Transport Infrastructure for CCS: Regional Opportunities for Deployment

September 30, 2021

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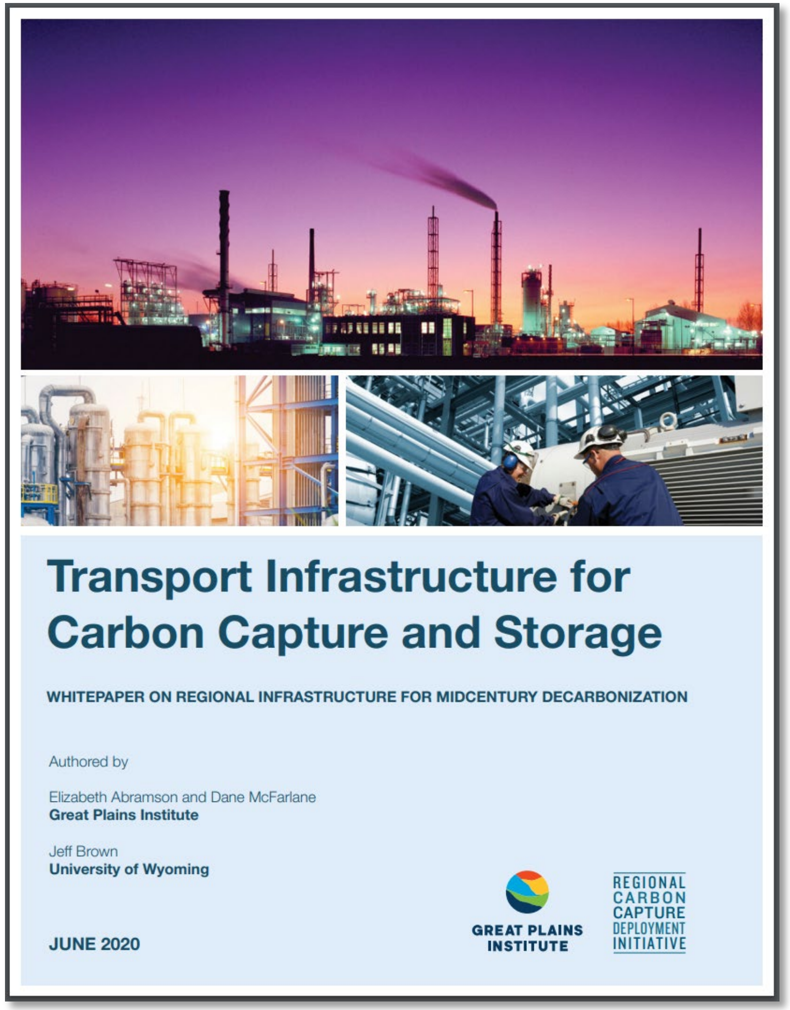
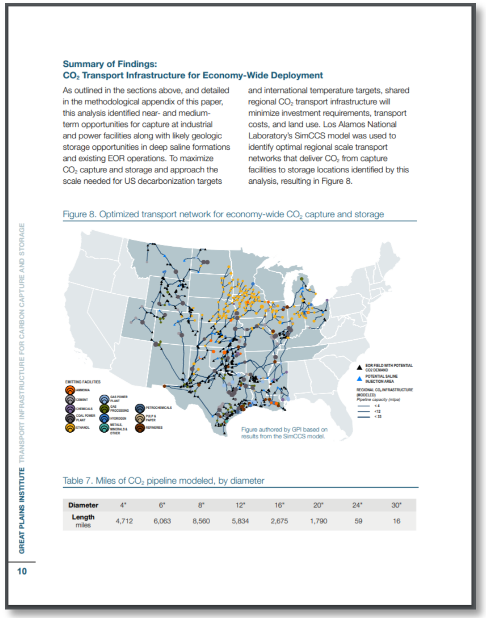
1. Carbon Transport Infrastructure Study
2. Jobs and Economic Impact Study
3. Preview: Carbon and Hydrogen Hub Modeling
4. Policy Priorities

Analytical Report

Published June 30, 2020





Download the paper at:

carboncaptureready.org/analysis

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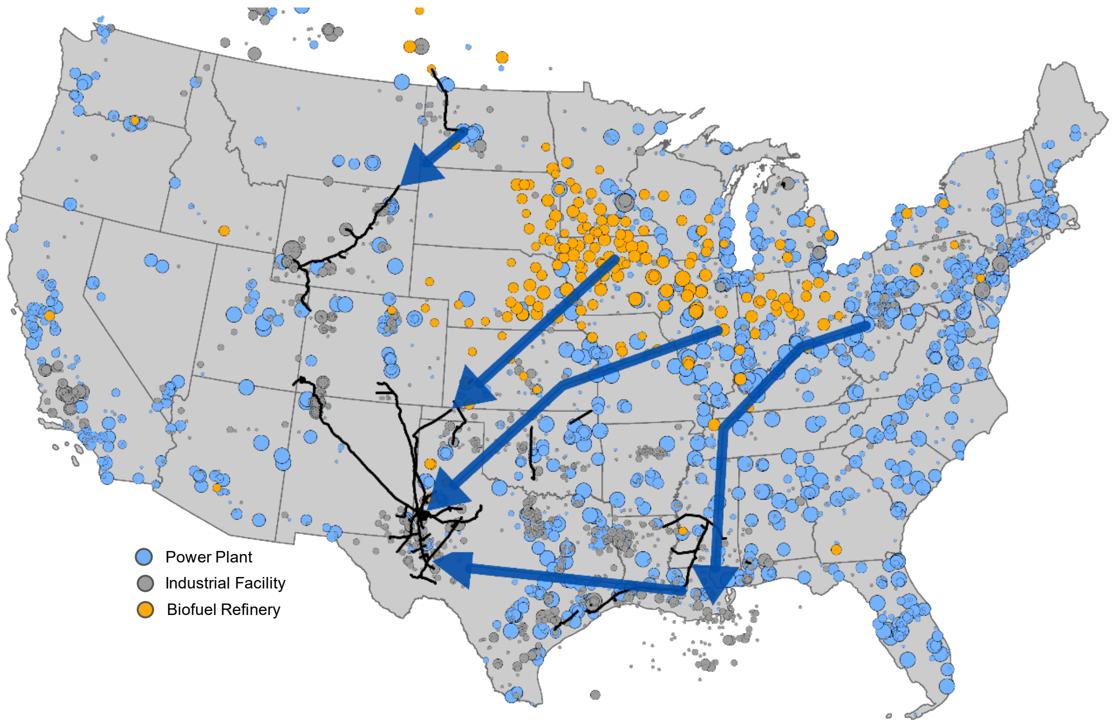
Regional CO_2 Transport Infrastructure Study

Study Components

1. Identify near-term opportunities for CO_2 capture retrofit
2. Locate areas of CO_2 storage and use
3. Model optimized CO_2 transport infrastructure to maximize capture and storage

Initial CO_2 Corridor Scoping



Primary Partners:

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE
Los Alamos NATIONAL LABORATORY EST. 1943
MONTANA STATE UNIVERSITY
B2 E2 BROWN BROTHERS ENERGY & ENVIRONMENT
INDIANA UNIVERSITY
Stanford University

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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

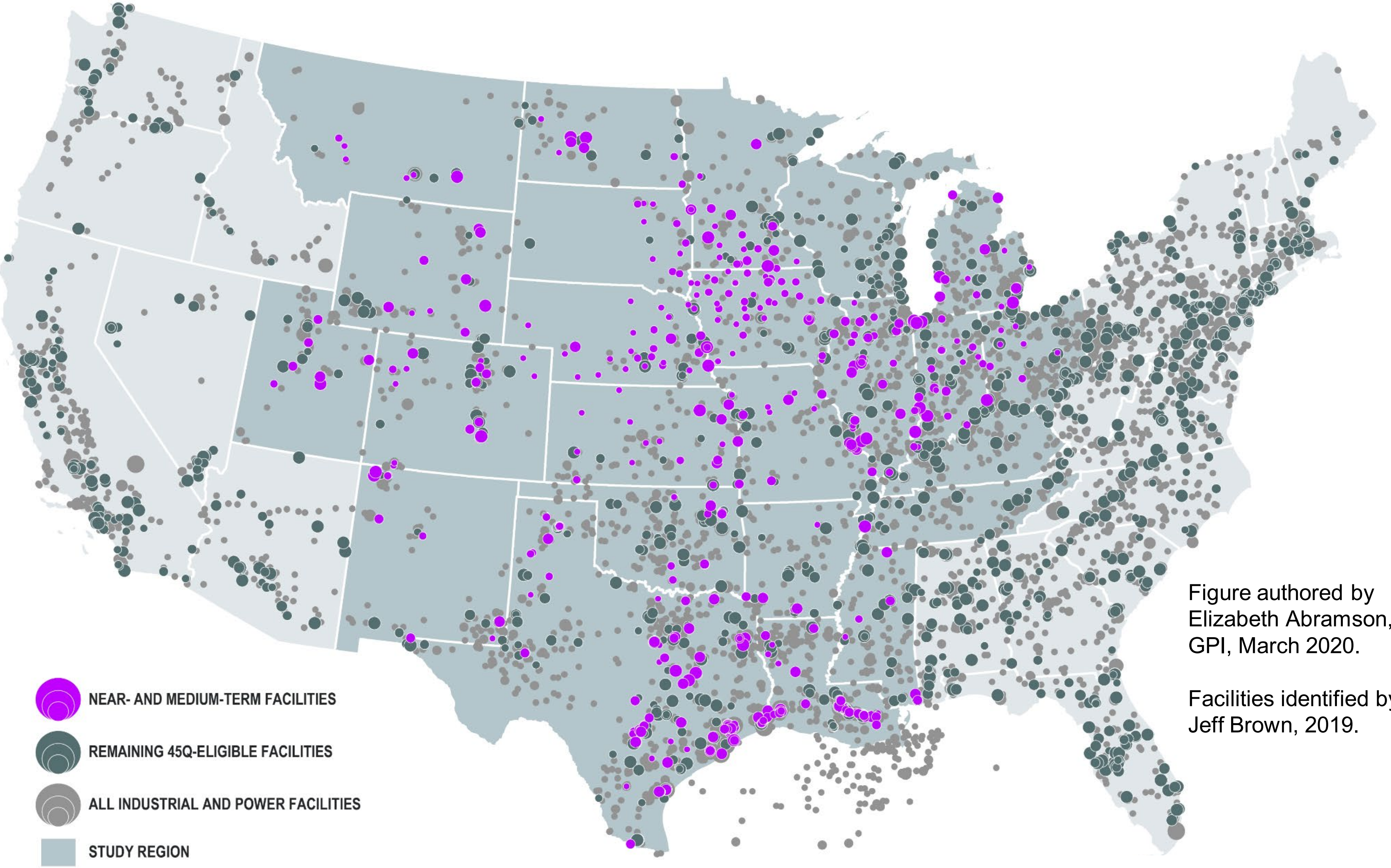

Figure authored by Elizabeth Abramson, GPI, March 2020.

