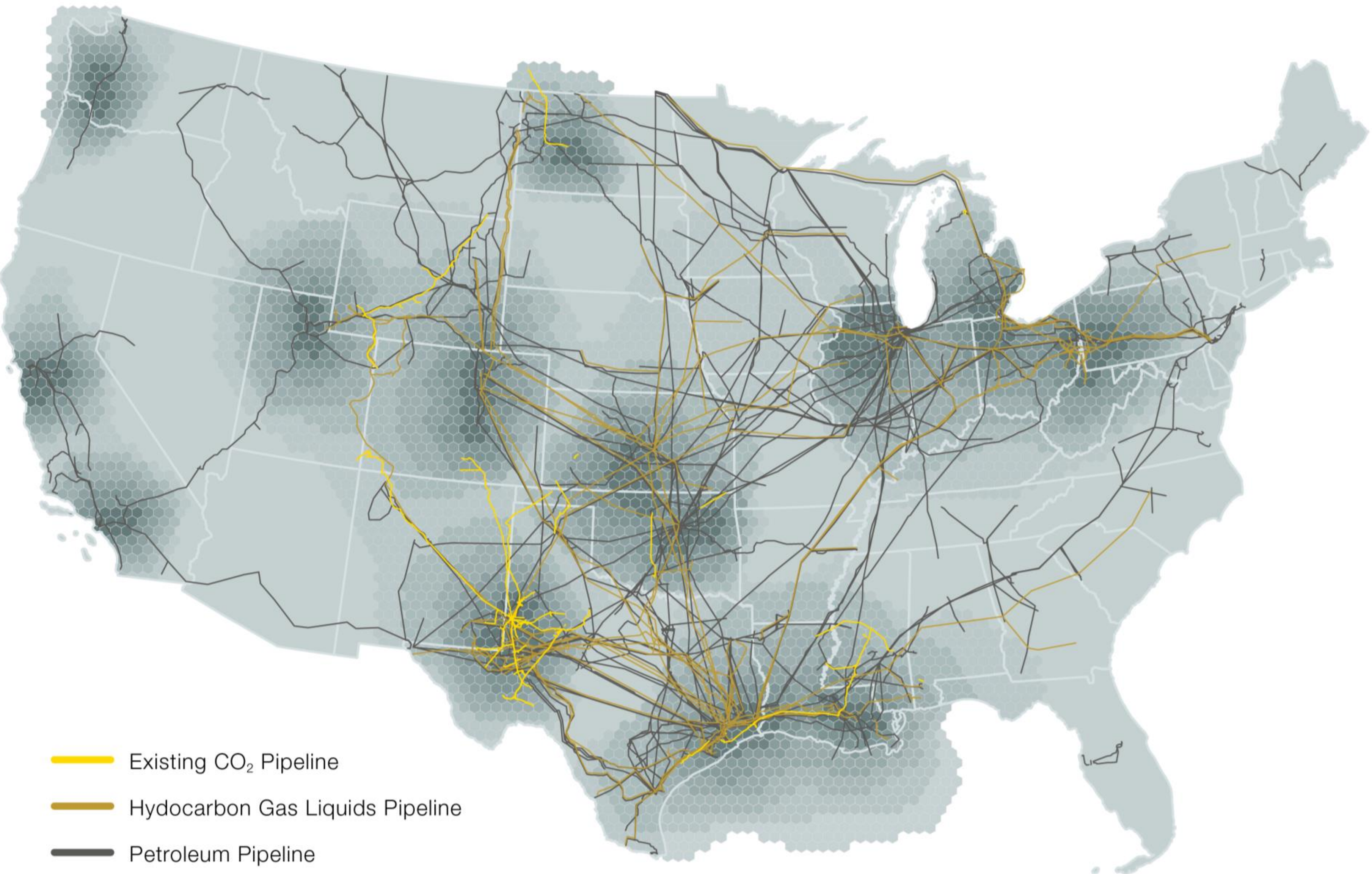

Figure authored by Elizabeth Abramson, GPI, 2021
Source: EIA 2020

Natural gas infrastructure: Existing right-of-way and blending of hydrogen

- Existing pipelines could provide an adjacent right-of-way that reduces land use, logistics, and planning costs for either CO2 or H2 infrastructure
- Hydrogen can, to a certain extent, be blended into the existing natural gas distribution system for co-firing
- Very extensive build-out of natural gas infrastructure over the last few decades:
  - average of 1,500 km of new natural gas pipelines have been completed each year for the past 10 years
  - maximum of 4,400 km completed in a single year
- US decarbonization goals may require a less aggressive buildout for CO_2 and H_2 than occurred for natural gas

