



Transport Infrastructure for CCS: Regional Opportunities for Deployment

September 30, 2021

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1. **Carbon Transport Infrastructure Study**
2. **Jobs and Economic Impact Study**
3. **Preview: Carbon and Hydrogen Hub Modeling**
4. **Policy Priorities**




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Analytical Report

Published June 30, 2020




Transport Infrastructure for Carbon Capture and Storage


WHITEPAPER ON REGIONAL INFRASTRUCTURE FOR MIDCENTURY DECARBONIZATION

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Jeff Brown
University of Wyoming



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REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

JUNE 2020

Summary of Findings:

CO₂ 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 CO₂ capture and storage and approach the scale needed for US decarbonization targets and international temperature targets, shared regional CO₂ 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 CO₂ from capture facilities to storage locations identified by this analysis, resulting in Figure 8.

Figure 8. Optimized transport network for economy-wide CO₂ capture and storage

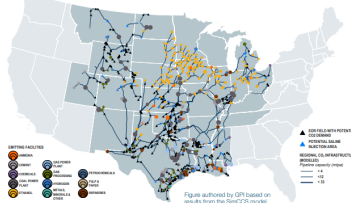


Table 7. Miles of CO₂ pipeline modeled, by diameter

Diameter	4"	6"	8"	12"	16"	20"	24"	30"
Length (miles)	4,712	6,063	8,560	5,834	2,675	1,700	59	16

The difference in build-out of CO₂ 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 CO₂ transport network will require capital investment that will not necessarily be paid simply through the sale of CO₂ 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 CO₂ capture and storage across the power and industrial sectors while minimizing the cost and land use of transport infrastructure. In reality, CO₂ 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 CO₂ infrastructure that is not of sufficient capacity to meet the scale of CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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.

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Download the paper at:

carboncaptureready.org/analysis



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Regional CO₂ Transport Infrastructure Study

Study Components

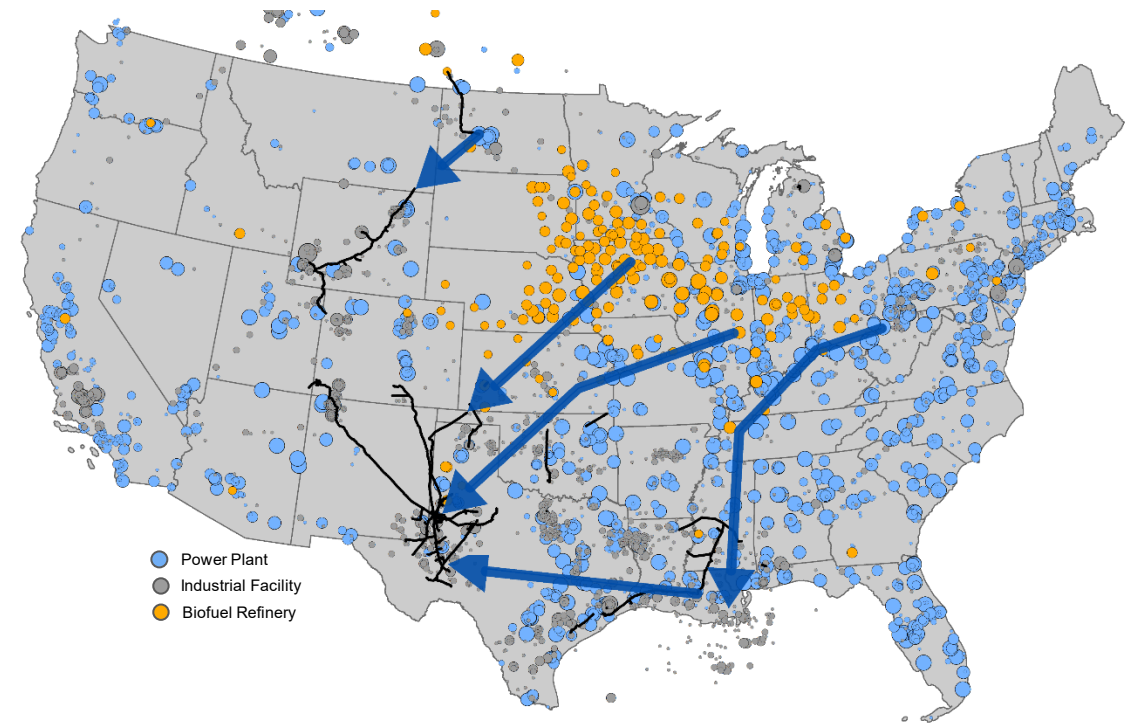
1. Identify near-term opportunities for CO₂ capture retrofit
2. Locate areas of CO₂ storage and use
3. Model optimized CO₂ transport infrastructure to maximize capture and storage

Primary Partners:

REGIONAL
CARBON
CAPTURE
DEPLOYMENT
INITIATIVE



Initial CO₂ Corridor Scoping



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CO₂ Capture Opportunities: Industrial and Power Facilities

Section 45Q Tax Credit for CO₂ Storage

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

Minimum Capture Thresholds

Industrial Facility: 100 thousand tons CO₂
Power Plants: 500 thousand tons CO₂

Near- and Medium-Term Screening Criteria:

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

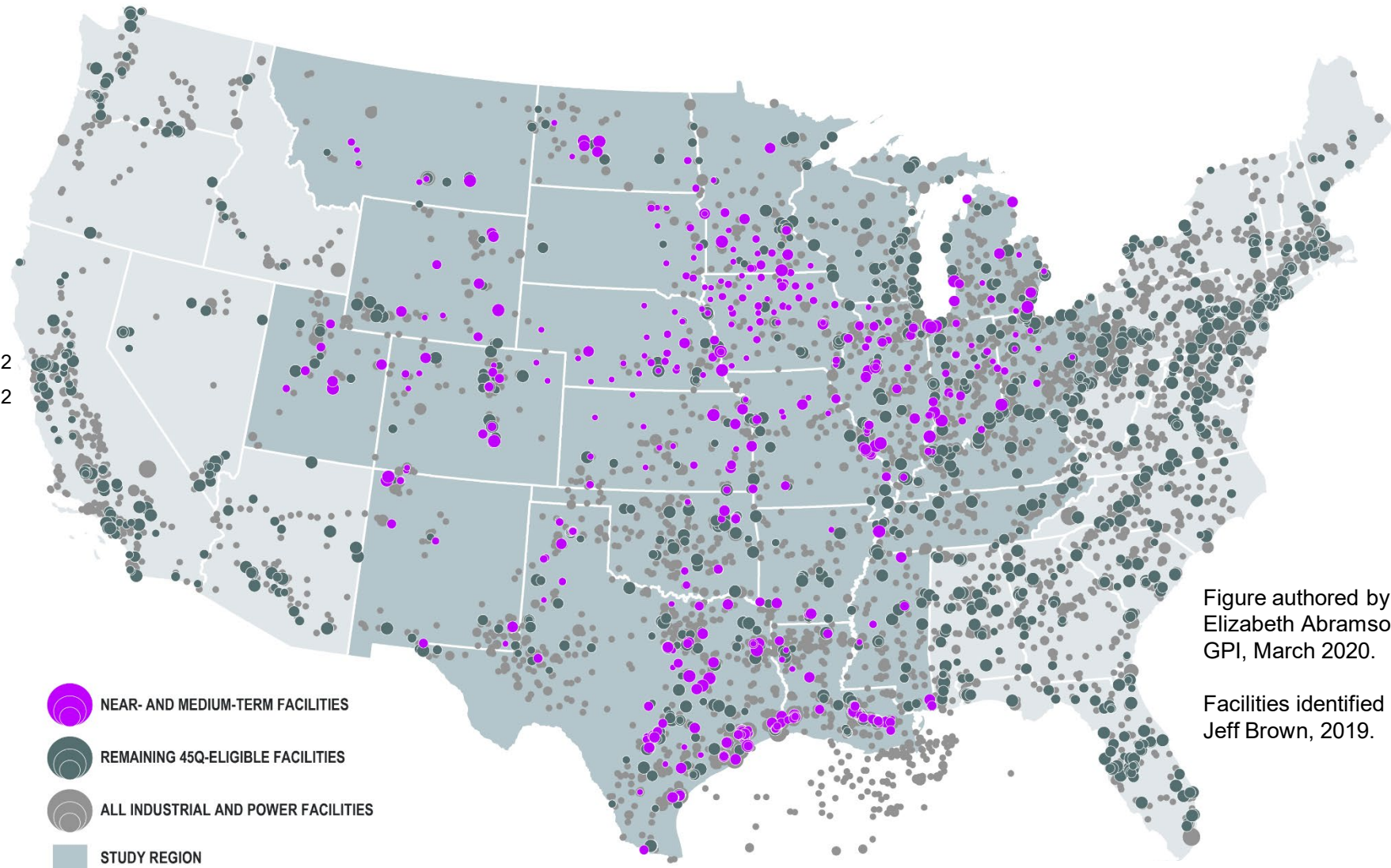


Figure authored by
Elizabeth Abramson,
GPI, March 2020.

Facilities identified by
Jeff Brown, 2019.