Facilities identified by Jeff Brown, 2019.

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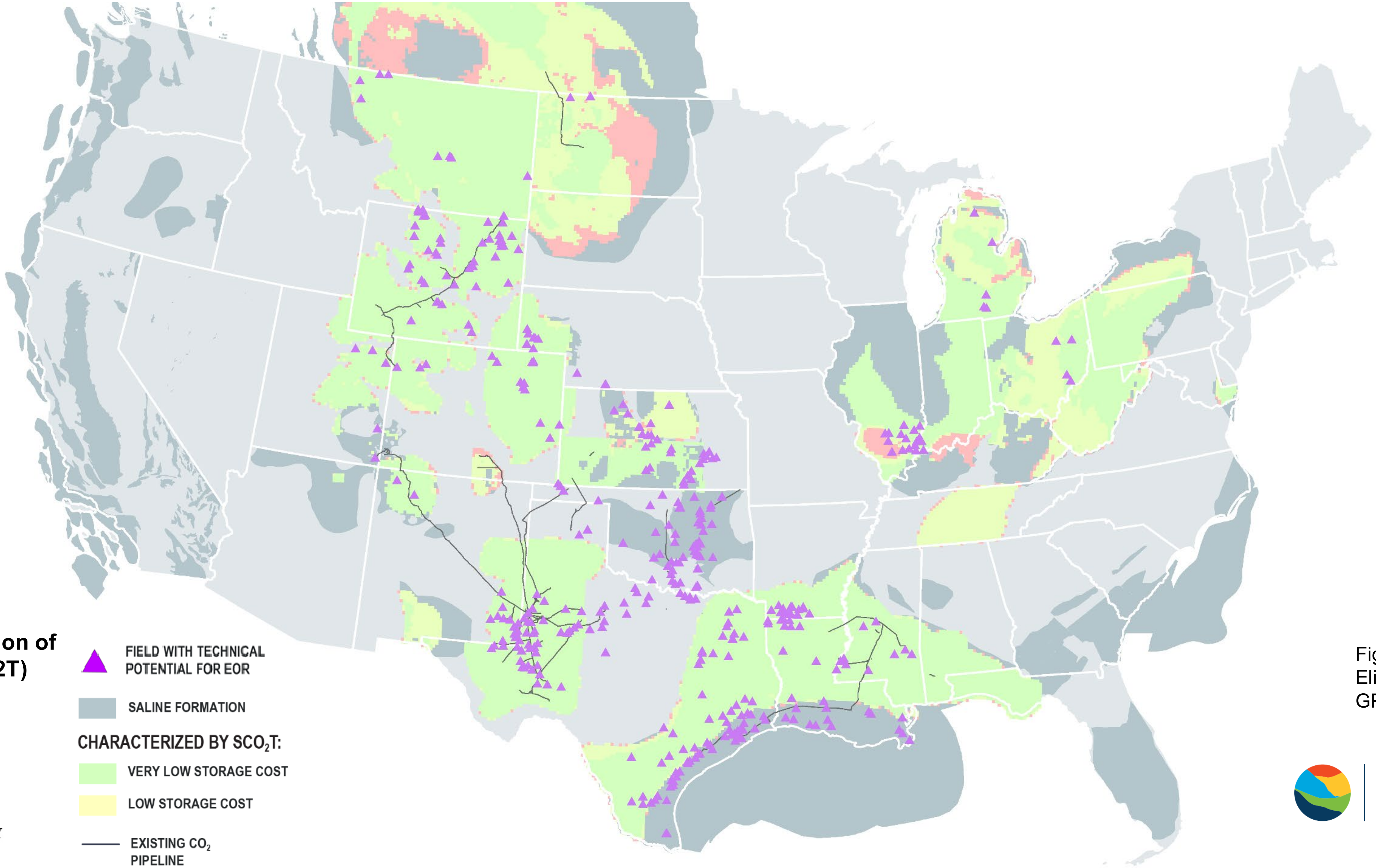
Saline: SCO2T & NATCARB 10km Grid Cells



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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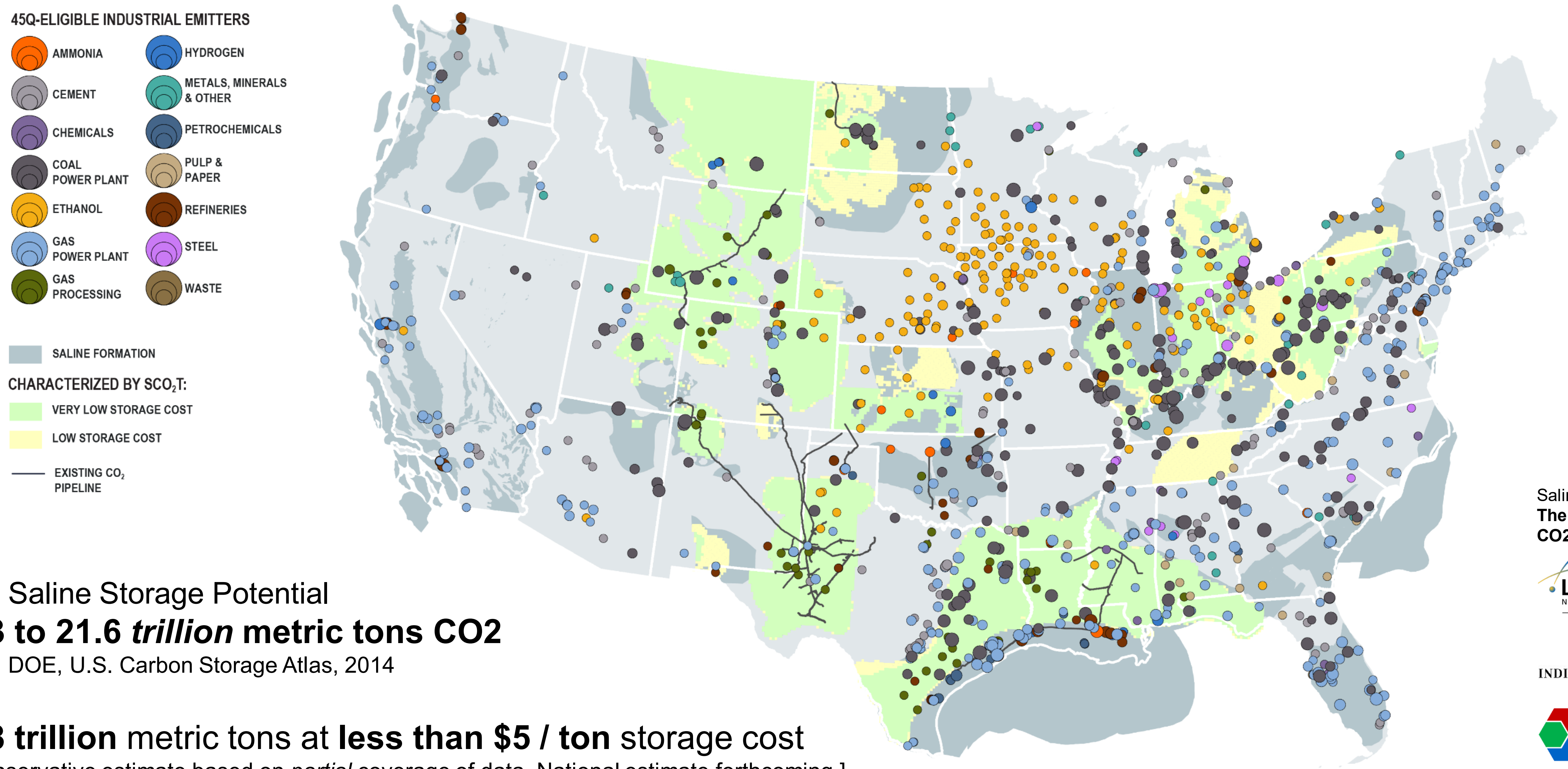
CO_2 Storage in Saline Formations & Petroleum Basins



Saline data via
The Sequestration of CO2 Tool (SCO2T)