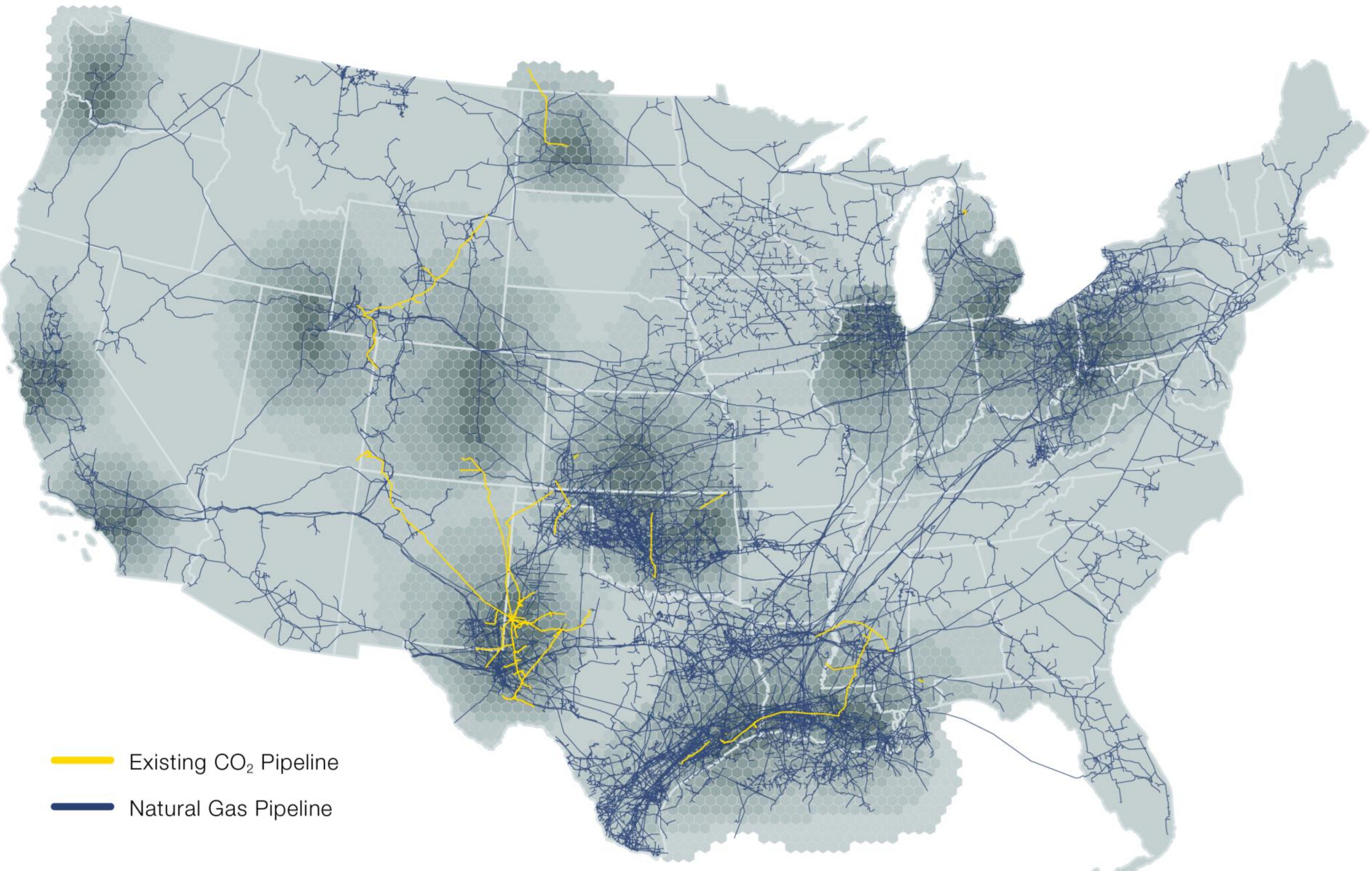

Figure authored by Elizabeth Abramson, GPI, 2021
Source: EIA 2020
Acknowledgement: Ryan Edwards