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Saline: SCO2T & NATCARB 10km Grid Cells

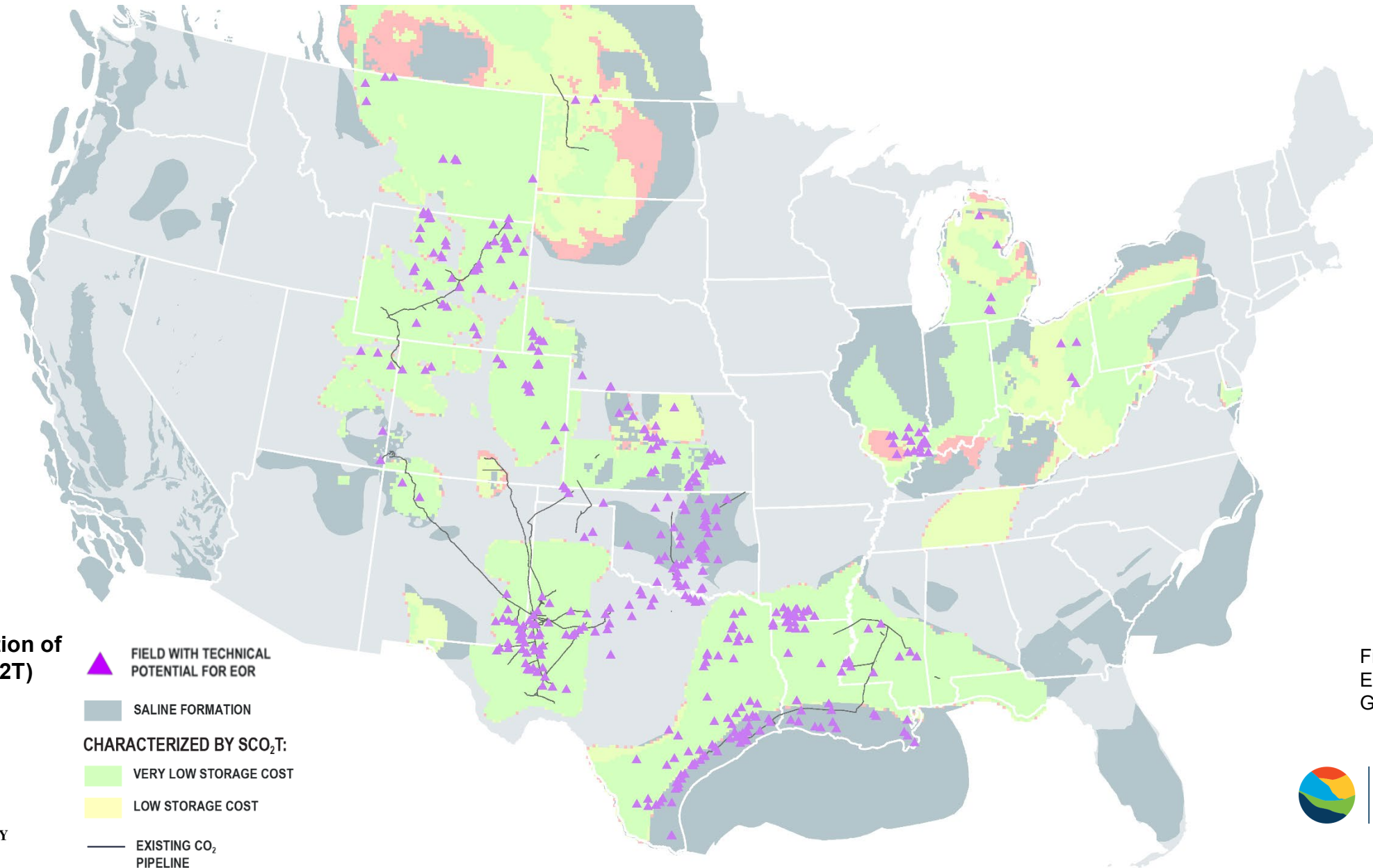
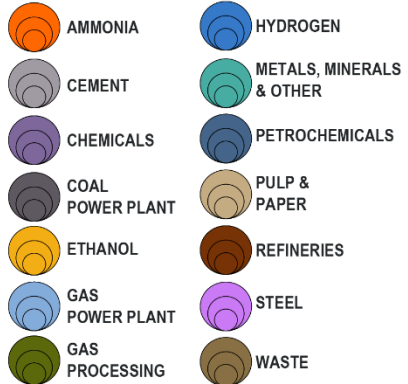


Figure authored by Elizabeth Abramson, GPI, March 2020

Saline data via The Sequestration of CO₂ Tool (SCO₂T)

CO₂ Storage in Saline Formations & Petroleum Basins

45Q-ELIGIBLE INDUSTRIAL EMITTERS



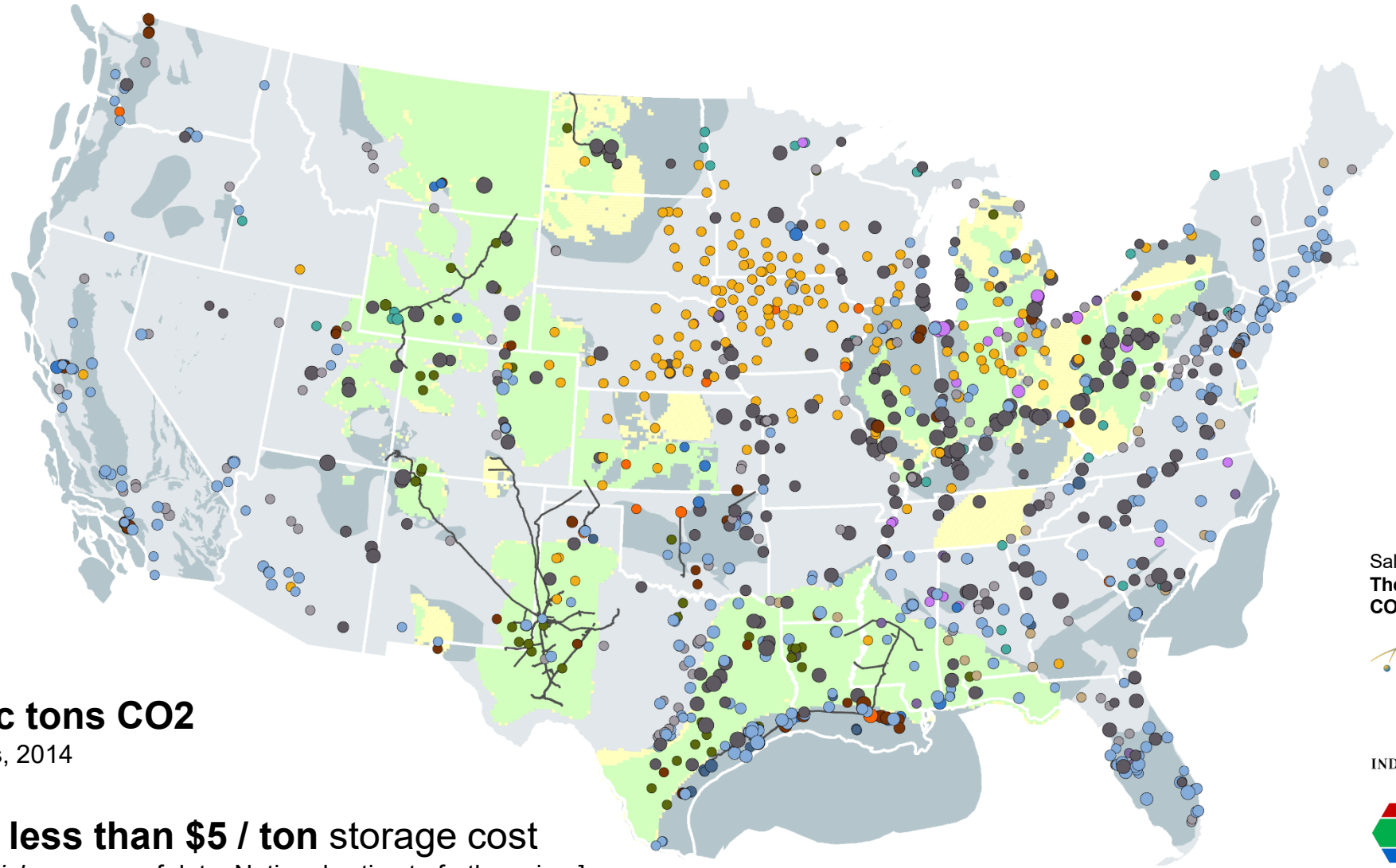
SALINE FORMATION

CHARACTERIZED BY SC₀₂T:

VERY LOW STORAGE COST

LOW STORAGE COST

EXISTING CO₂ PIPELINE



US Saline Storage Potential
8.3 to 21.6 trillion metric tons CO₂

U.S. DOE, U.S. Carbon Storage Atlas, 2014

1.8 trillion metric tons at less than \$5 / ton storage cost

[Conservative estimate based on *partial* coverage of data. National estimate forthcoming.]

Los Alamos National Lab and Indiana Geological Survey, SCO₂T Model, 2020

Saline data via
**The Sequestration of
 CO₂ Tool (SCO₂T)**



INDIANA UNIVERSITY



Figure authored by Elizabeth
 Abramson, GPI, March 2020



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Midcentury: Long-term Economy-Wide Deployment

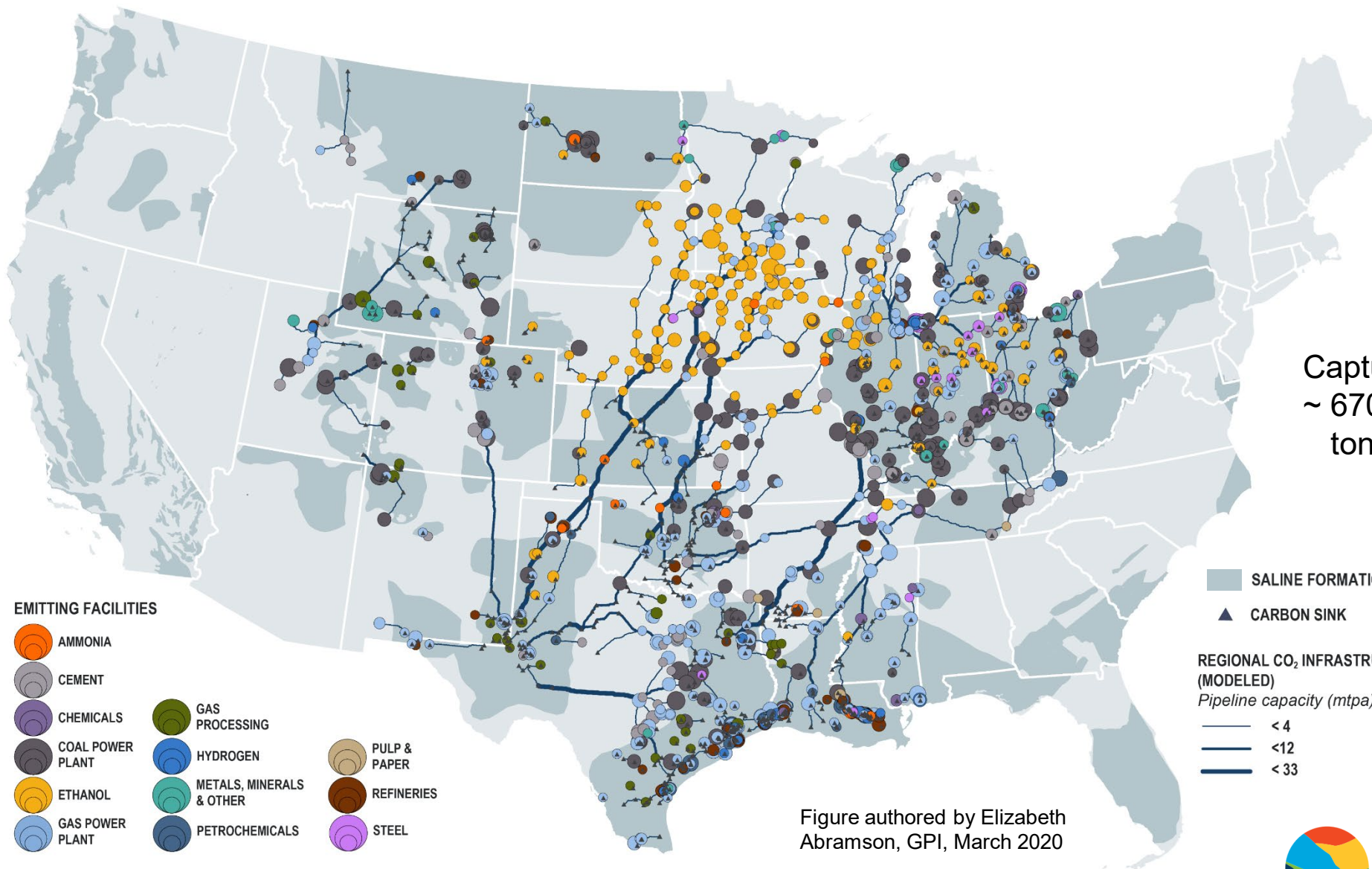
Expanded storage in saline formations and petroleum basins