Los Alamos National Laboratory EST. 1943

Indiana University

Carbon Solutions LLC

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

Figure authored by Elizabeth Abramson, GPI, March 2020

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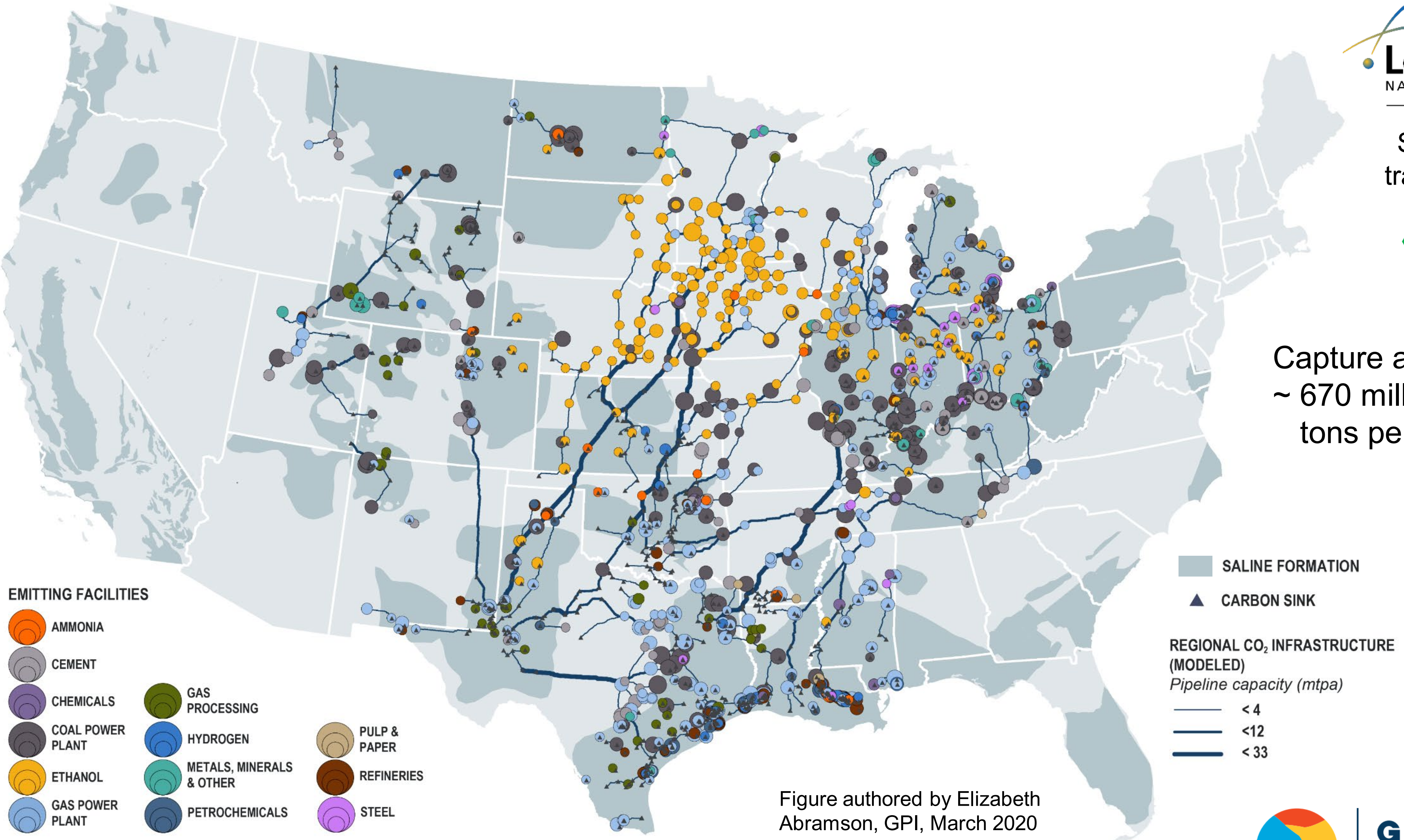
Midcentury: Long-term Economy-Wide Deployment
Expanded storage in saline formations and petroleum basins



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Los Alamos NATIONAL LABORATORY EST.1943

SimCCS CO_2 transport model

Carbon Solutions LLC

Capture and storage: ~ 670 million metric tons per year

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Shared CO_2 Transport Infrastructure: Beneficial Economies of Scale

Higher capacity achieves lower costs per ton

Infrastructure investment by capacity
$ per inch-mile

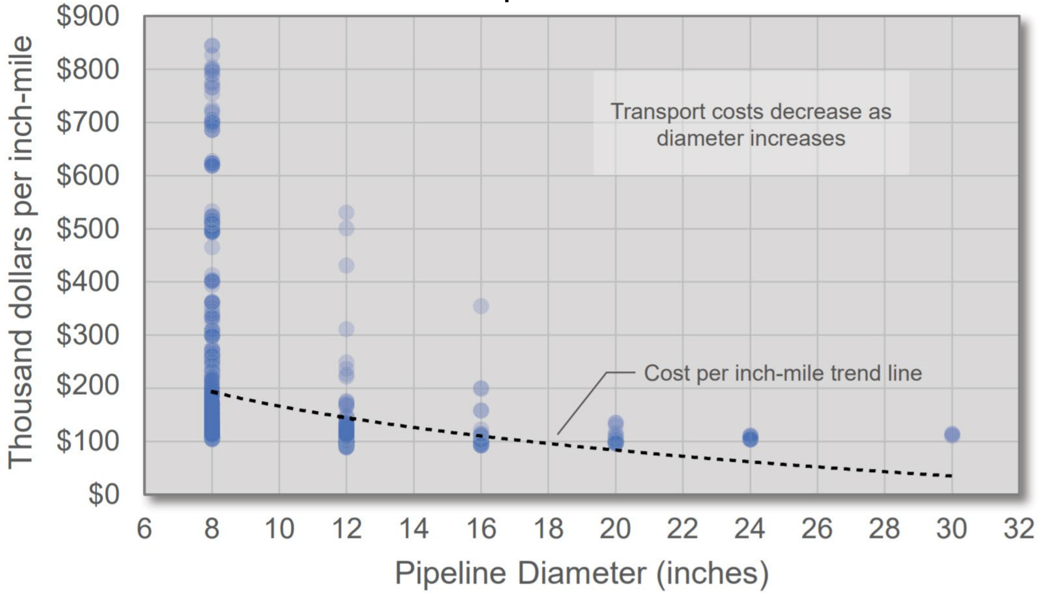

Figure authored by GPI based on calculations performed using the NETL CO_2 Transport Cost Model.

Transport tariff by capacity
$ per ton

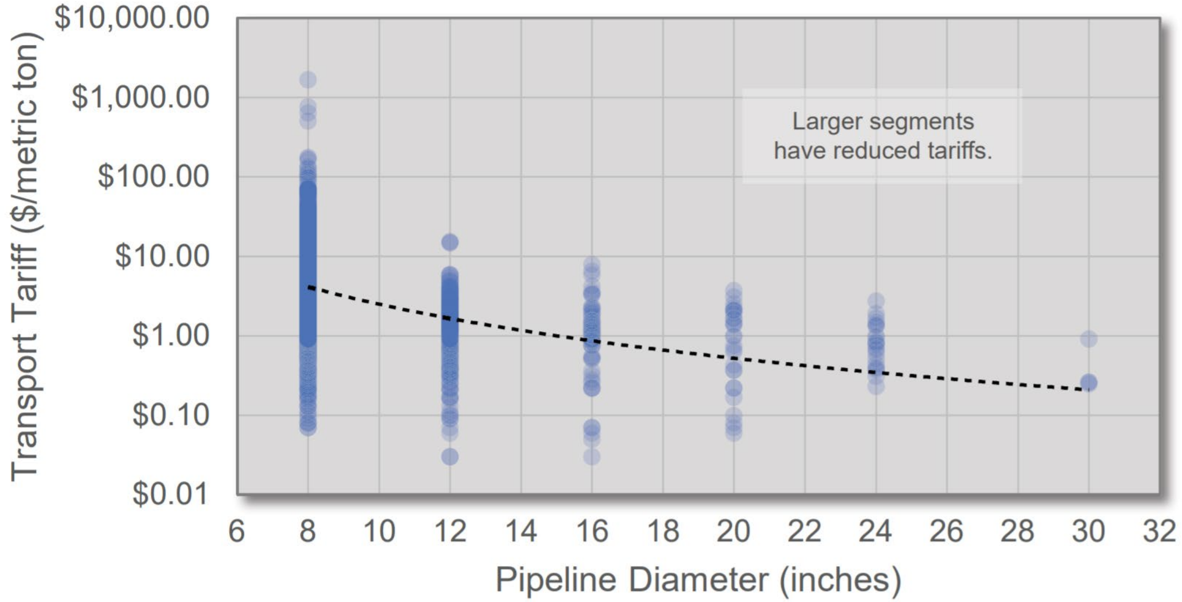

Figure authored by GPI based on calculations performed using the NETL CO_2 Transport Cost Model, as modified by McFarlane, Dubois, and Edwards, 2018.

Investment by owner/operator → **Cost to user/customer**

Calculated with:

NATIONAL ENERGY TECHNOLOGY LABORATORY CO_2 Transport Cost Model

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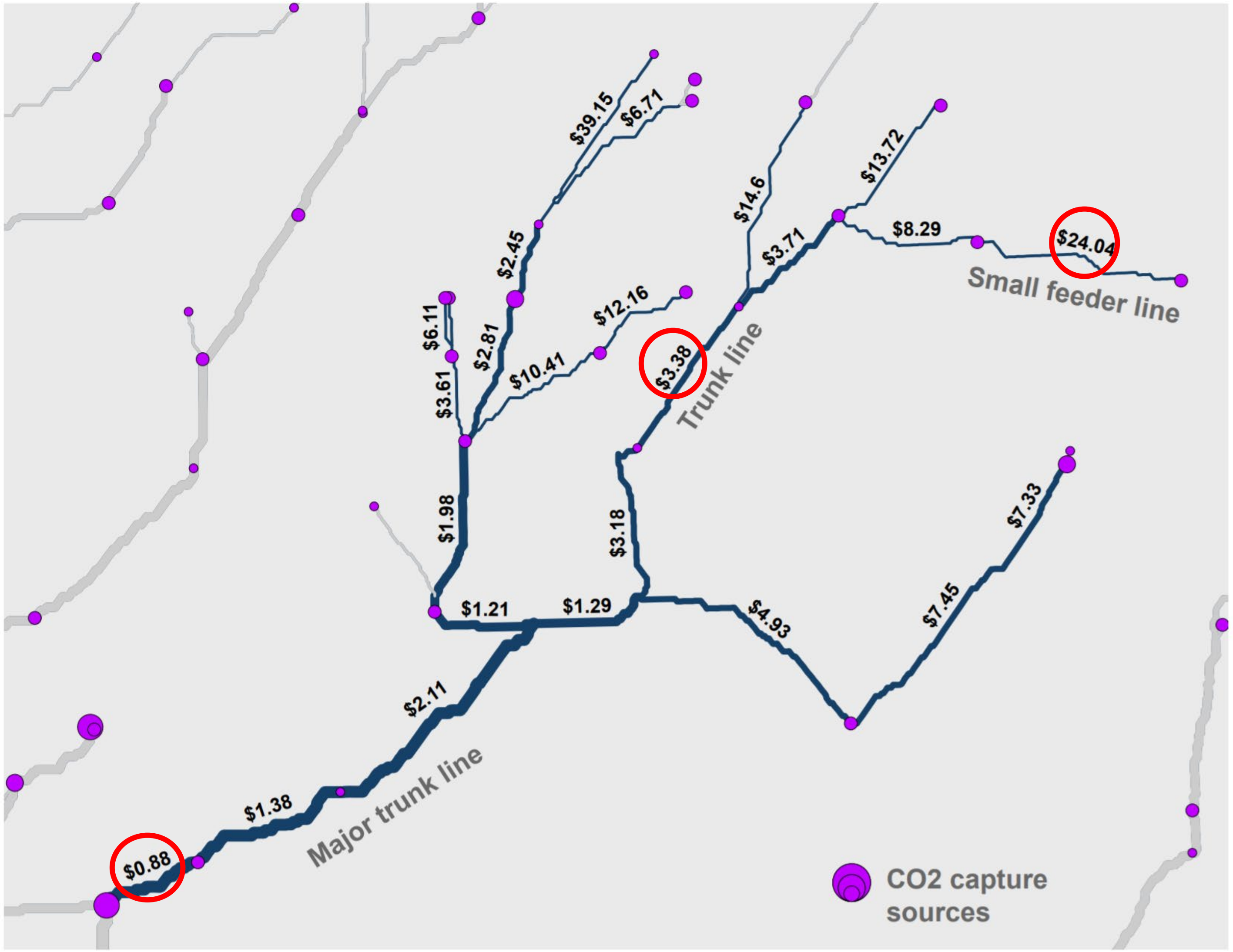
Shared CO_2 Transport Infrastructure: Beneficial Economies of Scale



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 CO_2 Transport Cost model.