Multi-modal transport and distribution: Railroads

- Multi-modal transport offers flexibility and near-term opportunity before regional pipeline networks are built
- Current widespread use of rail for long-distance fossil commodity and fuel transport between markets

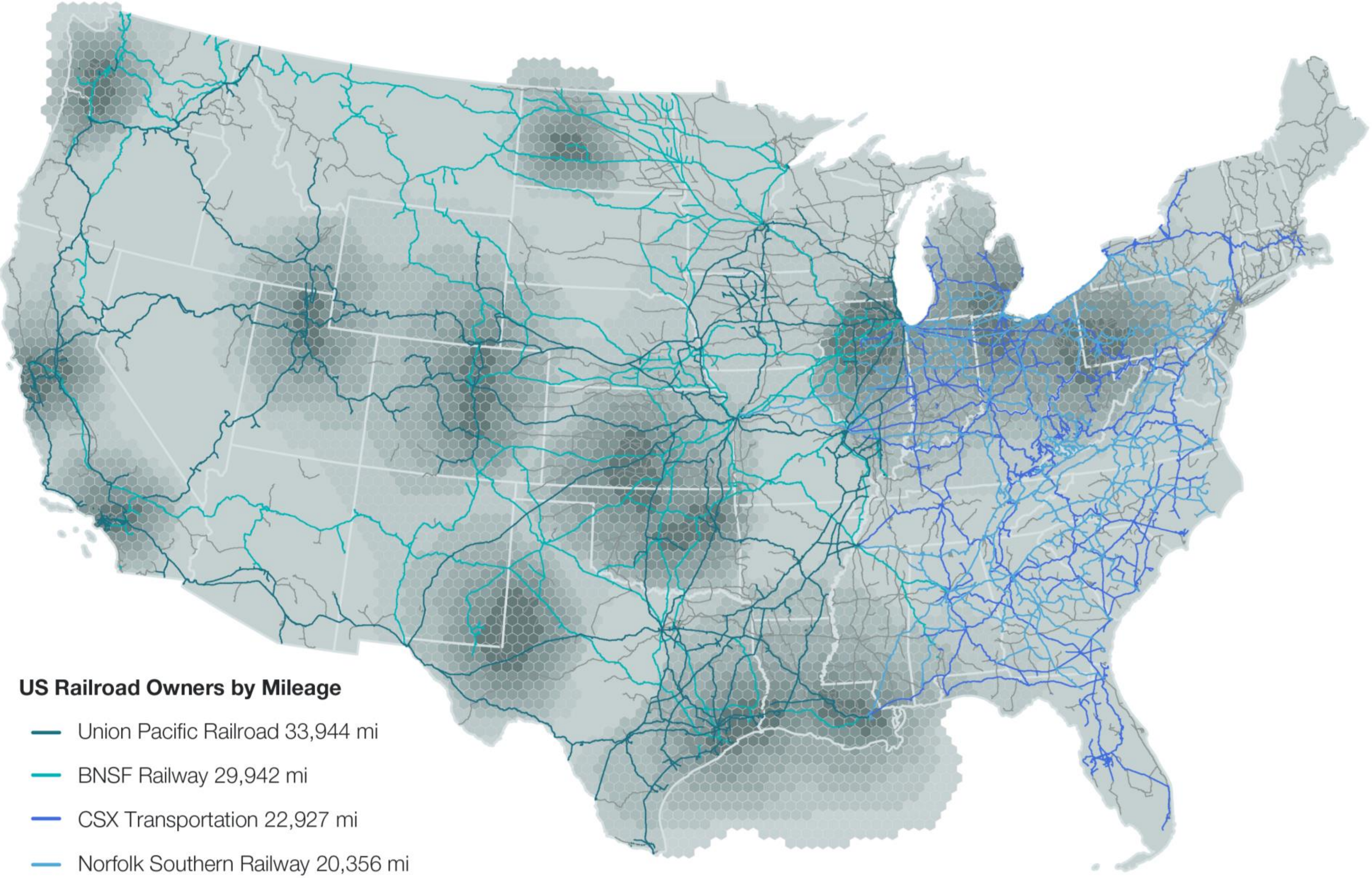

Figure authored by Elizabeth Abramson, GPI, 2021
Source: Esri; Federal Railroad Administration (FRA); Bureau of Transportation Statistics (BTS); DigitalGlobe; 2021.