SimCCS CO₂ transport model



Capture and storage:
~ 670 million metric tons per year



- EMITTING FACILITIES**
- AMMONIA
 - CEMENT
 - CHEMICALS
 - COAL POWER PLANT
 - ETHANOL
 - GAS POWER PLANT
 - GAS PROCESSING
 - HYDROGEN
 - METALS, MINERALS & OTHER
 - PETROCHEMICALS
 - PULP & PAPER
 - REFINERIES
 - STEEL

- SALINE FORMATION
- CARBON SINK

- REGIONAL CO₂ INFRASTRUCTURE (MODELED)**
- Pipeline capacity (mtpa)*
- < 4
 - < 12
 - < 33

Figure authored by Elizabeth Abramson, GPI, March 2020



Shared CO₂ Transport Infrastructure: Beneficial Economies of Scale

Higher capacity achieves lower costs per ton

Infrastructure investment by capacity
\$ per inch-mile

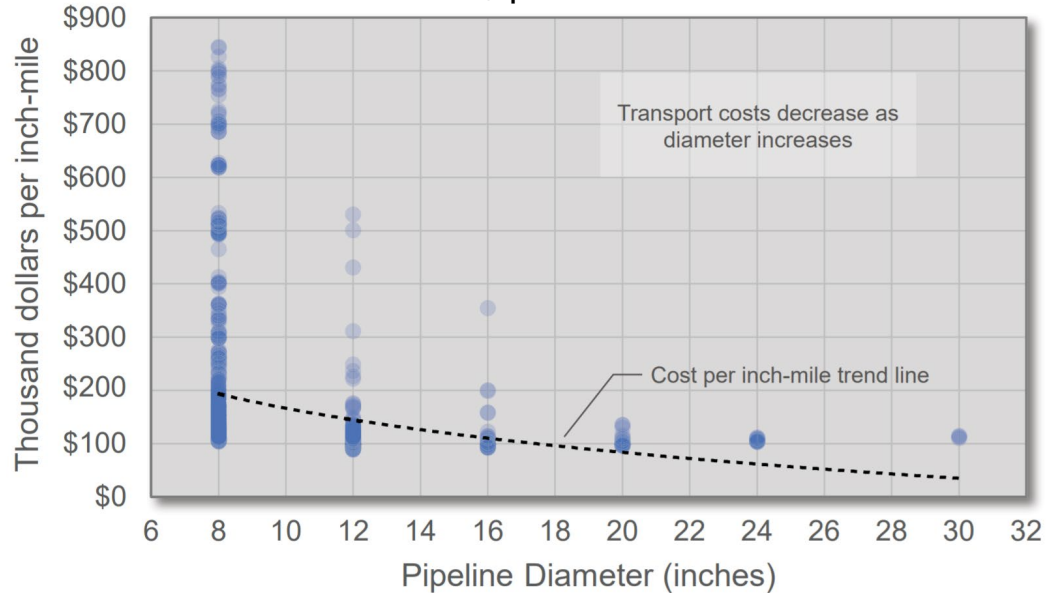


Figure authored by GPI based on calculations performed using the NETL CO₂ Transport Cost Model.

Transport tariff by capacity
\$ per ton

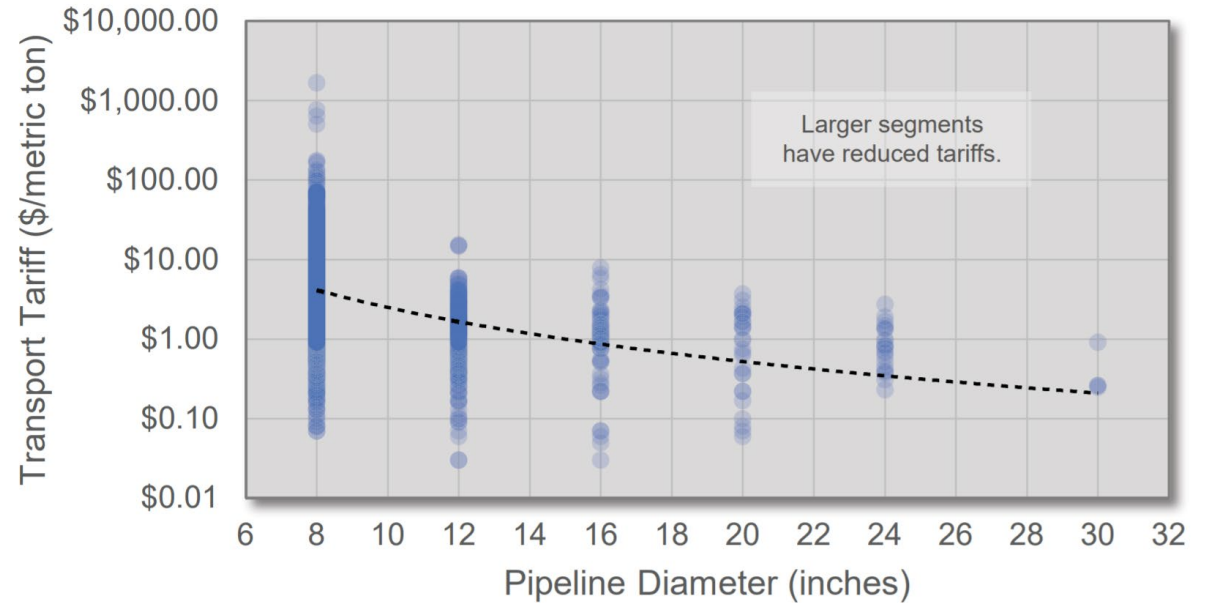


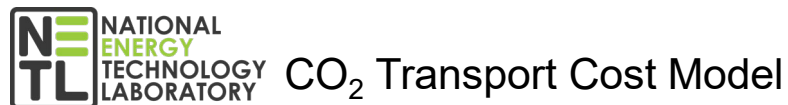
Figure authored by GPI based on calculations performed using the NETL CO₂ Transport Cost Model, as modified by McFarlane, Dubois, and Edwards, 2018.

Investment by owner/operator

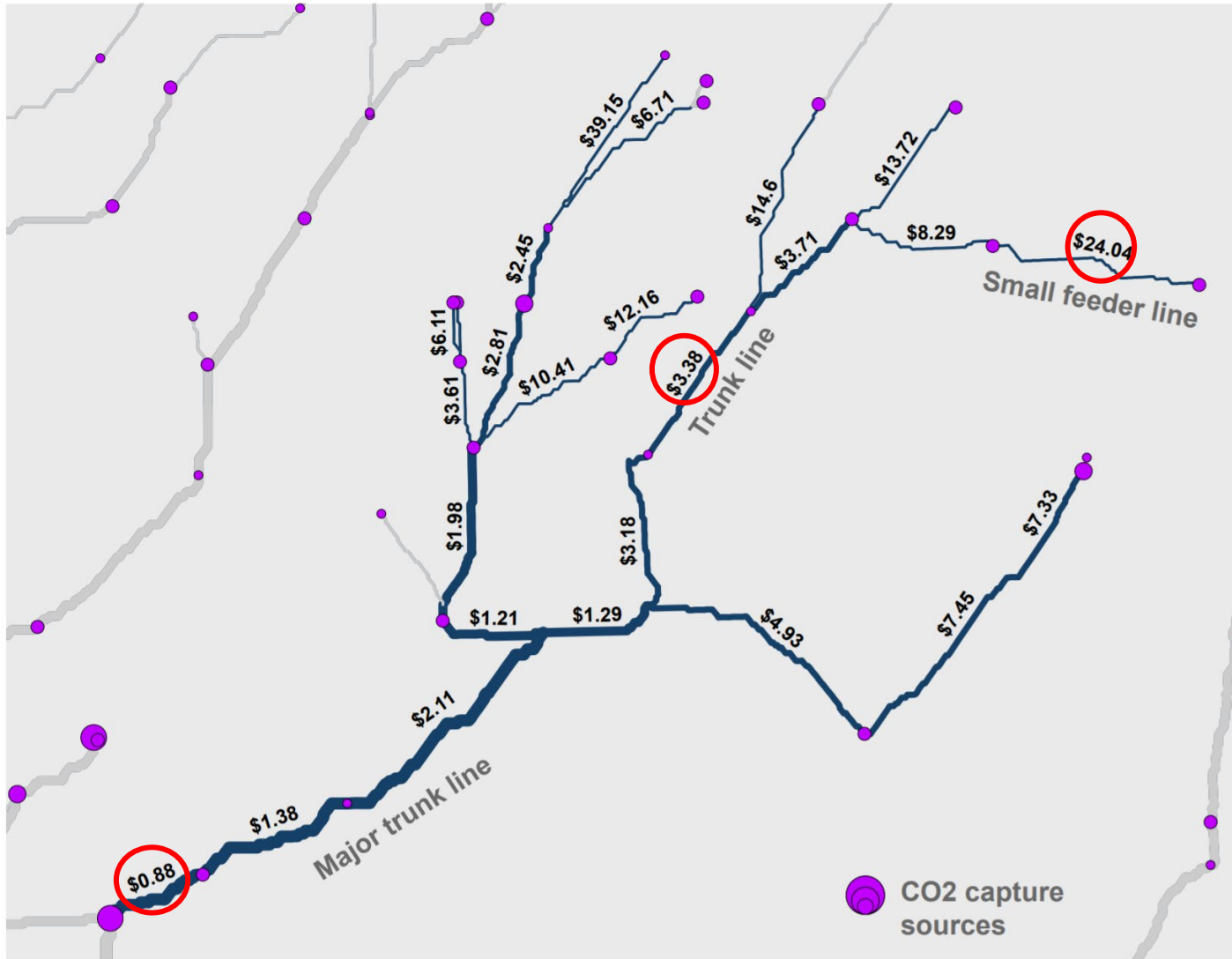


Cost to user/customer

Calculated with:



Shared CO₂ Transport Infrastructure: Beneficial Economies of Scale



Small feeder lines have a higher per-ton cost because they deliver less CO₂.