Small feeder lines have a higher per-ton cost because they deliver less CO_2.

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

Customers generally pay a transport tariff ($/ton) based on the route their CO_2 product takes through the transport network.

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Cost Efficiency through Capacity
Relative transport cost of network segments

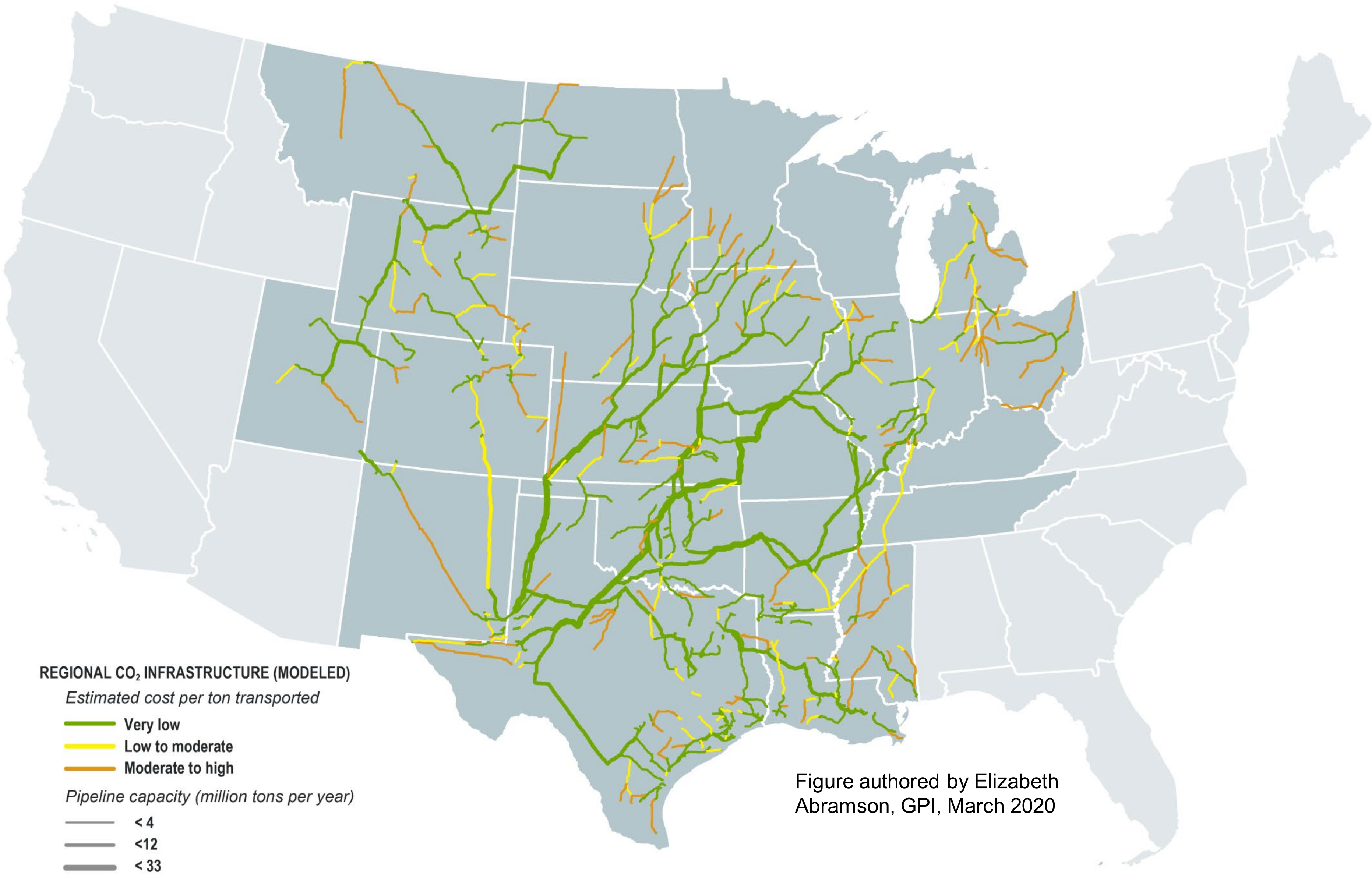

Figure authored by Elizabeth Abramson, GPI, March 2020

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

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Planning for Long-term Economy-Wide Deployment

Economies of scale benefit higher capacity for CO_2 delivery

Regional infrastructure can store more CO_2 at a lower cost

Long term planning results in more CO_2 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

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Jobs Study 2020-2021

Job Creation Potential of Carbon Capture Retrofit and Transportation Infrastructure

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

Rhodium Group

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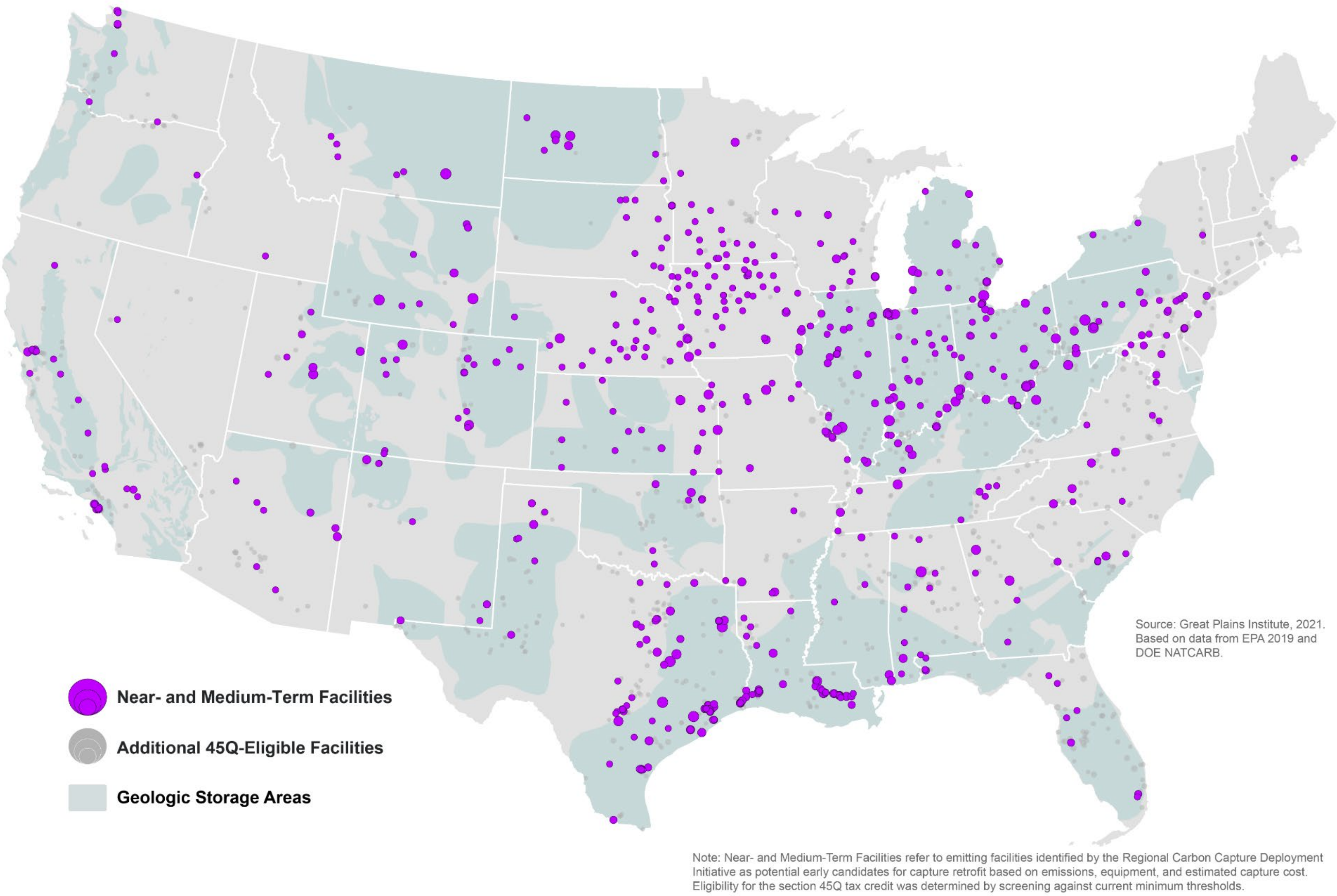
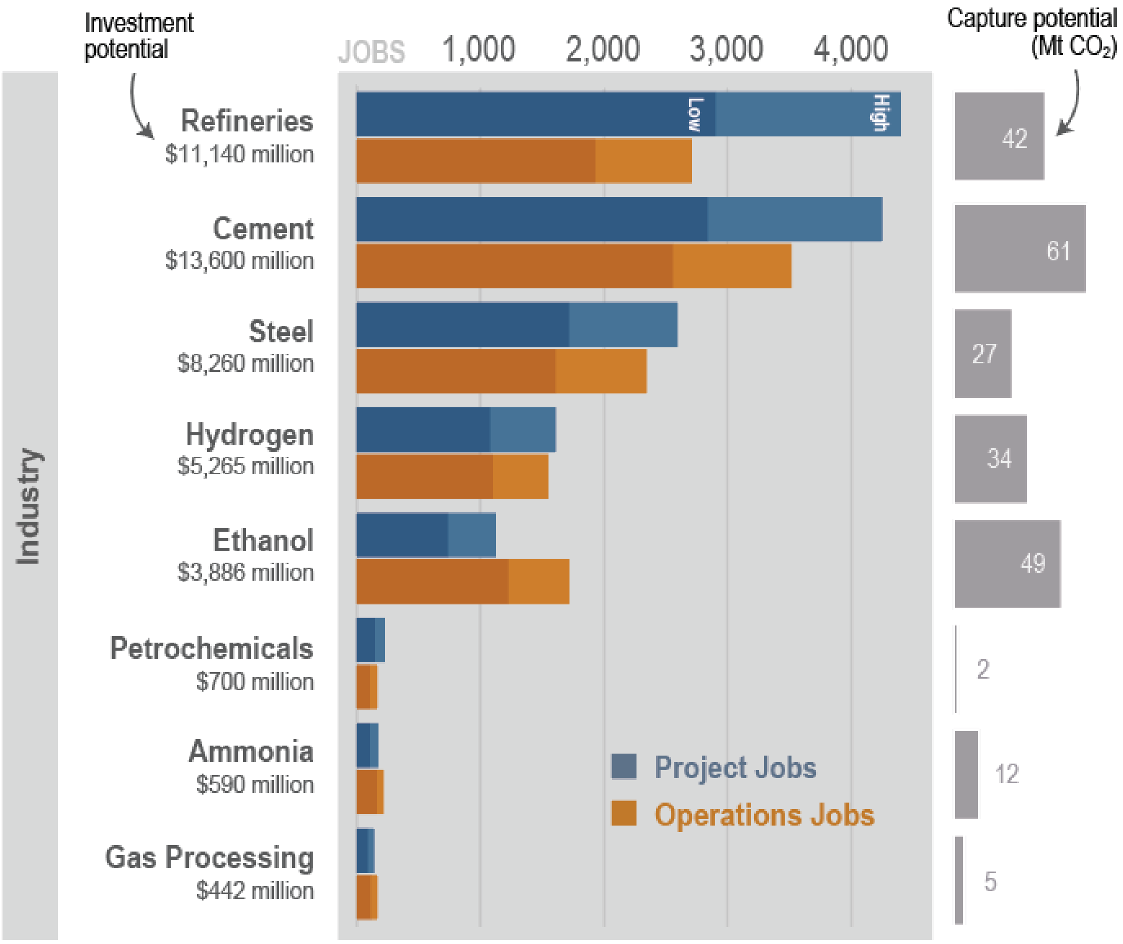
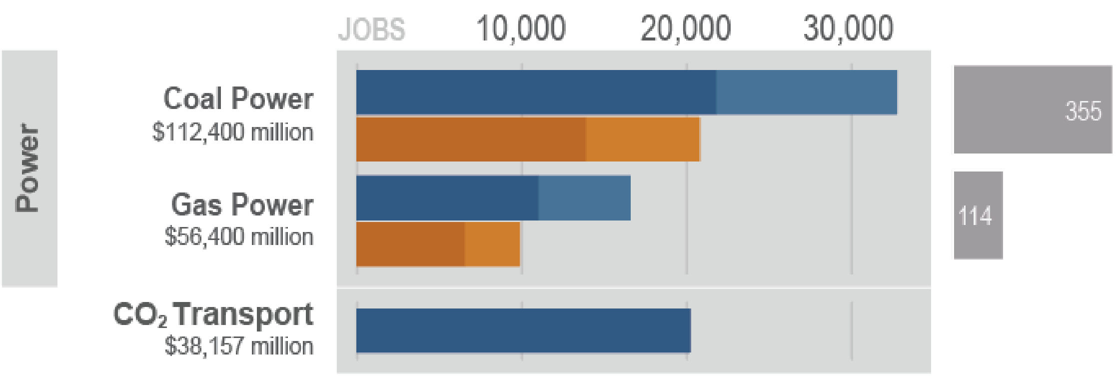
2021 - 2035
Near- and Medium-Term Deployment
Phase 1: RDI Region
Phase 2: Coastal Regions