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Multi-modal transport and distribution: Truck and Barge

- Multi-modal transport offers flexibility and near-term opportunity before regional pipeline networks are built
- Trucks, barges, and trains can connect both local facilities and distant markets

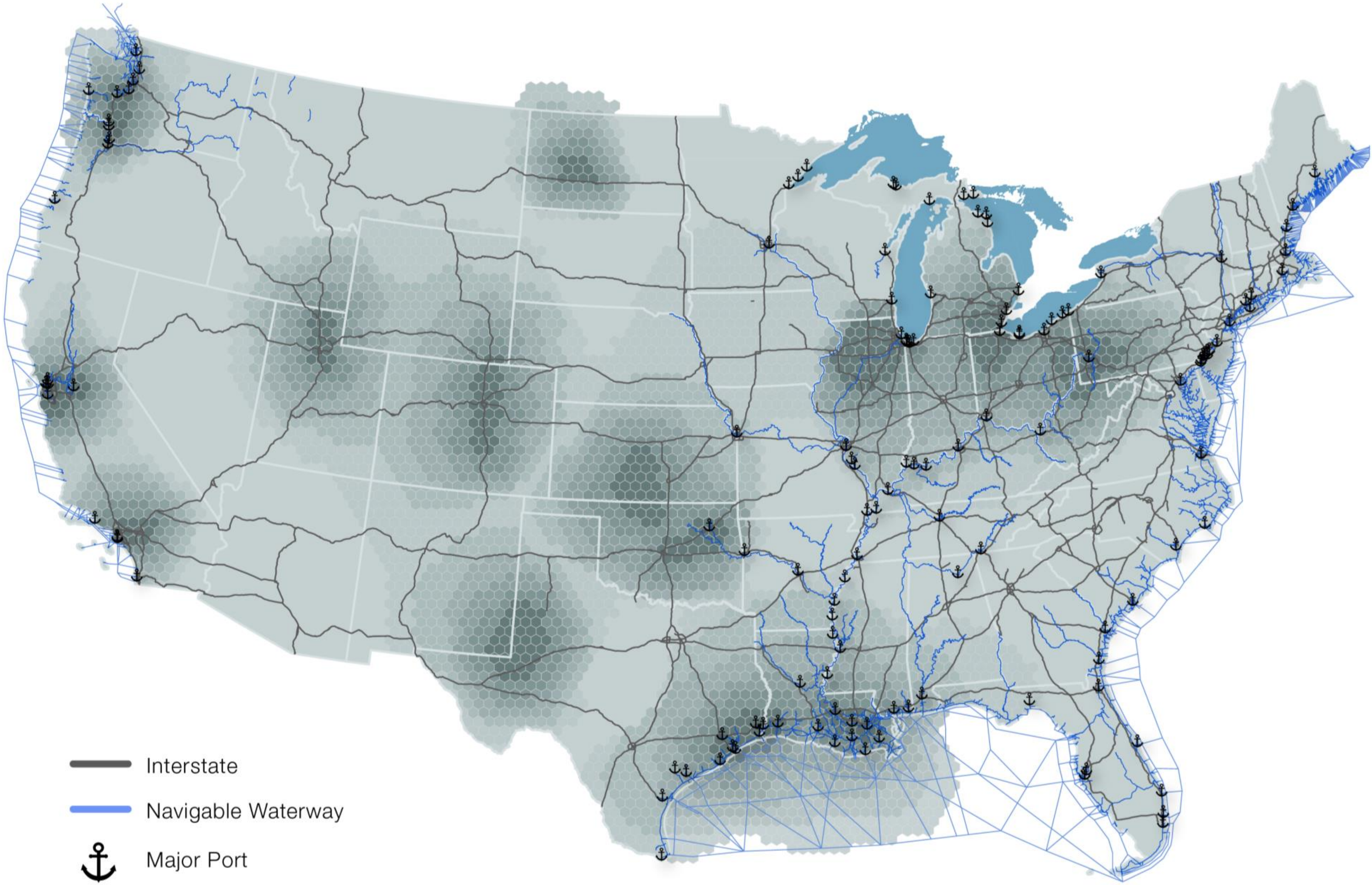

Figure authored by Elizabeth Abramson, GPI, 2021
Source: Esri; TomTom North America, Inc.; USDOT Bureau of Transportation Statistics National Transportation Atlas Database; 2021

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Potential US Carbon and Hydrogen Hubs

Guiding Criteria

- High concentration of large industrial emitters
- High quantities of fossil fuel use for on-site industrial energy production
- Presence of 45Q tax credit qualifying facilities for carbon capture retrofit, as well as identified near- and medium-term capture opportunities
- Current reported production of hydrogen and ammonia (optional)
- Large geologic saline and fossil formations for permanent CO2 storage
- Existing multi-modal commodity distribution infrastructure such as freight railroads, barge waterways and ports, and freight truck interstate highway routes
- Existing conventional fossil fuel distribution infrastructure for hydrogen blending and established right-of-way that minimizes impact of CO2 transport infrastructure

