
**REGIONAL
CARBON
CAPTURE
DEPLOYMENT
INITIATIVE**

Regional CO₂ Transport Infrastructure for US Midcentury Decarbonization

Dane McFarlane
Director of Research
Great Plains Institute
July 20, 2020

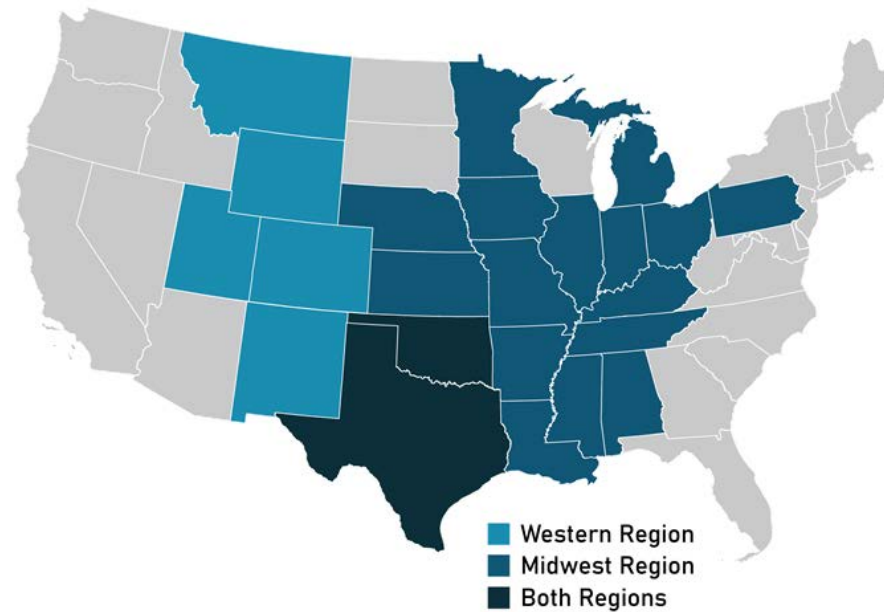


**GREAT PLAINS
INSTITUTE**

Facilitated by GPI:

**STATE
CARBON
CAPTURE
WORK
GROUP**

**REGIONAL
CARBON
CAPTURE
DEPLOYMENT
INITIATIVE**



State Participation in the Regional Deployment Initiative

State & Regional Efforts on Carbon Capture

STATE
CARBON
CAPTURE
WORK
GROUP

State Carbon Capture Work Group led by **Gov. Mead (WY)** and **Gov. Bullock (MT)**.

Work Group publishes additional papers on CO₂ transport infrastructure, electricity market issues and opportunities for carbon capture and ethanol.

Regional stakeholders across 25 states meet to evaluate initial analysis and begin to identify near-to medium-term opportunities for deployment.

Carbon Capture Ready website launched, providing states and stakeholders with best practices and other state-specific information relating to carbon capture.

2015

2016

2017

Early 2018

Fall 2018

2019

Winter 2019

2020

Work Group, comprised of **more than a dozen states**, develops comprehensive policy recommendations on carbon capture.

Work Group shifts from learning to action and launches **Regional Carbon Capture Deployment Initiatives in Midwest and Western regions**.

RDI work broadens to focus **on state policies and other regional efforts that can help close the “cost cap”** for carbon capture deployment.

Analytical white paper is published. RDI is working with states to prepare for **2021 legislative session**.

States are also cooperating on **regional CO₂ transport infrastructure and hub development**.

Analytical research initiated.

REGIONAL
CARBON
CAPTURE
DEPLOYMENT
INITIATIVE





CARBON CAPTURE COALITION

Unprecedented National Coalition in U.S. Energy & Climate Policy

*Achieve economywide deployment of carbon capture to reduce emissions,
foster domestic energy and industrial production, and support high-wage jobs.*

Climate, jobs and energy/industrial benefits
unite diverse interests in a common purpose

Over 75 members, including industry, labor
and environmental NGOs



To learn more and view our
complete membership list, visit
www.carboncapturecoalition.org