2035 – 2050
Mid-Century Deployment
Phase 3: Nation-wide



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.

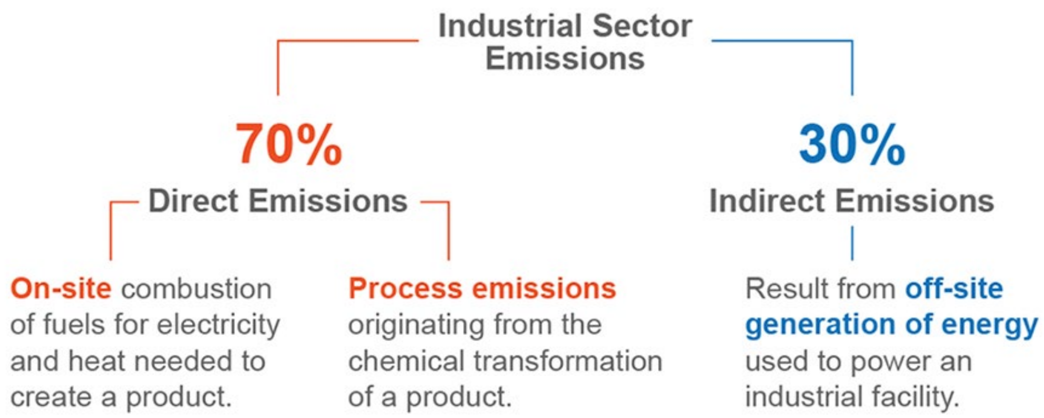
A diverse array of opportunities are available

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

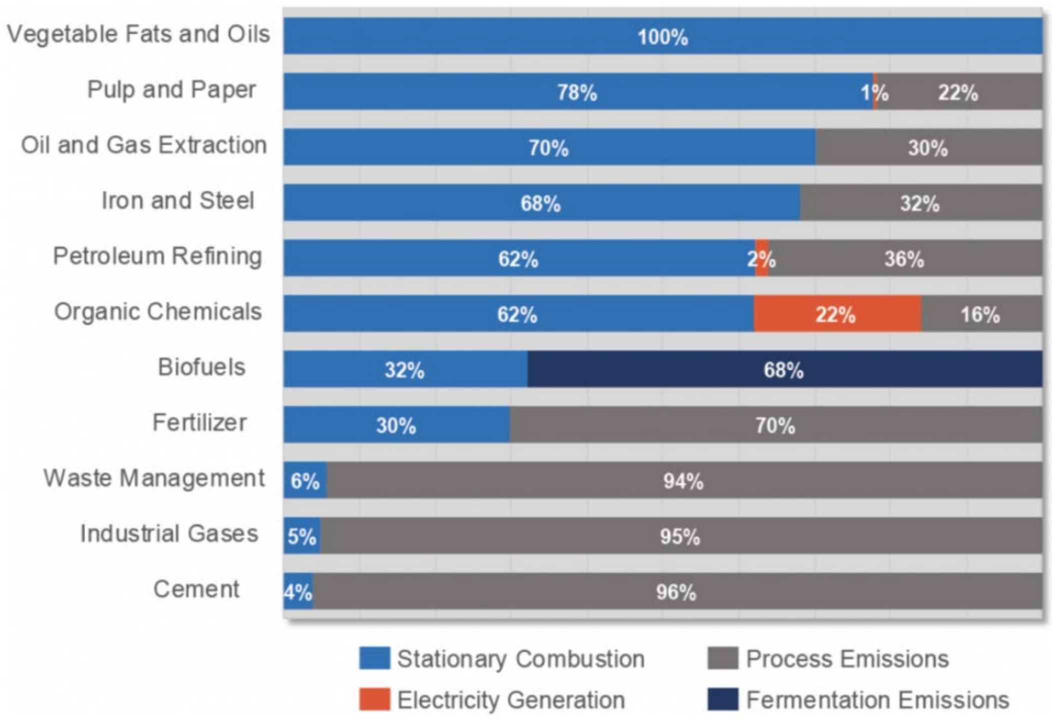
Carbon capture can play to each states' strengths

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



Direct Emissions: US Midcontinent Facilities



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

Emissions	Reduction Strategy
On-site combustion:	Electrification & Fuel Switching
Process Emissions:	Carbon Capture
Indirect Emissions:	Decarbonizing Electric Grid

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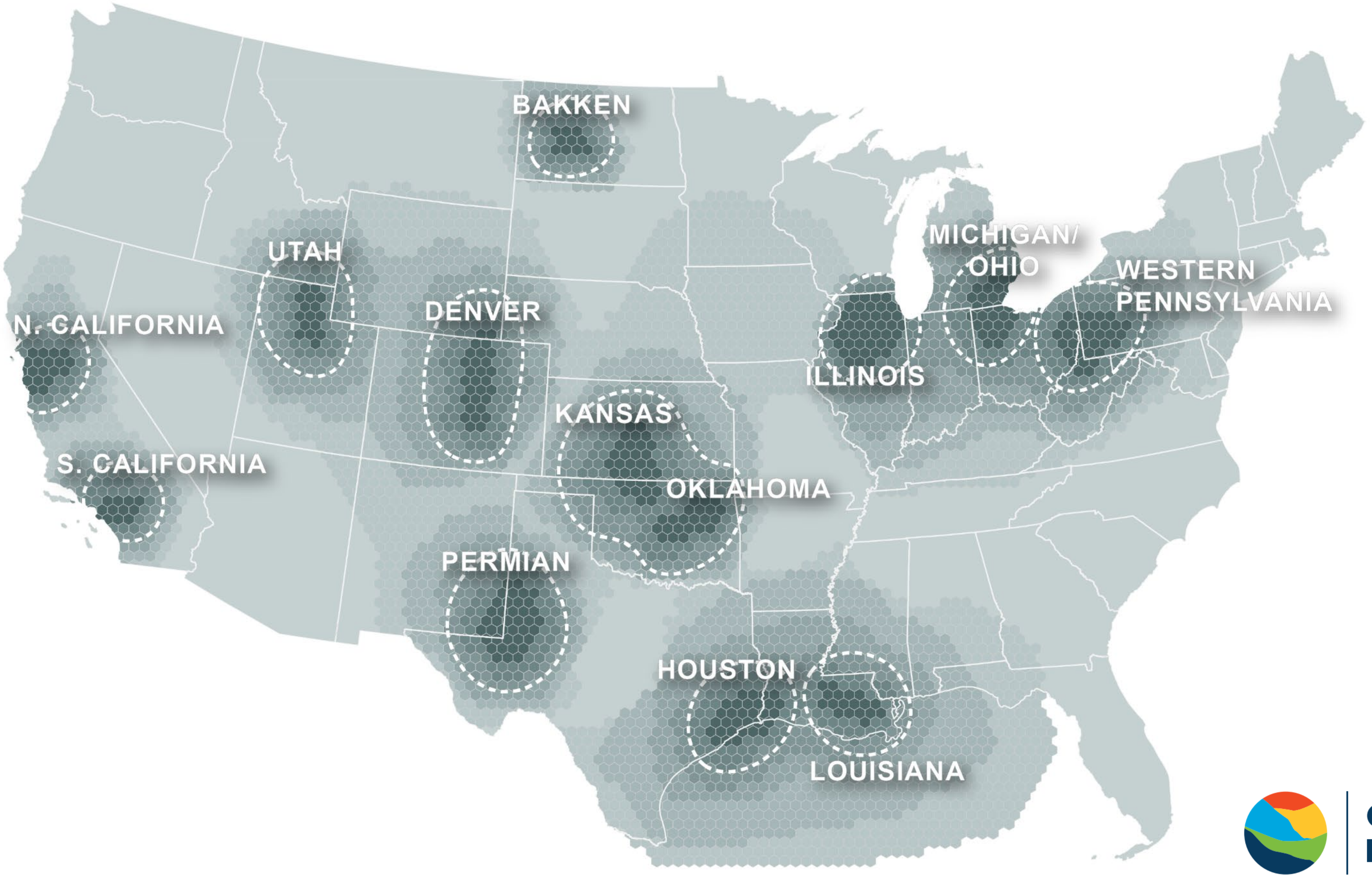
CO2 & H2 Hubs