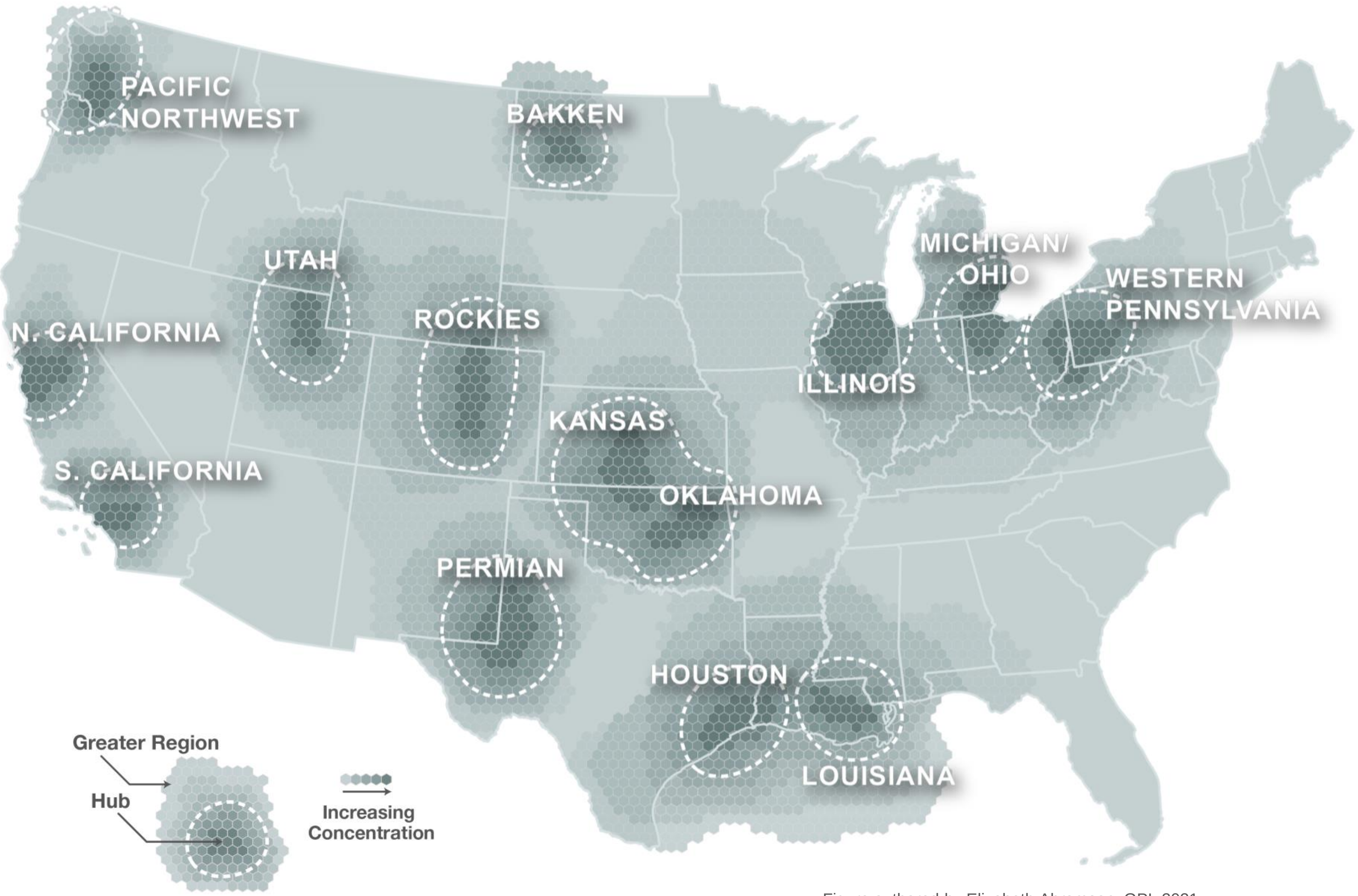

Figure authored by Elizabeth Abramson, GPI, 2021
Source: Carbon and Hydrogen Hubs Atlas, GPI 2022

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United States
Direct Air Capture (DAC) Hubs Atlas

Geographic siting considerations:

- Geologic storage, CO2 transport infrastructure
- Expected electric load, electric carbon intensity, and price
- Natural gas supply for heating requirements