Participants

- Accelergy
- AFL-CIO
- Air Liquide
- Air Products
- AK Steel
- American Carbon Registry
- ArcelorMittal
- Arch Coal
- Archer Daniels Midland Co.
- Baker Hughes, a GE Company
- Bipartisan Policy Center
- Capital Power
- Carbon180
- Carbon Wrangler LLC
- Center for Climate and Energy Solutions
- Citizens for Responsible Energy Solutions Forum
- Clean Air Task Force
- ClearPath Foundation
- Cloud Peak Energy
- Conestoga Energy Partners
- Core Energy LLC
- DTE Energy
- EBR Development LLC
- EnergyBlue Project
- Energy Innovation Reform Project
- Glenrock Petroleum
- Great River Energy
- Greene Street Capital
- Impact Natural Resources LLC
- ION Engineering LLC
- International Brotherhood of Boilermakers
- International Brotherhood of Electrical Workers
- Jackson Hole Center for Global Affairs
- Jupiter Oxygen Corporation
- Lake Charles Methanol
- LanzaTech
- Linde LLC
- Mitsubishi Heavy Industries America, Inc.
- National Audubon Society
- National Farmers Union
- National Wildlife Federation
- NET Power
- New Steel International, Inc.
- NRG Energy
- Occidental Petroleum Corporation
- Pacific Ethanol
- Peabody
- Prairie State Generating Company
- Praxair Inc.
- Shell
- SMART Transportation Division (of the Sheet, Metal, Air, Rail and Transportation Workers)
- Summit Power Group
- Svante
- Tenaska Energy
- The Nature Conservancy
- Third Way
- Thunderbolt Clean Energy LLC
- United Mine workers of America
- United Steel Workers
- Utility Workers Union of America
- White Energy
- Wyoming Outdoor Council


Observers

- Algae Biomass Organization
- Biomass Power Association
- Carbon Engineering
- Carbon Utilization Research Council
- Chart Industries
- Cornerpost CO2 LLC
- Enhanced Oil Recovery Institute, University of Wyoming
- Environmental Defense Fund
- Growth Energy
- Institute of Clean Air Companies
- Melzer Consulting
- Renewable Fuels Association
- Tellus Operating Group
- World Resources Institute



Regional Deployment Initiative Analytical Report

Published June 30, 2020




Transport Infrastructure for Carbon Capture and Storage


WHITEPAPER ON REGIONAL INFRASTRUCTURE FOR MIDCENTURY DECARBONIZATION

Authored by
Elizabeth Abramson and Dane McFarlane
Great Plains Institute

Jeff Brown
University of Wyoming



GREAT PLAINS
INSTITUTE



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, the 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. The Argonne National Laboratory's GeoCCO 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"	8"	12"	16"	20"	24"	30"
Length (miles)	4,712	6,363	8,563	8,824	2,275	1,700	59

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 452 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 U.S. 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 U.S.

networks for economy-wide deployment of carbon capture and storage. By midcentury, local, regional, 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 interstate CO₂ transportation corridors, interconnected pipeline networks owned or shared by multiple private entities, and state and federal support for future-proofing pipeline capacity through "open-siding" 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.

Download the paper at:

carboncaptureready.org/analysis



GREAT PLAINS
INSTITUTE

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

Primary Partners:

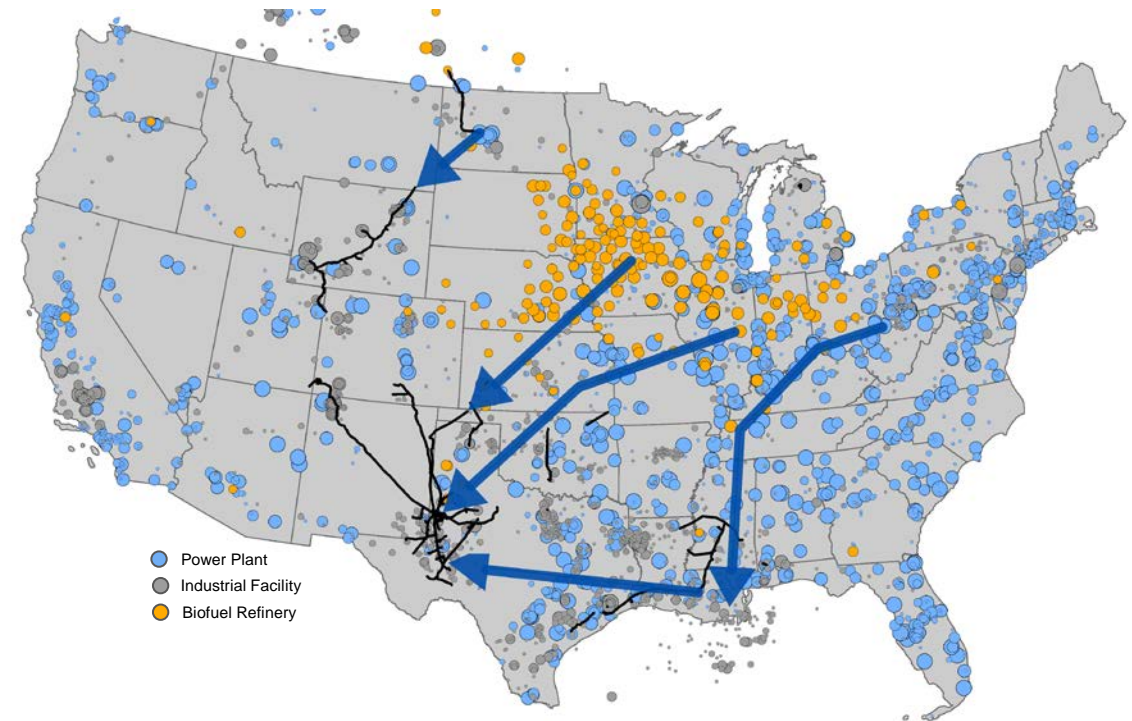


INDIANA UNIVERSITY



Stanford University

Initial CO₂ Corridor Scoping



GREAT PLAINS INSTITUTE

CO₂ Capture Opportunities: Industrial and Power Facilities

Section 45Q Tax Credit for CO₂ Storage

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

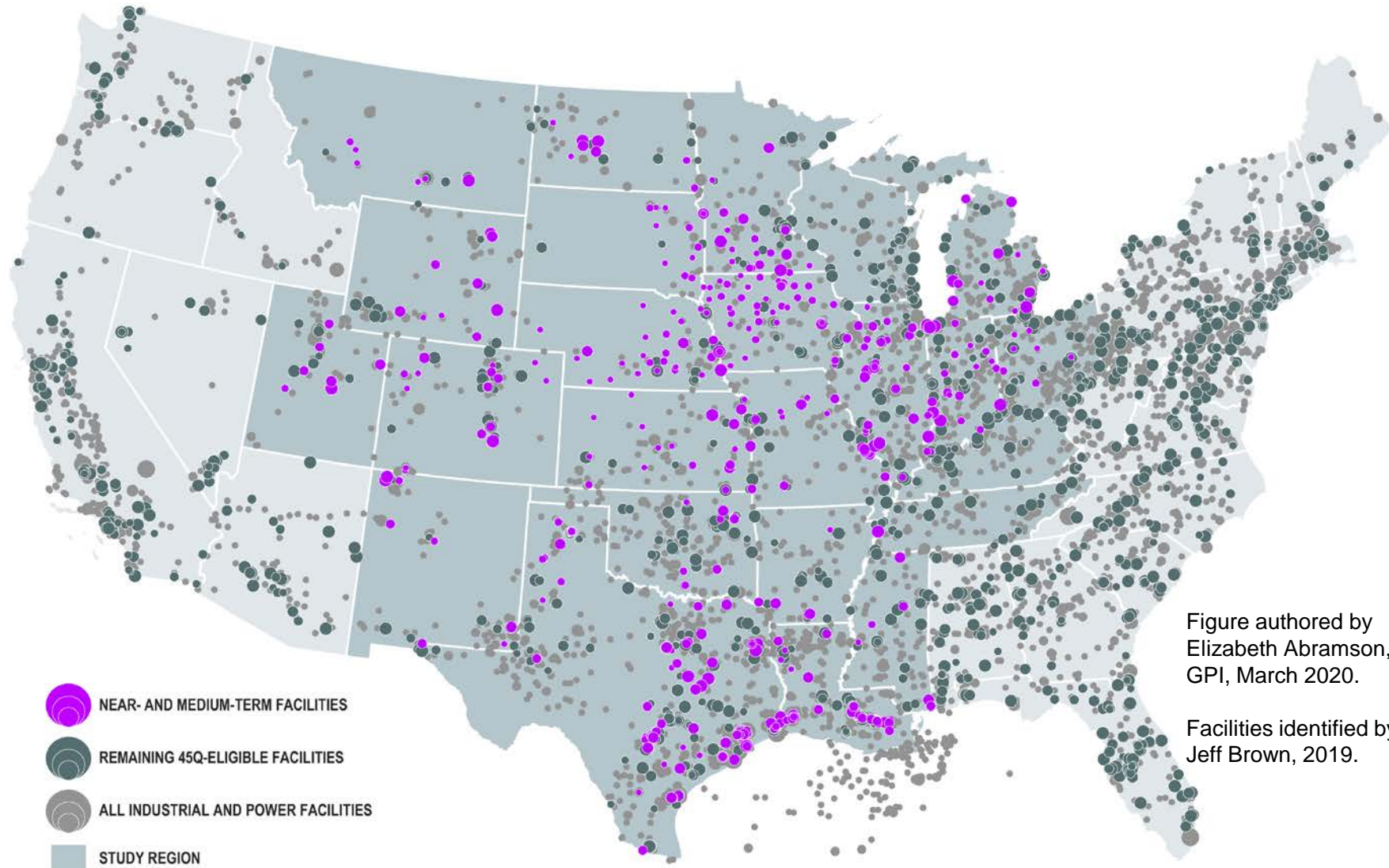


Figure authored by
Elizabeth Abramson,
GPI, March 2020.

Facilities identified by
Jeff Brown, 2019.