- **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



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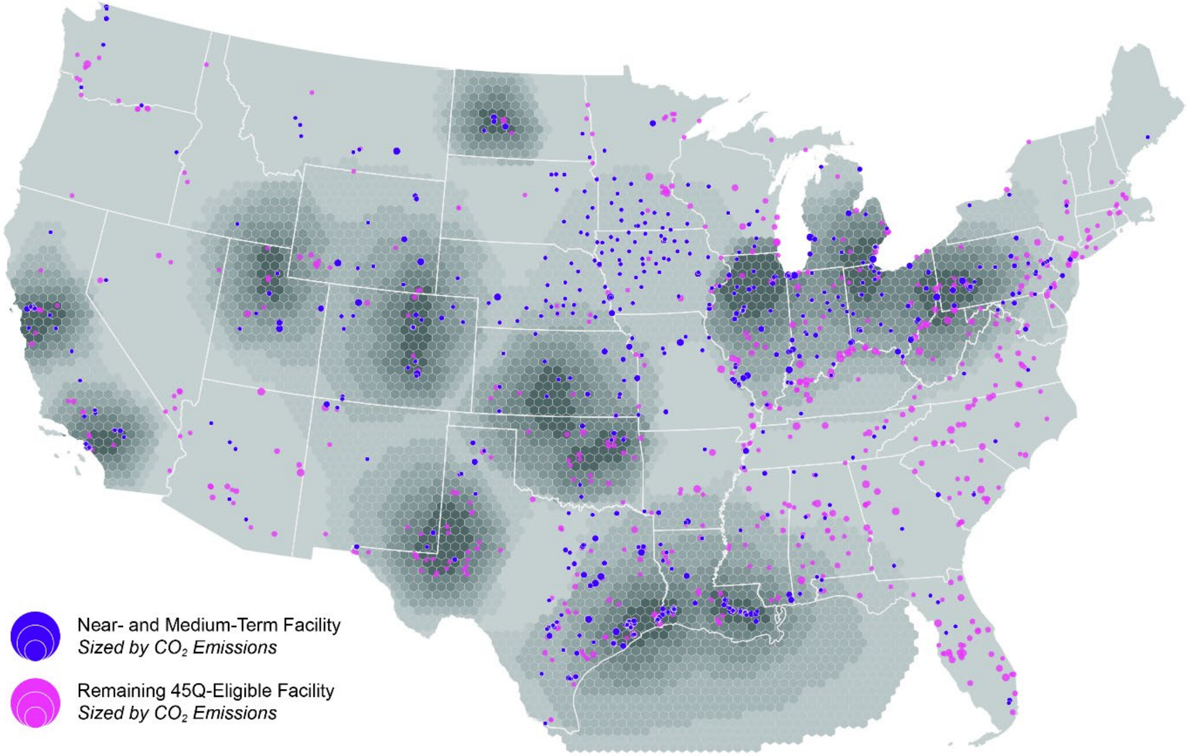
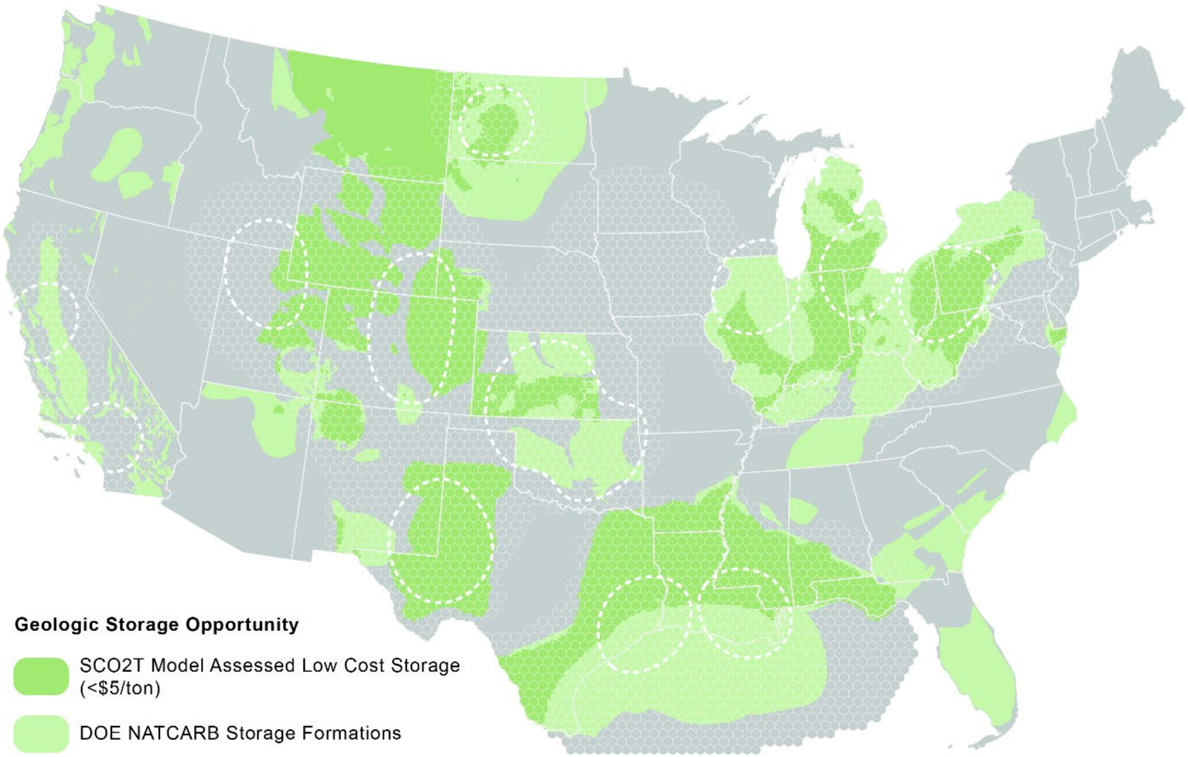
US CO2-H2 Hubs: Great Plains Institute 2021