Shared high-capacity transport segments achieve beneficial economies of scale.

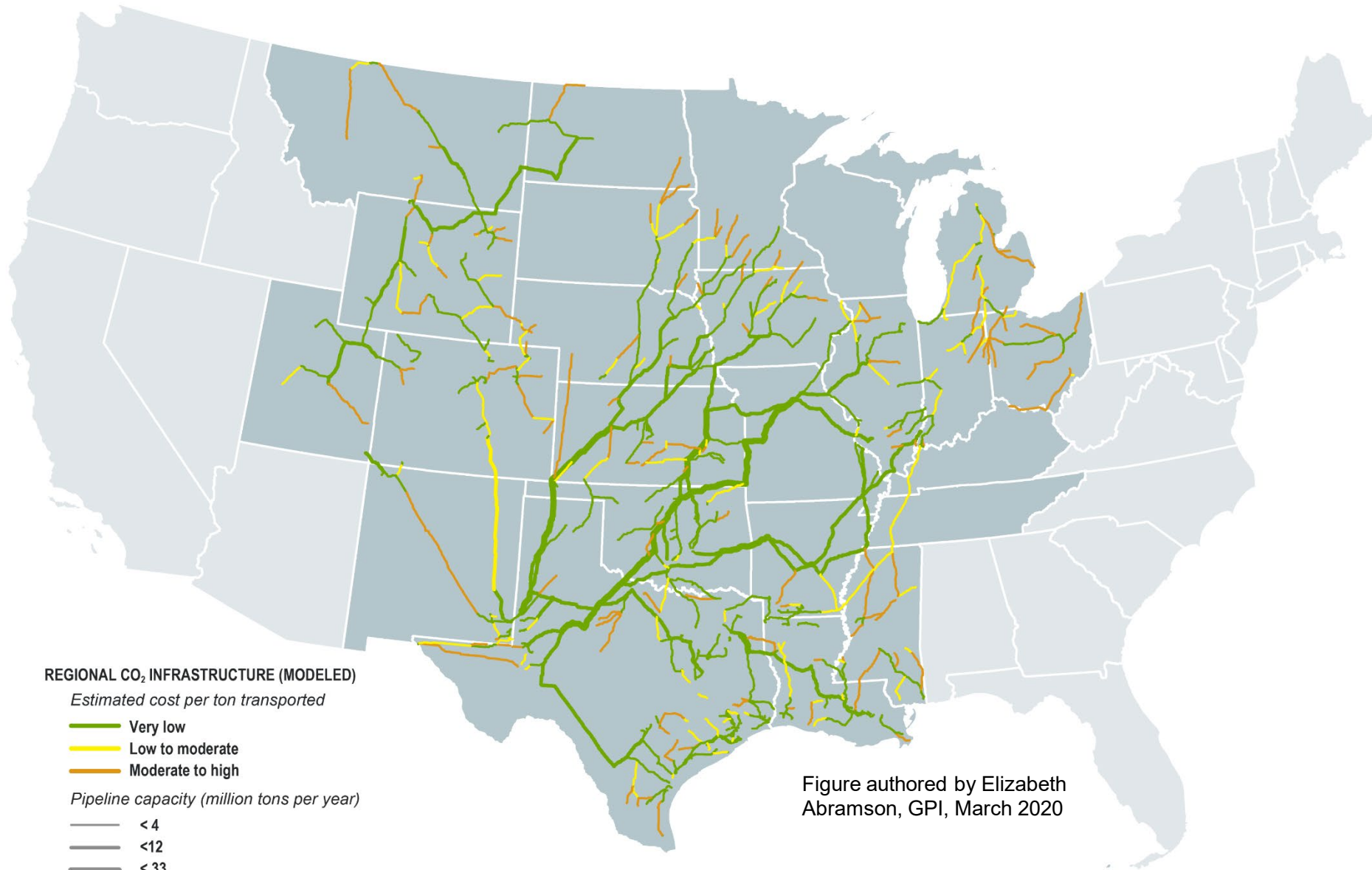
Customers generally pay a transport tariff (\$/ton) based on the route their CO₂ product takes through the transport network.

Example network section from the Near- and Medium-Term Scenario. Figure authored by GPI based on results from the SimCCS model, with cost estimates calculated by the NETL CO₂ Transport Cost model.



Cost Efficiency through Capacity

Relative transport cost of network segments



REGIONAL CO₂ INFRASTRUCTURE (MODELED)

Estimated cost per ton transported

- Very low
- Low to moderate
- Moderate to high

Pipeline capacity (million tons per year)

- < 4
- < 12
- < 33

Large trunk lines achieve best economies of scale and lowest per-ton transport cost.

Small-feeder lines to individual facilities require less capital but have higher per-ton cost.

Cost Range	Length (miles)
Very Low	18,006
Low to Moderate	4,744
Moderate to High	6,960

Figure authored by Elizabeth Abramson, GPI, March 2020



Planning for Long-term Economy-Wide Deployment

Economies of scale
benefit higher capacity
for CO₂ delivery

Regional infrastructure
can store more CO₂ at a
lower cost

Long term planning results
in more CO₂ stored, smaller
land use, and lower marginal
cost

Scenario	CO ₂ Stored	Land Use	Capital Investment	Project Labor Investment	Annual O&M Spending
Midcentury	669 million metric tons	29,922 miles	\$19.3 billion	\$15.3 billion	\$254 million



Jobs Study 2020-2021

Job Creation Potential of Carbon Capture Retrofit and Transportation Infrastructure