- Low carbon heat supply: geothermal, biomass, concentrated solar, fossil fuels with CCS, waste heat

Tools:

- **NECTAR:** **Negative Co2 TrAnsition Roadmap**
  DAC siting and heat resource model
- ***SCO_2T***: **Sequestration of CO_2 Tool**
  Geologic CO2 storage formation database and model
- **SimCCS**
  CO2 transport network model

Carbon Solutions Research Team:

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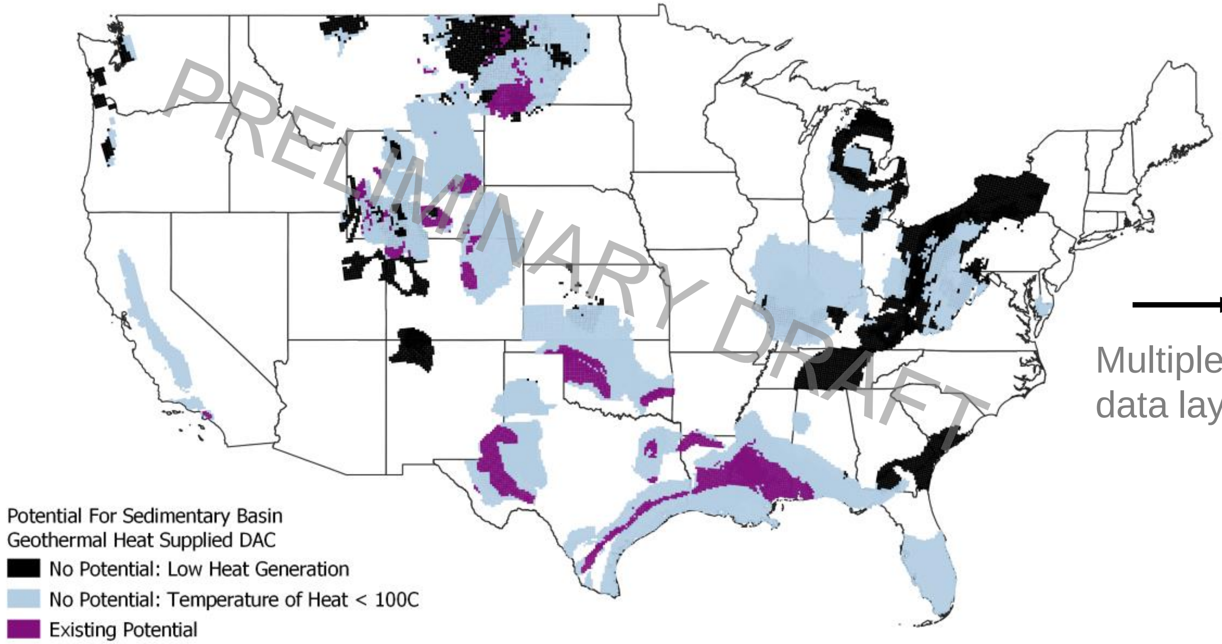
Carbon Solutions LLC