Near Term Opportunities and 45Q Eligible Facilities



Geologic Storage Potential



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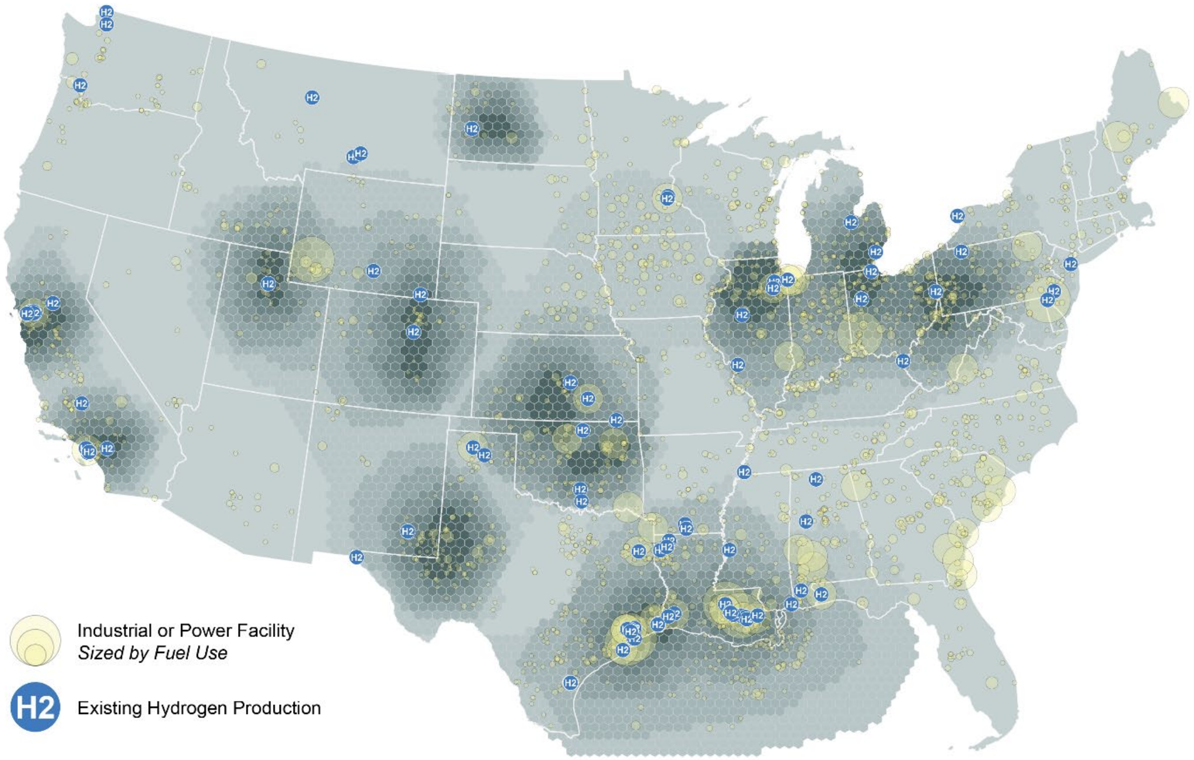
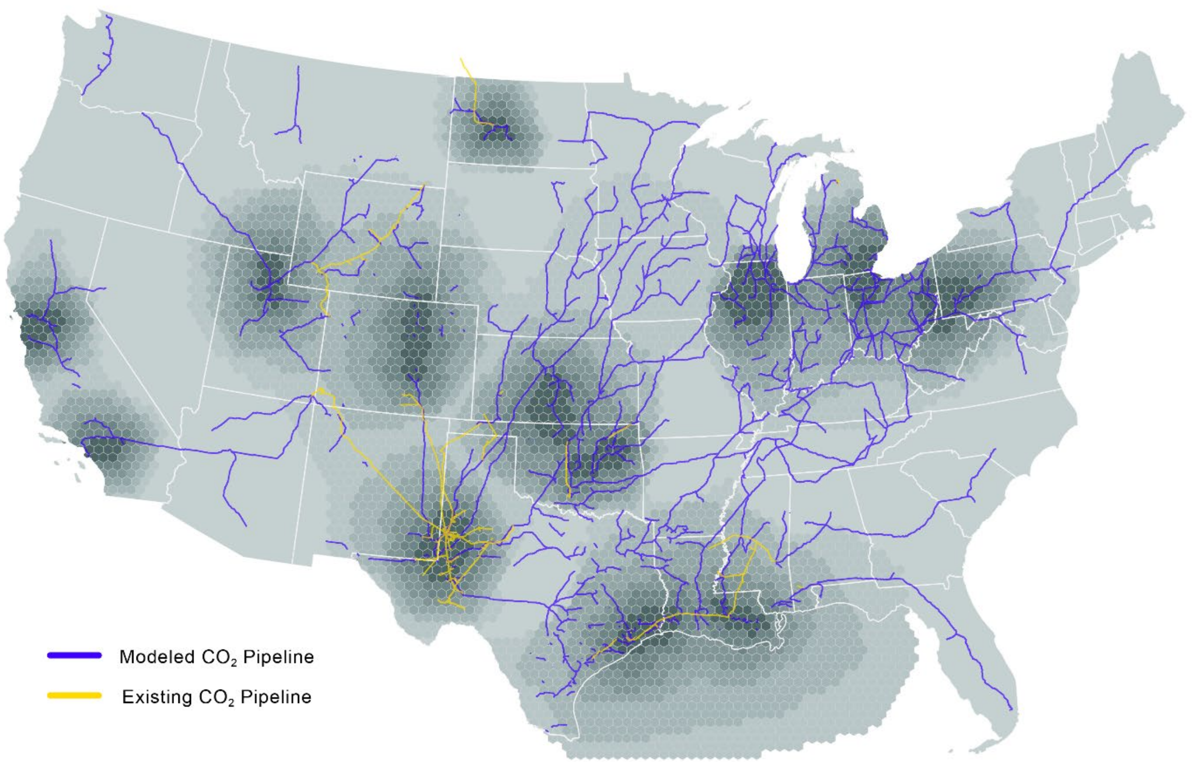
US CO2-H2 Hubs: Great Plains Institute 2021

Current H2 Production and Industrial Fuel Use



CO2 Transport Infrastructure: Regional Networks



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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 CO_2 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 Nancy Pelosi
Speaker of the House
H-232, The Capitol
Washington, D.C. 20515

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

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

CARBON CAPTURE COALITION

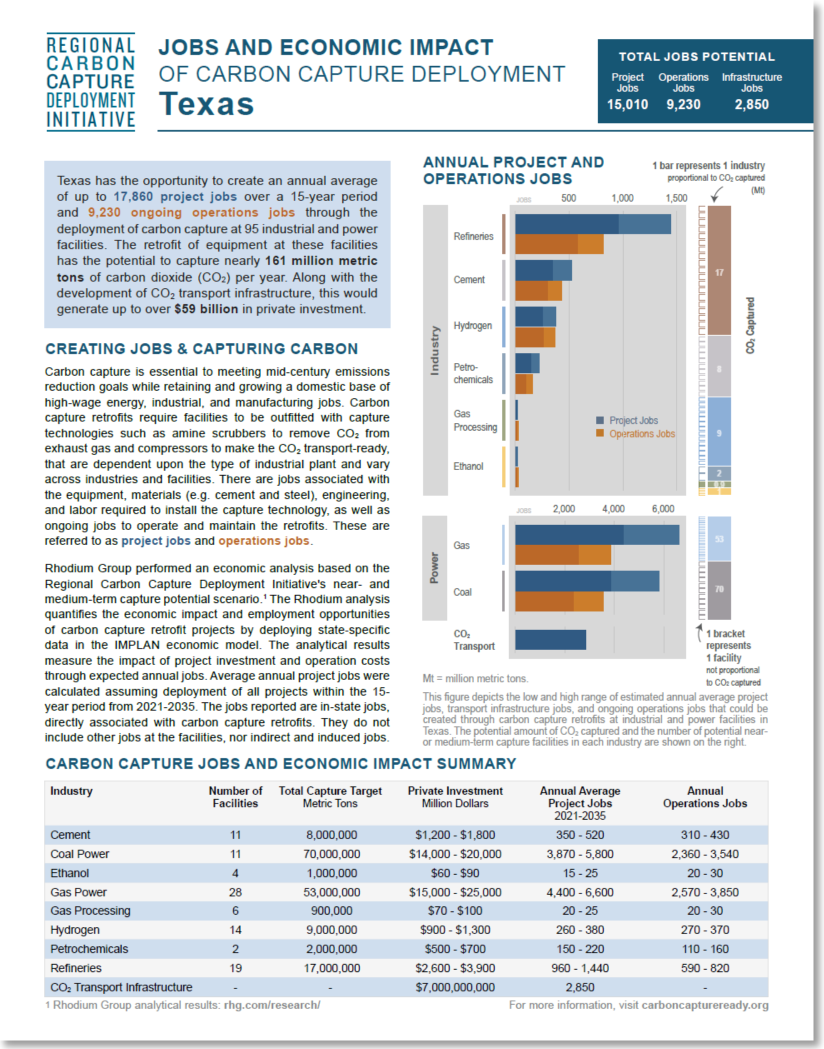
State MOU for CO_2 Transport Infrastructure

- **Seeks** to accelerate, through state leadership and coordination, the deployment of common regional CO_2 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 CO_2 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 CO_2 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


REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

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 (CO_2) per year. Along with the development of CO_2 transport infrastructure, this would generate up to over **$59 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 CO_2 from exhaust gas and compressors to make the CO_2 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.

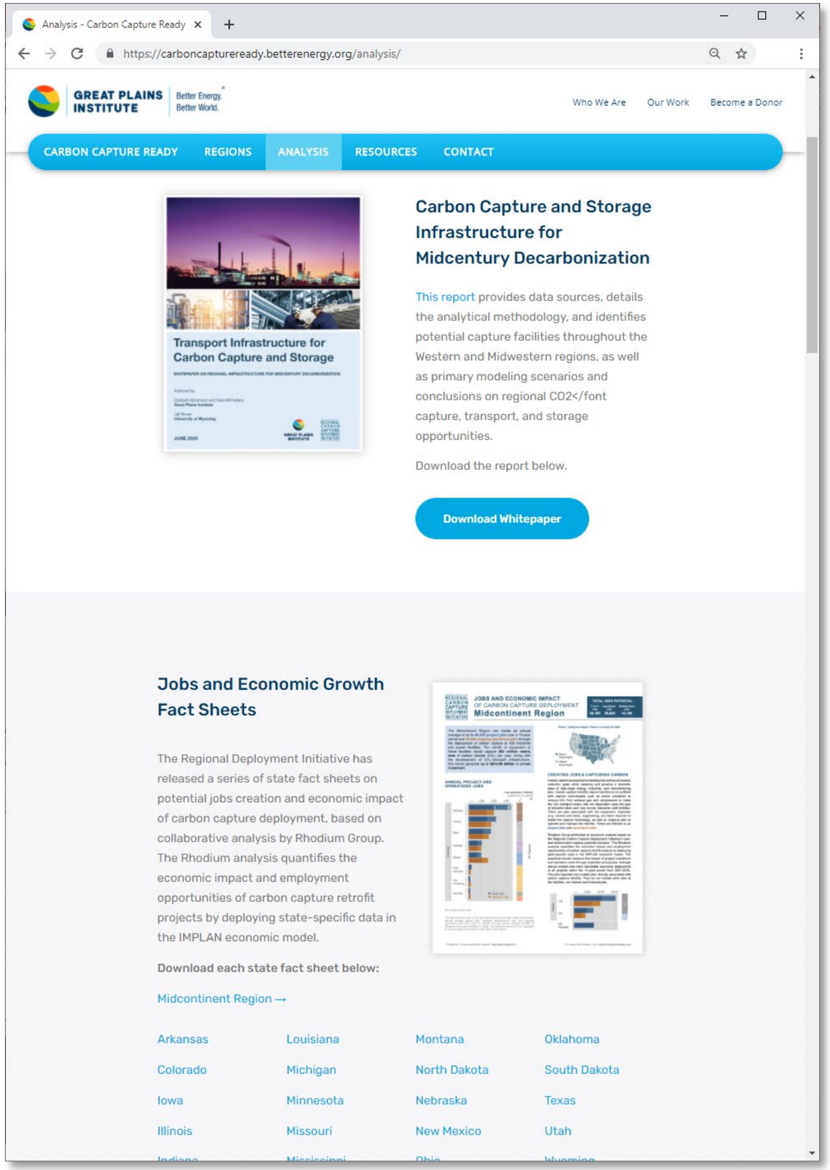
This figure depicts the low and high range of estimated annual average project jobs, transport infrastructure jobs, and ongoing operations jobs that could be created through carbon capture retrofits at industrial and power facilities in Texas. The potential amount of CO_2 captured and the number of facilities with 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