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DEPLOYMENT
INITIATIVE

Rh^g

Rhodium
Group



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2021 - 2035

Near- and Medium-Term Deployment

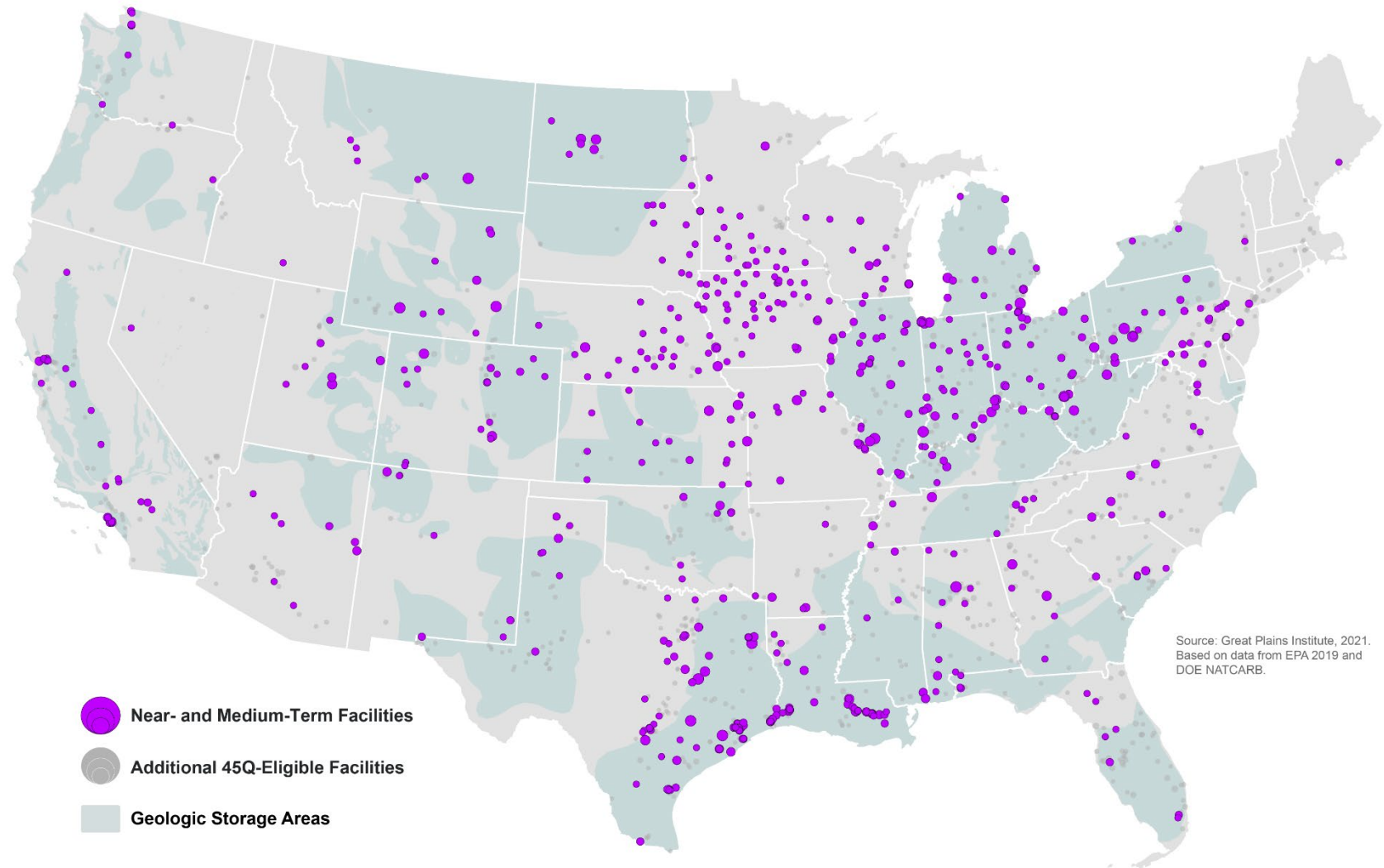
Phase 1: RDI Region

Phase 2: Coastal Regions

2035 – 2050

Mid-Century Deployment

Phase 3: Nation-wide

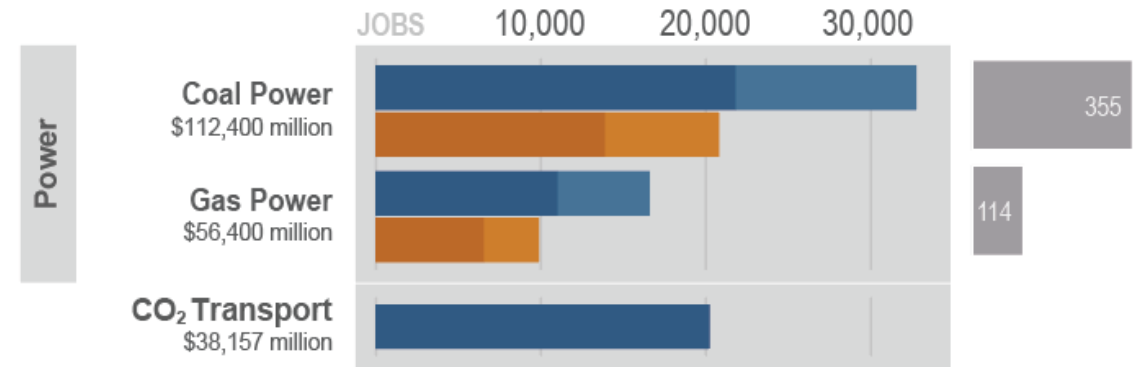
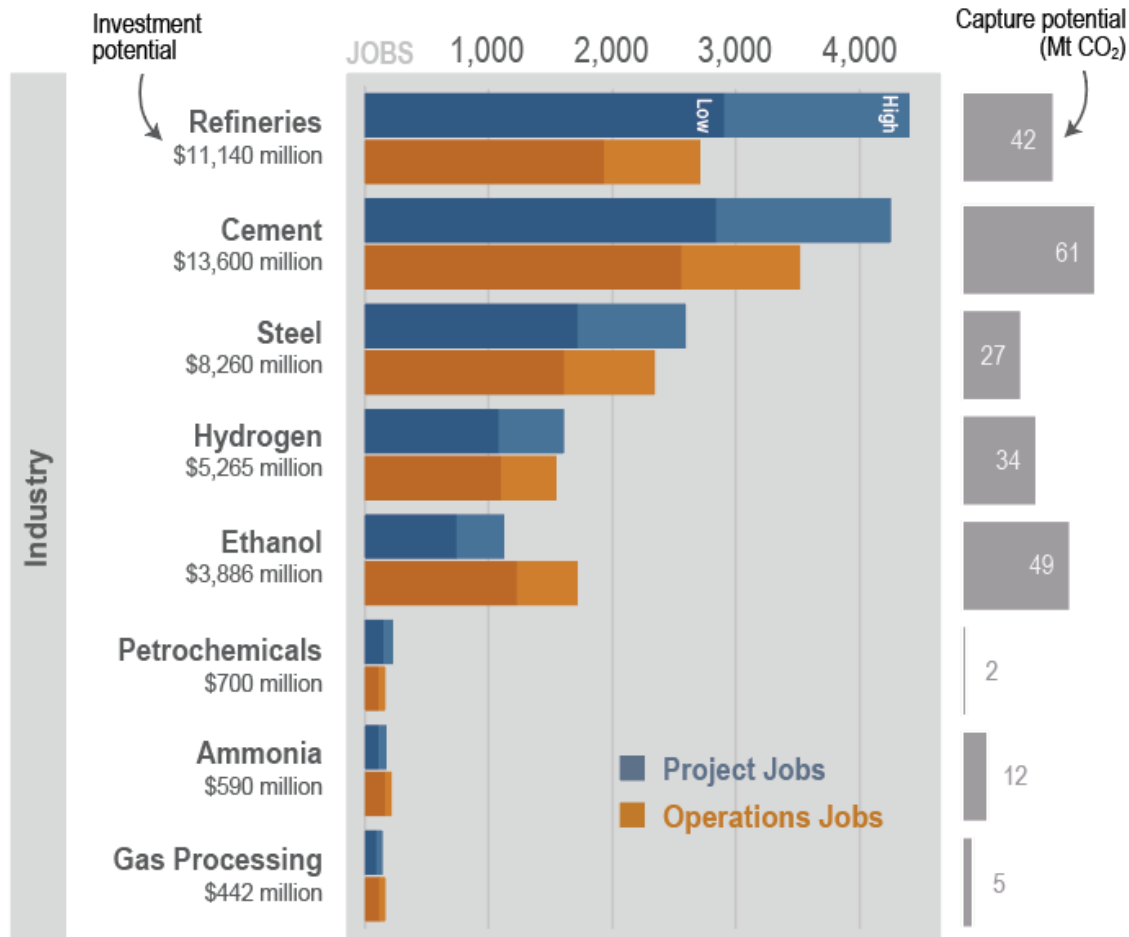


Source: Great Plains Institute, 2021.
Based on data from EPA 2019 and
DOE NATCARB.

Note: Near- and Medium-Term Facilities refer to emitting facilities identified by the Regional Carbon Capture Deployment Initiative as potential early candidates for capture retrofit based on emissions, equipment, and estimated capture cost. Eligibility for the section 45Q tax credit was determined by screening against current minimum thresholds.

2021-2035

Nation-wide Jobs Study: Near- and Medium-Term Deployment



59,830 Project Jobs

(Jobs associated with the equipment, materials (e.g., cement and steel), engineering, and labor required to install the capture technology)

39,672 Operations Jobs

(Ongoing jobs to operate and maintain the retrofits)

Key Takeaways

Carbon capture is a multibillion-dollar investment opportunity

Pursuing all carbon capture opportunities across Regional Deployment Initiative states will require \$121-\$183 billion in capital investment over the next 15 years.

Carbon capture investment will lead to good jobs

Jobs associated with carbon capture retrofits in these states total 36,000-54,200 on average per year over the next 15 years.

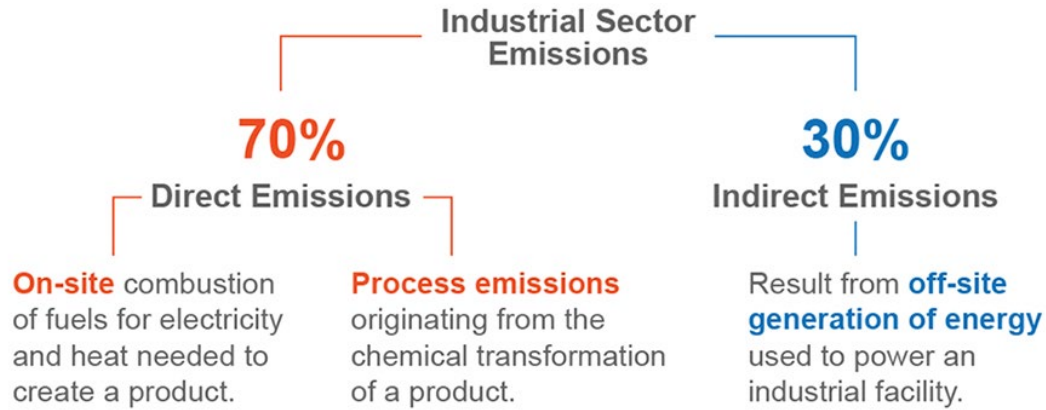
A diverse array of opportunities are available

Jobs can be created in a variety of industries from electric power generation to steel, cement, ethanol and refining.

Carbon capture can play to each states' strengths

Economic opportunities associated with carbon capture are available in all states regardless of their energy and economic profile. States that are large electricity producers have opportunities, so do manufacturing heavy states as well as oil and gas producers.

CO2 & H2 Hubs: Enabling Industrial Decarbonization



Emissions

On-site combustion:

Process Emissions:

Indirect Emissions:

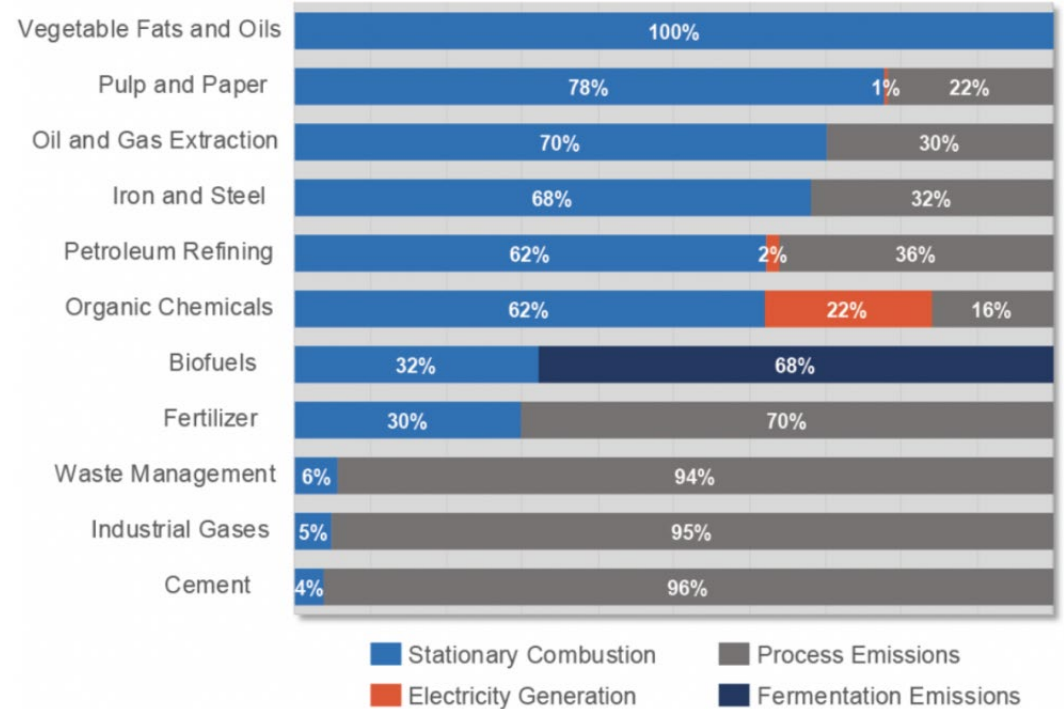
Reduction Strategy

Electrification & Fuel Switching

Carbon Capture

Decarbonizing Electric Grid

Direct Emissions: US Midcontinent Facilities



Figures authored by Elizabeth Abramson, Great Plains Institute, 2020
Source: EPA 2018