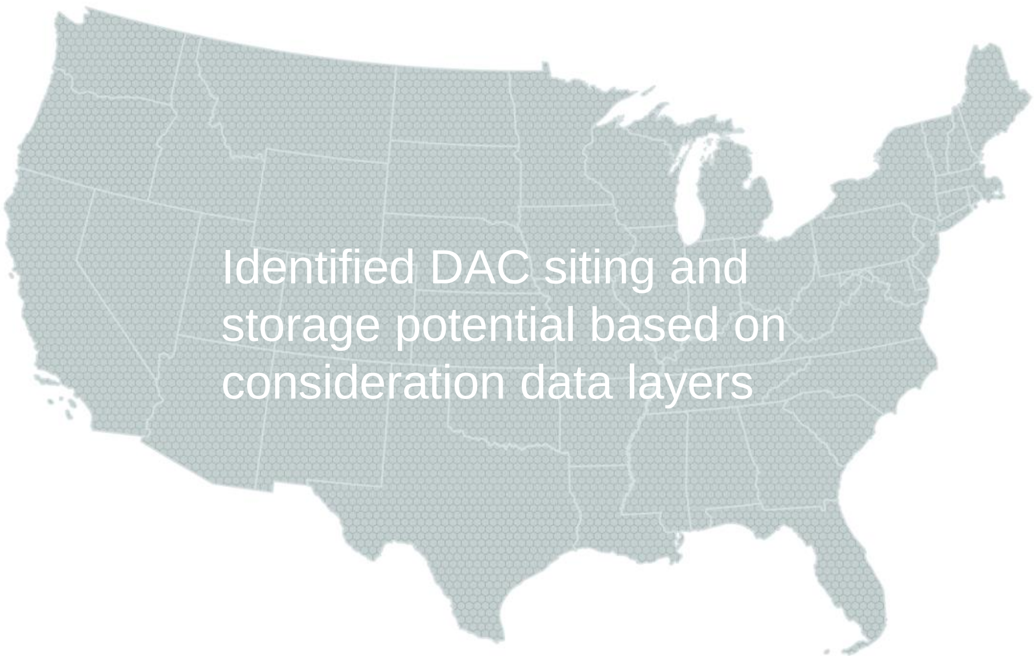
United States
Direct Air Capture (DAC) Hubs Atlas

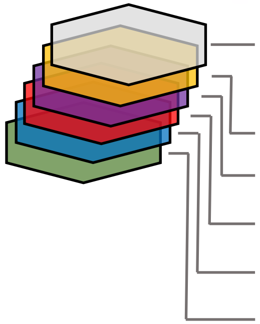
NECTAR Model Geothermal-only DAC Potential



Multiple data layers

DAC Hubs Potential – National Grid Cells





Resulting DAC Suitability Score

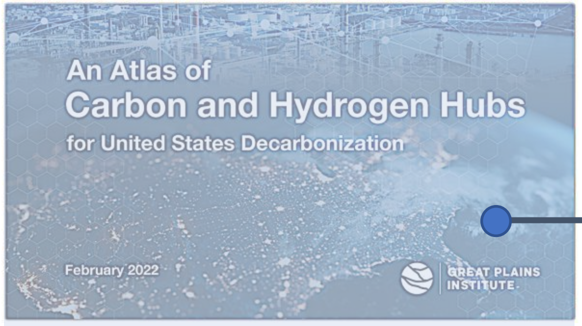
Energy Supply

Electric Grid

Carbon Intensity

Industrial Ecosystem

Geologic Storage



DAC focused follow up to the Carbon and Hydrogen Hubs Atlas

Winter 2022-2023

Carbon Solutions LLC

Thank You

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Better World.