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

Thank You

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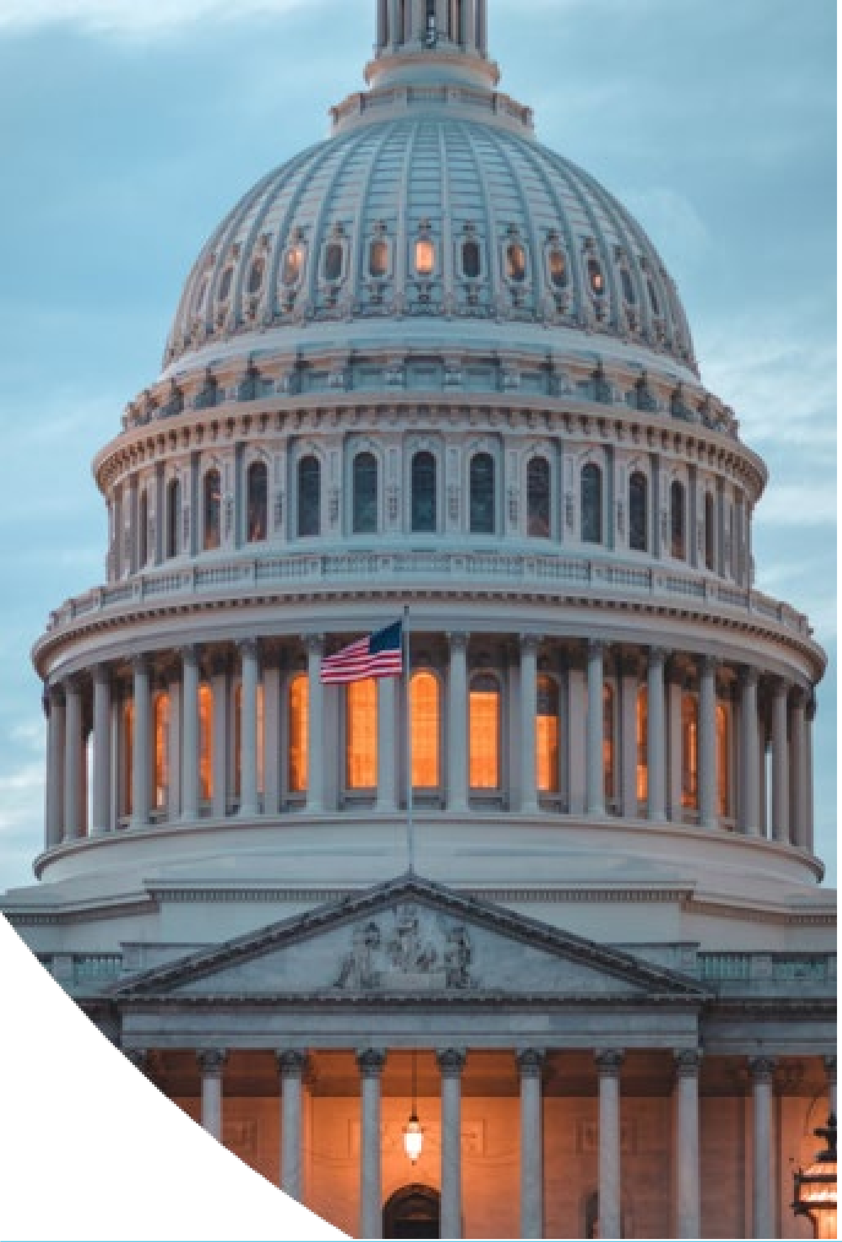
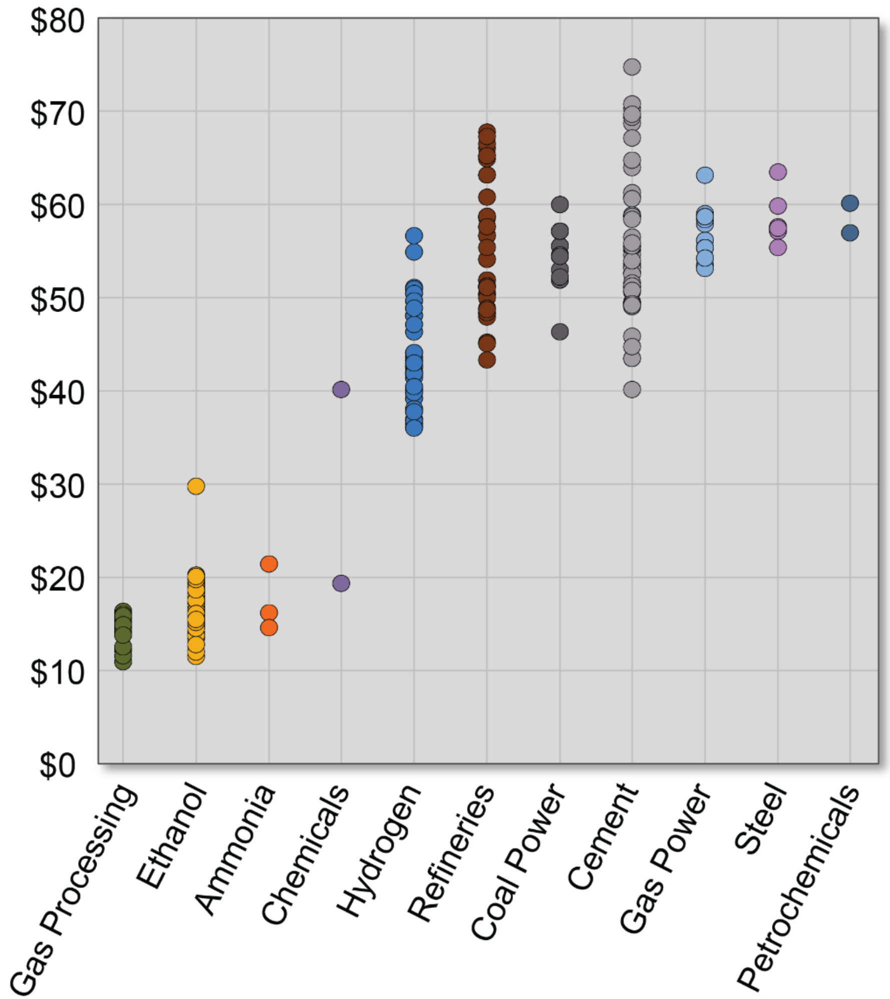
Appendix



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

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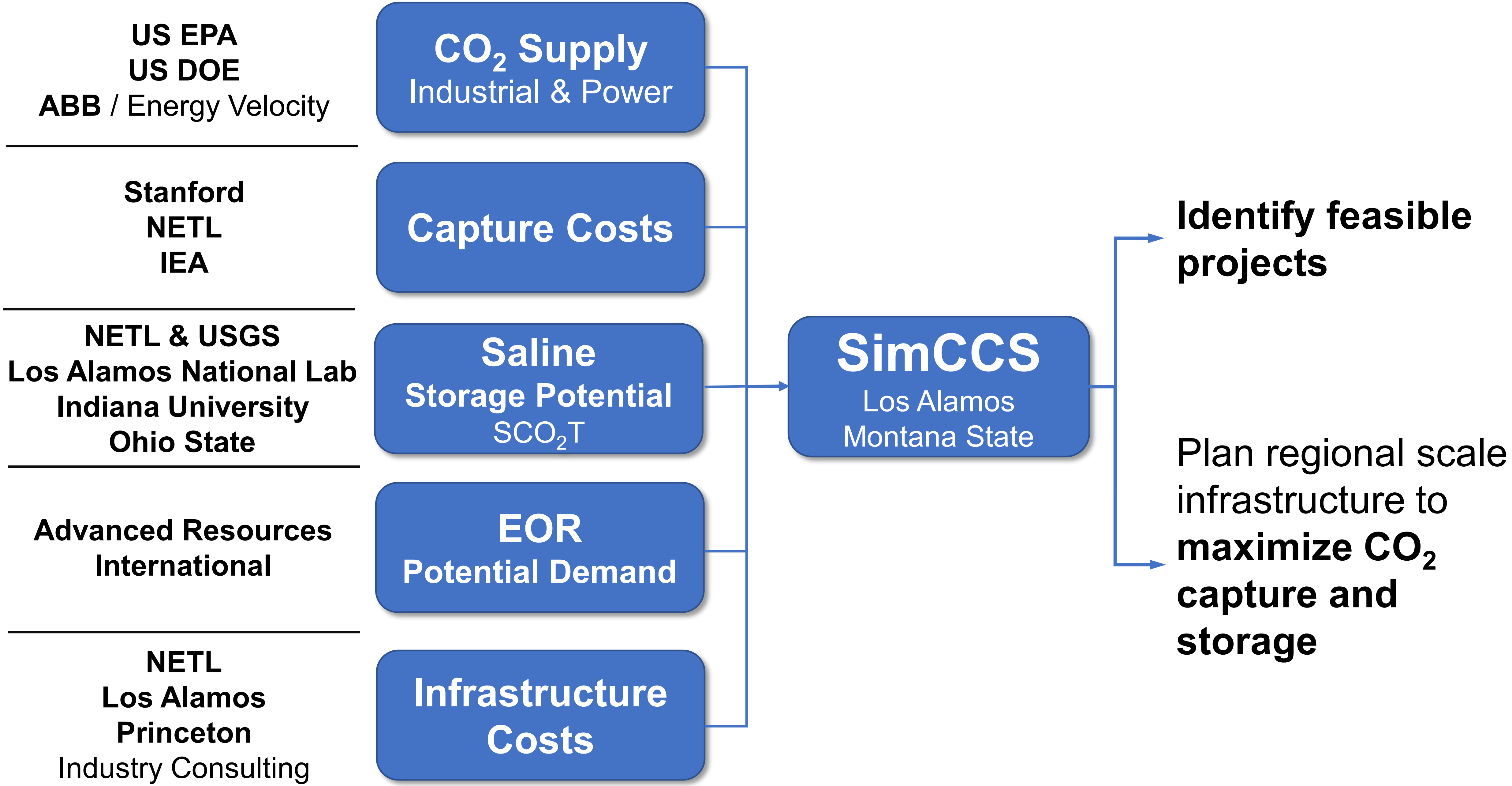

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US DOE
ABB / Energy Velocity
Stanford
NETL
IEA
NETL & USGS
Los Alamos National Lab
Indiana University
Ohio State
Advanced Resources International
NETL
Los Alamos
Princeton
Industry Consulting
CO_2 Supply
Industrial & Power
Capture Costs
Saline
Storage Potential
SCO_2T
EOR
Potential Demand
Infrastructure Costs
SimCCS
Los Alamos
Montana State
Identify feasible projects
Plan regional scale infrastructure to maximize CO_2 capture and storage