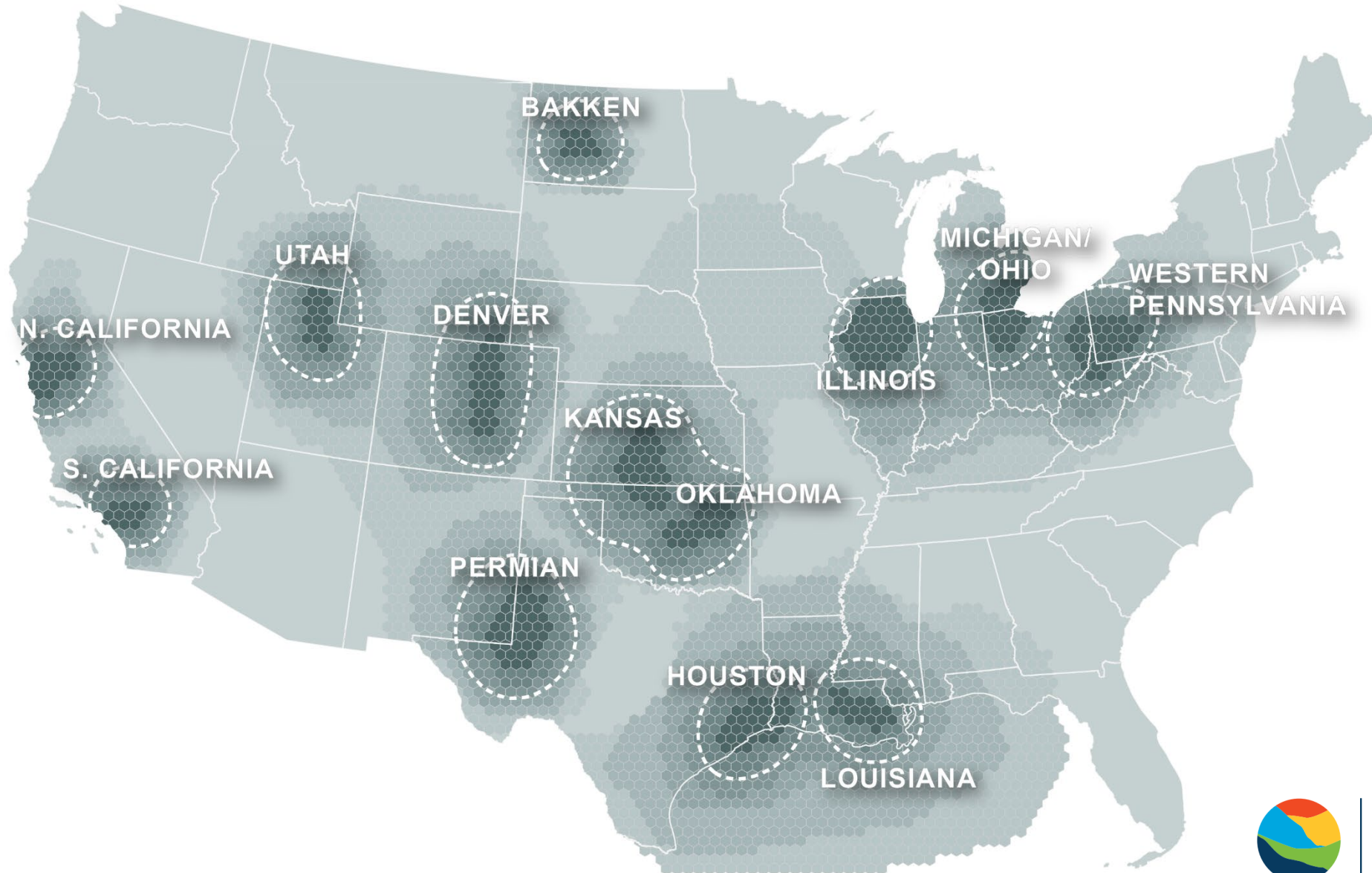
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CO2 & H2 Hubs

- **Carbon capture** is essential to decarbonization for **global climate targets**
- **Hydrogen** enables decarbonization of **industrial energy applications and production**.
- Carbon capture is an essential pathway to producing **low carbon hydrogen** in the near term.
- New **infrastructure** is required for both
 - Carbon capture, **transport**, and **storage/use**
 - Hydrogen **production, delivery, and use**
- **Challenge:** Commercial technology demonstration that leads to **deployment at scale**
- Hubs provide collaborative opportunities for demonstration and deployment
 - Early adopters become anchors and enablers of future regional infrastructure
 - Benefits of industrial clustering and economies of scale
 - Targeted policy incentives for focused investment

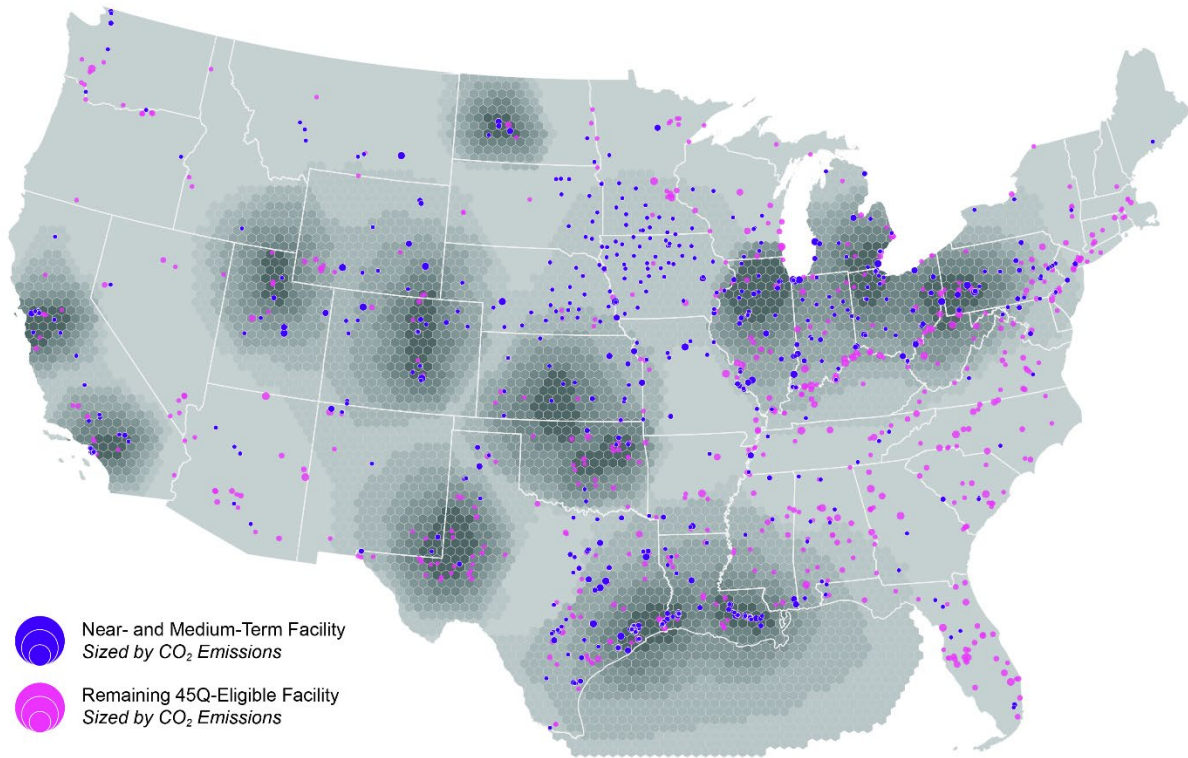


US CO2-H2 Hubs: Great Plains Institute 2021

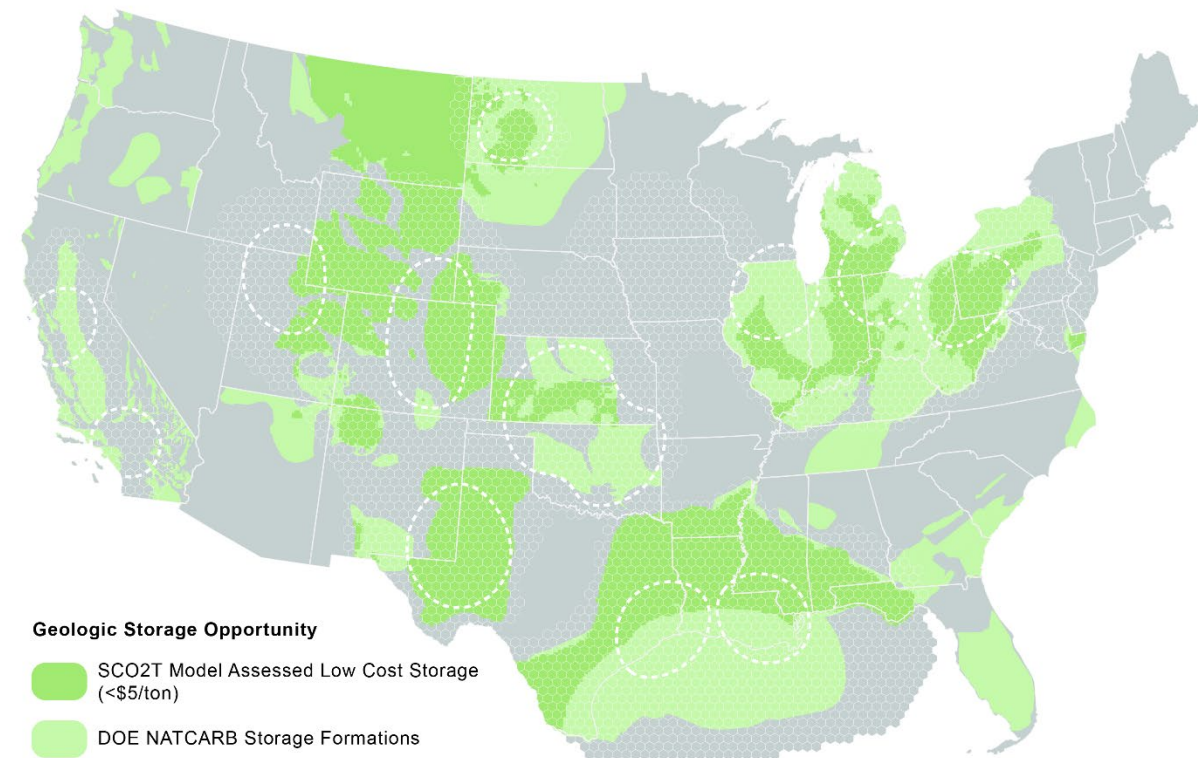


US CO₂-H₂ Hubs: Great Plains Institute 2021

Near Term Opportunities and 45Q Eligible Facilities

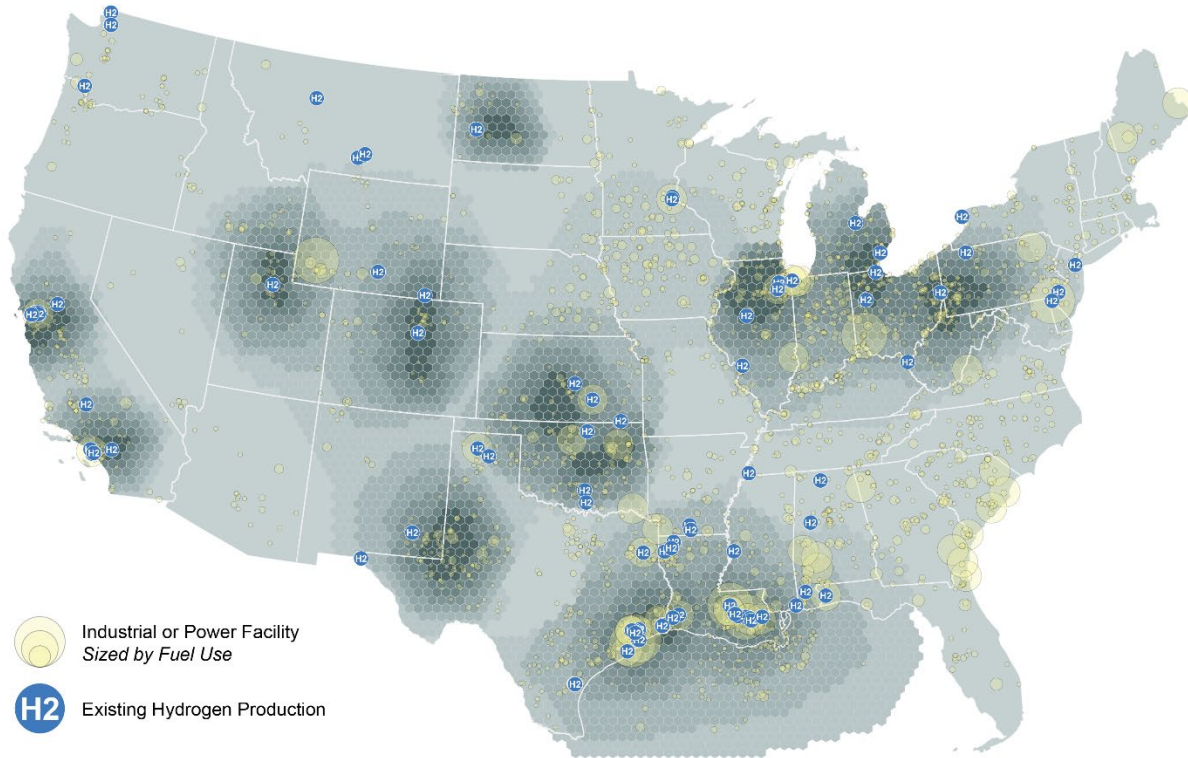


Geologic Storage Potential

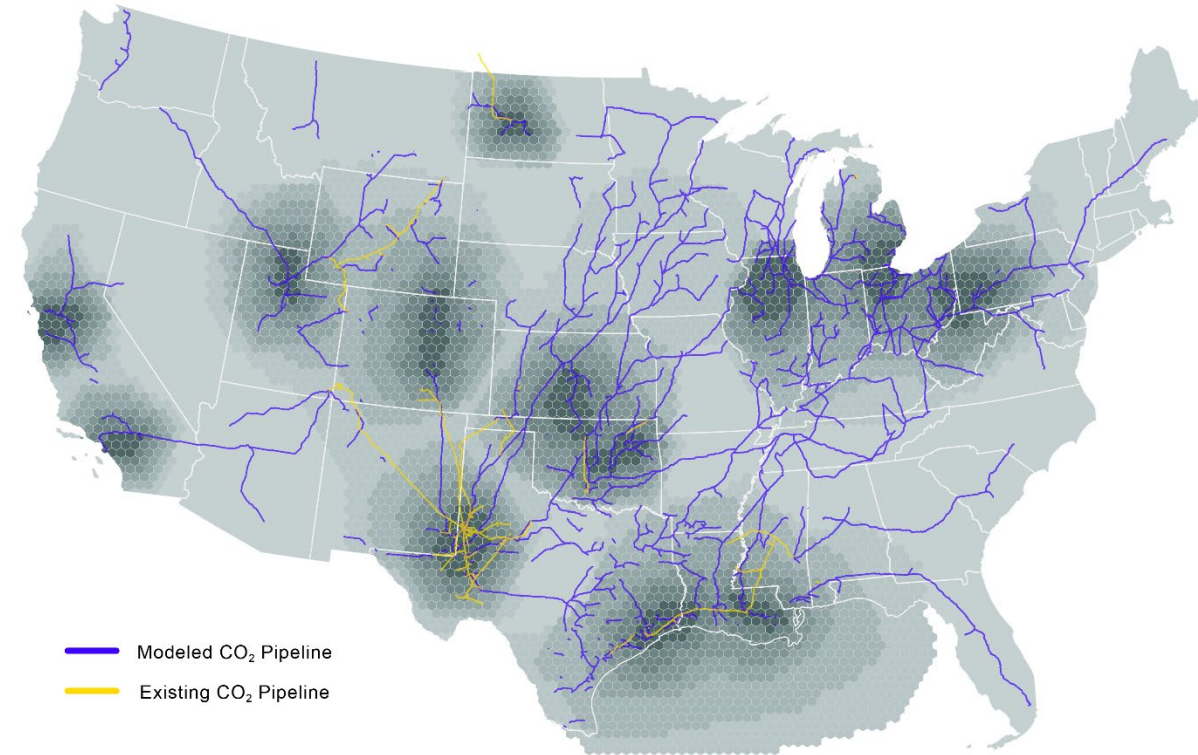


US CO₂-H₂ Hubs: Great Plains Institute 2021

Current H₂ Production and Industrial Fuel Use



CO₂ Transport Infrastructure: Regional Networks



Carbon Management Policy Priorities in the 117th Congress

- Providing a direct pay option for the federal Section 45Q tax credit
- Extending the commence construction window for the 45Q credit
- Enhancing 45Q credit values for industrial and power plant carbon capture and direct air capture
- Eliminating annual carbon capture thresholds
- Financing the buildout of regional CO₂ transport and storage networks
- Robust funding for commercial scale carbon capture pilot projects and demonstration programs

August 3, 2021

The Honorable Charles Schumer
U.S. Senate Majority Leader
S-221, The Capitol
Washington, D.C. 20510

The Honorable Mitch McConnell
U.S. Senate Minority Leader
S-230, The Capitol
Washington, D.C. 20510

The Honorable Nancy Pelosi
Speaker of the House
H-232, The Capitol
Washington, D.C. 20515

The Honorable Kevin McCarthy
House Minority Leader
H-204, The Capitol
Washington, D.C. 20515

Dear Majority Leader Schumer, Minority Leader McConnell, Speaker Pelosi and Minority Leader McCarthy:

On behalf of the undersigned, thank you for your continued commitment to expand and accelerate carbon capture deployment to reduce emissions, create and retain highly-skilled jobs that pay above prevailing wages and spur investment in domestic energy, industry and manufacturing. As you consider legislative proposals to strengthen our nation's infrastructure, combat climate change and recover from the COVID-19 pandemic, **we urge you to prioritize a targeted suite of carbon management policies as an essential component of any forthcoming legislative package.**

In the wake of the COVID-19 pandemic, we have the opportunity to rebuild and retool America's domestic energy, industrial and manufacturing sectors in ways that put our economy on track to reach net-zero emissions by midcentury. Carbon management must be central to achieving emissions reduction goals, while preserving and creating middle class jobs that pay family-sustaining wages, providing environmental and other benefits to communities, and supporting regional economies across our country. Specifically, **we request that you include in any moving legislative package key policy elements described below, which are featured in strongly supported, broadly bipartisan legislation** and critically important to realizing economywide deployment of carbon capture, removal, transport, utilization and storage:

- **Providing a direct pay option for the federal Section 45Q tax credit:** The 45Q tax credit is the cornerstone federal policy for enabling economywide deployment of carbon management technologies, and a direct pay option is crucial to realizing the full emissions reduction and job creation benefits of the credit. Direct pay would address the current significant loss of tax credit value to burdensome, costly and inefficient tax equity transactions, creating an urgently needed alternative for most project developers, who otherwise lack sufficient taxable income to fully utilize the credits, or who are exempt from federal tax liability altogether. The full value of federally funded tax credits should go directly to investments in technology innovation, emissions reductions and job creation, not to financial and legal third parties. The bipartisan Carbon Capture, Utilization and Storage Tax Credits Amendment Act (S. 986) and the Accelerating Carbon Capture and Extending Secure Storage (ACCESS) through 45Q Act (H.R. 1062) both provide a direct pay option for 45Q with no discount; S. 986 is cosponsored by one-fifth of the U.S. Senate.
- **Extending the commence construction window for the 45Q credit:** Extending the commence construction window to qualify for 45Q by an additional ten years, to the end of 2035, would establish a critically needed investment horizon to give carbon management projects the time required to scale up between now and midcentury. While federal tax credits were first established for wind and solar energy in 1992 and 2005, respectively, the current 45Q tax credit has only been in place since 2018. Carbon capture, direct air capture, and carbon utilization technologies deserve a comparable timeframe to benefit from the availability of this crucial federal 45Q incentive. In addition to implementing direct pay, bipartisan bills S. 986 and H.R. 1062 extend 45Q to provide the urgently needed timeframe and certainty for project planning, engineering, permitting and financing.
- **Enhancing 45Q credit values for industrial and power plant carbon capture and direct air capture:** Modeling by the Intergovernmental Panel on Climate Change and the International Energy Agency make clear that economywide deployment of carbon capture and direct air capture is vital to meeting midcentury climate goals. However, recent analyses and commercial experience underscore that current 45Q credit values are insufficient to drive the early

State MOU for CO₂ Transport Infrastructure

- **Seeks** to accelerate, through state leadership and coordination, the deployment of common regional CO₂ transport infrastructure networks and carbon hubs to help industries take advantage of economies of scale
- **Includes** KS, LA, MD, MT, ND, OK, PA and WY as signatories, other states considering joining
- **Recognizes** that development of CO₂ transport networks, together with financial incentives for carbon capture, can:
 - ✓ support long-term production and use of **domestic natural resources**;
 - ✓ create and preserve **high-paying jobs** in energy-producing, agricultural and industrial states; and
 - ✓ significantly **reduce net carbon emissions**
- **Provides** a collaborative mechanism to jointly develop and implement an action plan for building out regional CO₂ transport infrastructure to enable large-scale carbon management
- **Action Plan** describing strategies to incentivize project deployment will be released **October 1, 2021**

Carbon Capture Ready Website

RDI Homepage

- State fact sheets
- Jobs fact sheets
- Analytical white paper
- Policy briefs
- Resources on carbon capture

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JOBS AND ECONOMIC IMPACT OF CARBON CAPTURE DEPLOYMENT Texas

TOTAL JOBS POTENTIAL

Project Jobs	Operations Jobs	Infrastructure Jobs
15,010	9,230	2,850

Texas has the opportunity to create an annual average of up to **17,860 project jobs** over a 15-year period and **9,230 ongoing operations jobs** through the deployment of carbon capture at 95 industrial and power facilities. The retrofit of equipment at these facilities has the potential to capture nearly **161 million metric tons** of carbon dioxide (CO₂) per year. Along with the development of CO₂ transport infrastructure, this would generate up to over **\$69 billion** in private investment.

CREATING JOBS & CAPTURING CARBON

Carbon capture is essential to meeting mid-century emissions reduction goals while retaining and growing a domestic base of high-wage energy, industrial, and manufacturing jobs. Carbon capture retrofits require facilities to be outfitted with capture technologies such as amine scrubbers to remove CO₂ from exhaust gas and compressors to make the CO₂ transport-ready, that are dependent upon the type of industrial plant and vary across industries and facilities. There are jobs associated with the equipment, materials (e.g. cement and steel), engineering, and labor required to install the capture technology, as well as ongoing jobs to operate and maintain the retrofits. These are referred to as **project jobs** and **operations jobs**.

Rhodium Group performed an economic analysis based on the Regional Carbon Capture Deployment Initiative's near- and medium-term capture potential scenario.¹ The Rhodium analysis quantifies the economic impact and employment opportunities of carbon capture retrofit projects by deploying state-specific data in the IMPLAN economic model. The analytical results measure the impact of project investment and operation costs through expected annual jobs. Average annual project jobs were calculated assuming deployment of all projects within the 15-year period from 2021-2035. The jobs reported are in-state jobs, directly associated with carbon capture retrofits. They do not include other jobs at the facilities, nor indirect and induced jobs.

ANNUAL PROJECT AND OPERATIONS JOBS

Mt = million metric tons.
This figure depicts the low and high range of estimated annual average project jobs, transport infrastructure jobs, and ongoing operations jobs that could be created through carbon capture retrofits at industrial and power facilities in Texas. The potential amount of CO₂ captured and the number of potential near- or medium-term capture facilities in each industry are shown on the right.

CARBON CAPTURE JOBS AND ECONOMIC IMPACT SUMMARY

Industry	Number of Facilities	Total Capture Target Metric Tons	Private Investment Million Dollars	Annual Average Project Jobs 2021-2035	Annual Operations Jobs
Cement	11	8,000,000	\$1,200 - \$1,800	350 - 520	310 - 430
Coal Power	11	70,000,000	\$14,000 - \$20,000	3,870 - 5,800	2,360 - 3,540
Ethanol	4	1,000,000	\$60 - \$90	15 - 25	20 - 30
Gas Power	28	53,000,000	\$15,000 - \$25,000	4,400 - 6,600	2,570 - 3,850
Gas Processing	6	900,000	\$70 - \$100	20 - 25	20 - 30
Hydrogen	14	9,000,000	\$900 - \$1,300	260 - 380	270 - 370
Petrochemicals	2	2,000,000	\$500 - \$700	150 - 220	110 - 160
Refineries	19	17,000,000	\$2,600 - \$3,900	960 - 1,440	590 - 820
CO ₂ Transport Infrastructure	-	-	\$7,000,000,000	2,850	-

¹ Rhodium Group analytical results: rhg.com/research/ For more information, visit carboncaptureready.org

carboncaptureready.org

Analysis - Carbon Capture Ready x

https://carboncaptureready.betterenergy.org/analysis/

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CARBON CAPTURE READY REGIONS ANALYSIS RESOURCES CONTACT

Carbon Capture and Storage Infrastructure for Midcentury Decarbonization

This report provides data sources, details the analytical methodology, and identifies potential capture facilities throughout the Western and Midwestern regions, as well as primary modeling scenarios and conclusions on regional CO₂/front capture, transport, and storage opportunities.

Download the report below.

[Download Whitepaper](#)

Jobs and Economic Growth Fact Sheets

The Regional Deployment Initiative has released a series of state fact sheets on potential jobs creation and economic impact of carbon capture deployment, based on collaborative analysis by Rhodium Group. The Rhodium analysis quantifies the economic impact and employment opportunities of carbon capture retrofit projects by deploying state-specific data in the IMPLAN economic model.

Download each state fact sheet below:

Midcontinent Region →

Arkansas Louisiana Montana Oklahoma
Colorado Michigan North Dakota South Dakota
Iowa Minnesota Nebraska Texas
Illinois Missouri New Mexico Utah
Indiana Mississippi Ohio Wisconsin



Thank You

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Appendix



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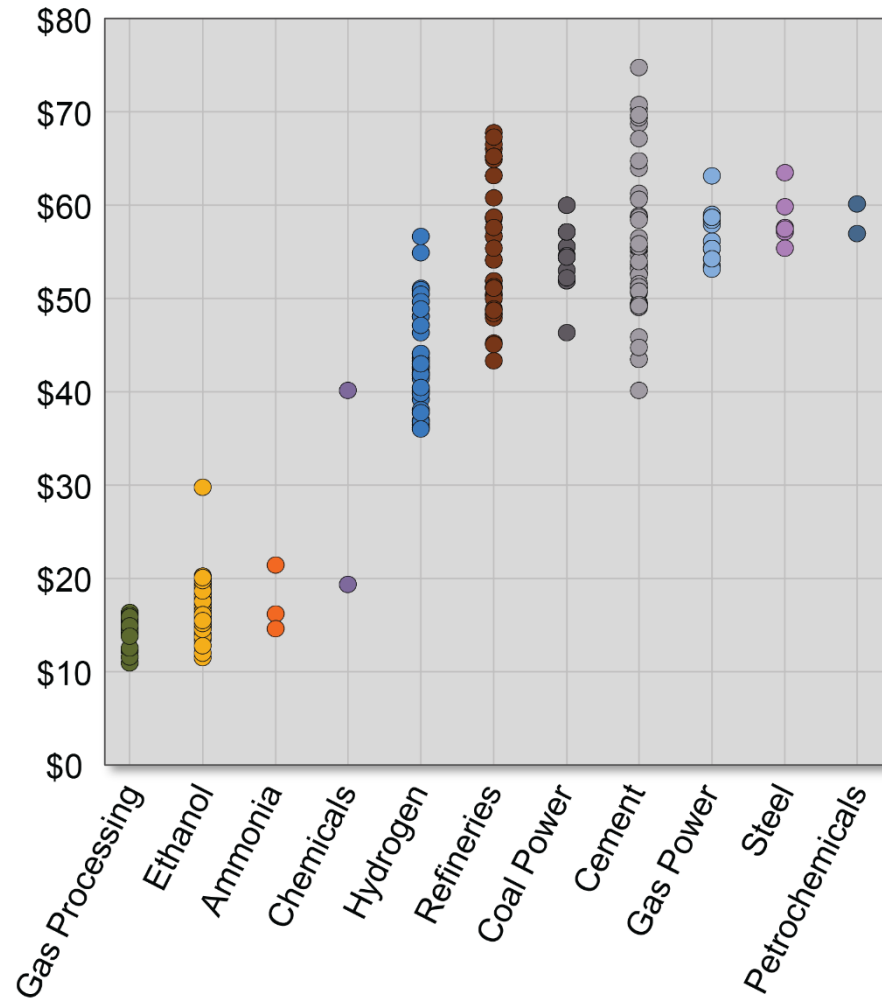


Budget Reconciliation and Other Legislative Vehicles

- Ways and Means base text – mixed bag for carbon management:
 - Multi-year extension of 45Q
 - Direct pay option
 - Increased credit values for direct air capture
 - Industrial and power generation projects left out
 - Lower capture thresholds
 - New percentage capture requirements applied at facility level
- Senate Finance text – expected soon
 - Hopeful to include increased values for industrial and power sector



Estimated Cost of Capture per Industry for Near-Term Facilities in Study Area



Industry	# of Facilities	Optimized Capture (mmt/year)	Average Estimated Cost \$/ton
Ethanol	150	50.6	\$17
Cement	45	32.7	\$56
Refineries	38	26.5	\$56
Steel	6	14.6	\$59
Hydrogen	34	14.4	\$44
Gas Processing	20	4.5	\$14
Petrochemicals	2	1.7	\$59
Ammonia	3	0.9	\$17
Chemicals	2	0.7	\$30
Coal Power Plant	58	143.4	\$56
Gas Power Plant	60	67.9	\$57
Grand Total	418	357.8	\$39

Source: Jeff Brown, 2019



**GREAT PLAINS
INSTITUTE**

US EPA
US DOE
ABB / Energy Velocity

CO₂ Supply
Industrial & Power

Stanford
NETL
IEA

Capture Costs

NETL & USGS
Los Alamos National Lab
Indiana University
Ohio State

Saline
Storage Potential
SCO₂T

Advanced Resources
International

EOR
Potential Demand

NETL
Los Alamos
Princeton
Industry Consulting

Infrastructure
Costs

SimCCS
Los Alamos
Montana State

Identify feasible
projects

Plan regional scale
infrastructure to
maximize CO₂
capture and
storage