**GREAT PLAINS
INSTITUTE**

CO₂ Storage in Saline Formations & Petroleum Basins

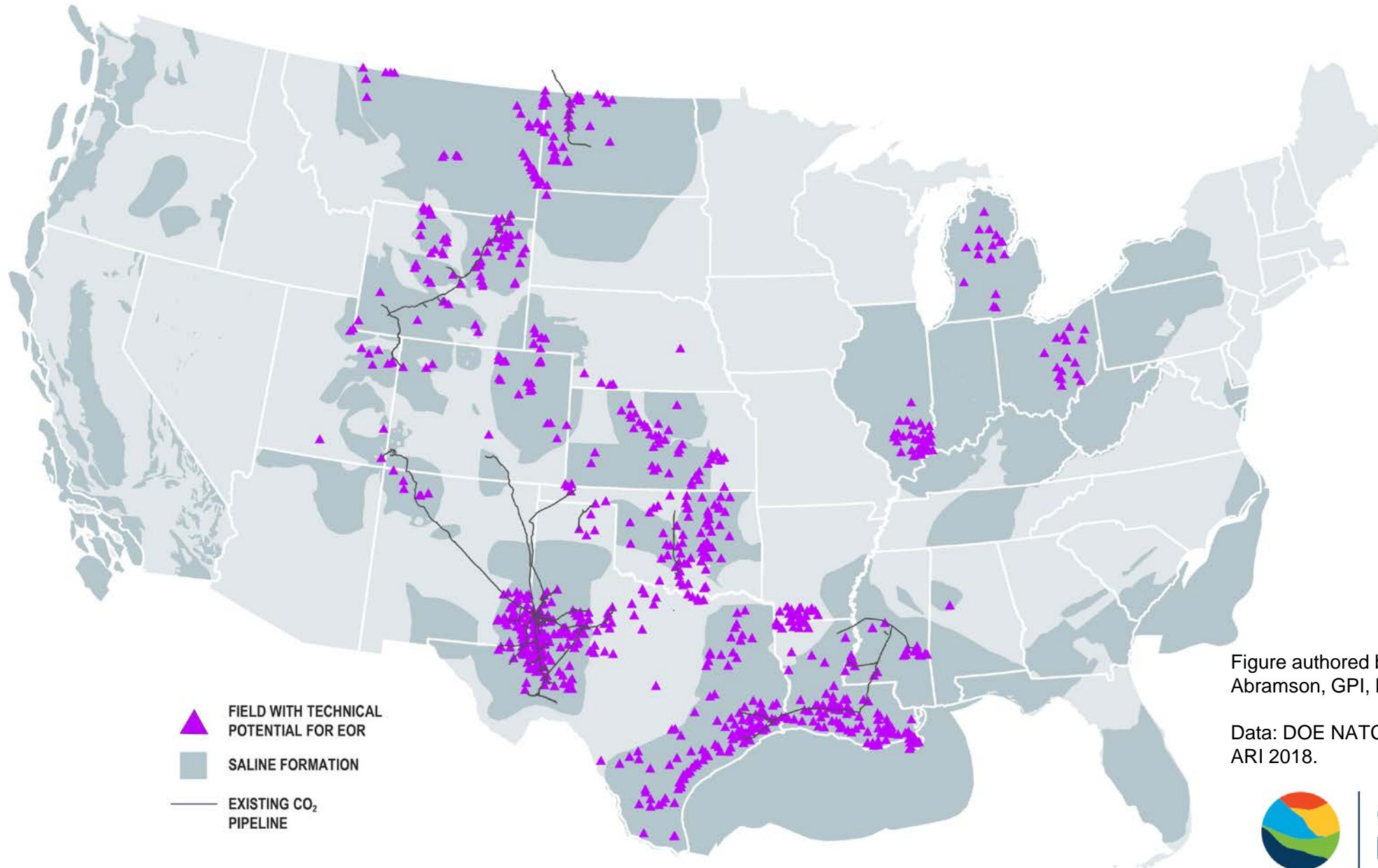


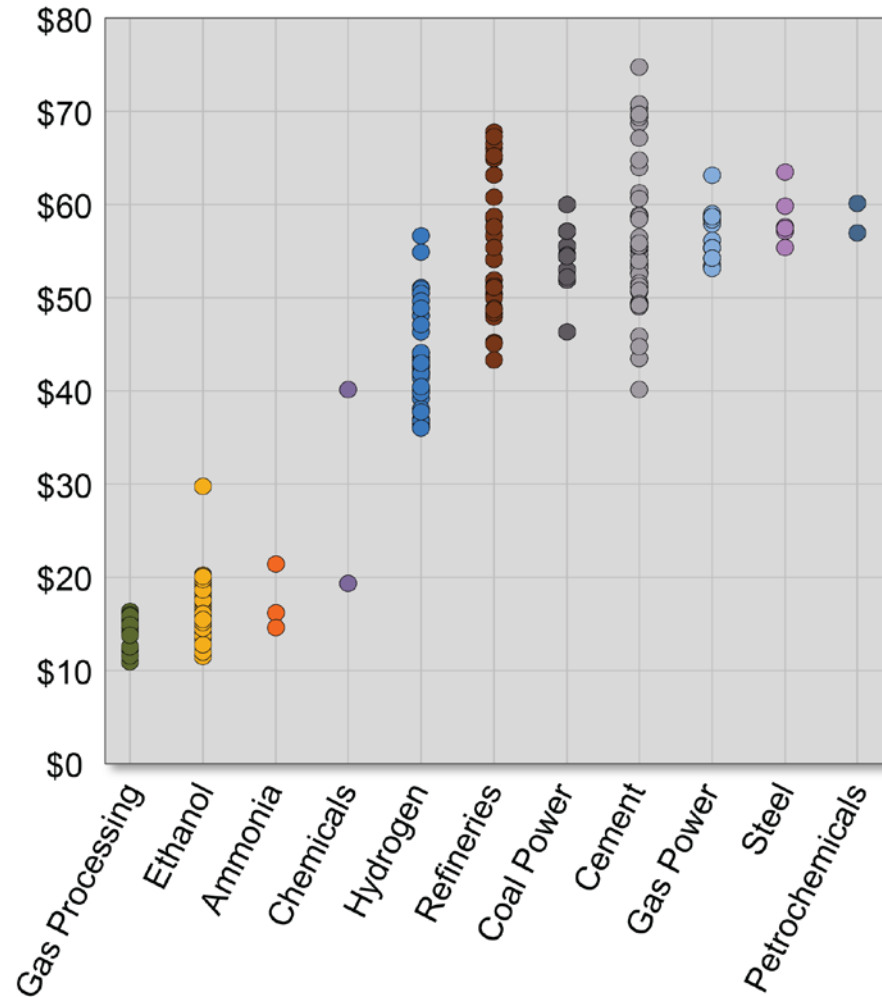
Figure authored by Elizabeth Abramson, GPI, March 2020

Data: DOE NATCARB 2016; ARI 2018.



**GREAT PLAINS
INSTITUTE**

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



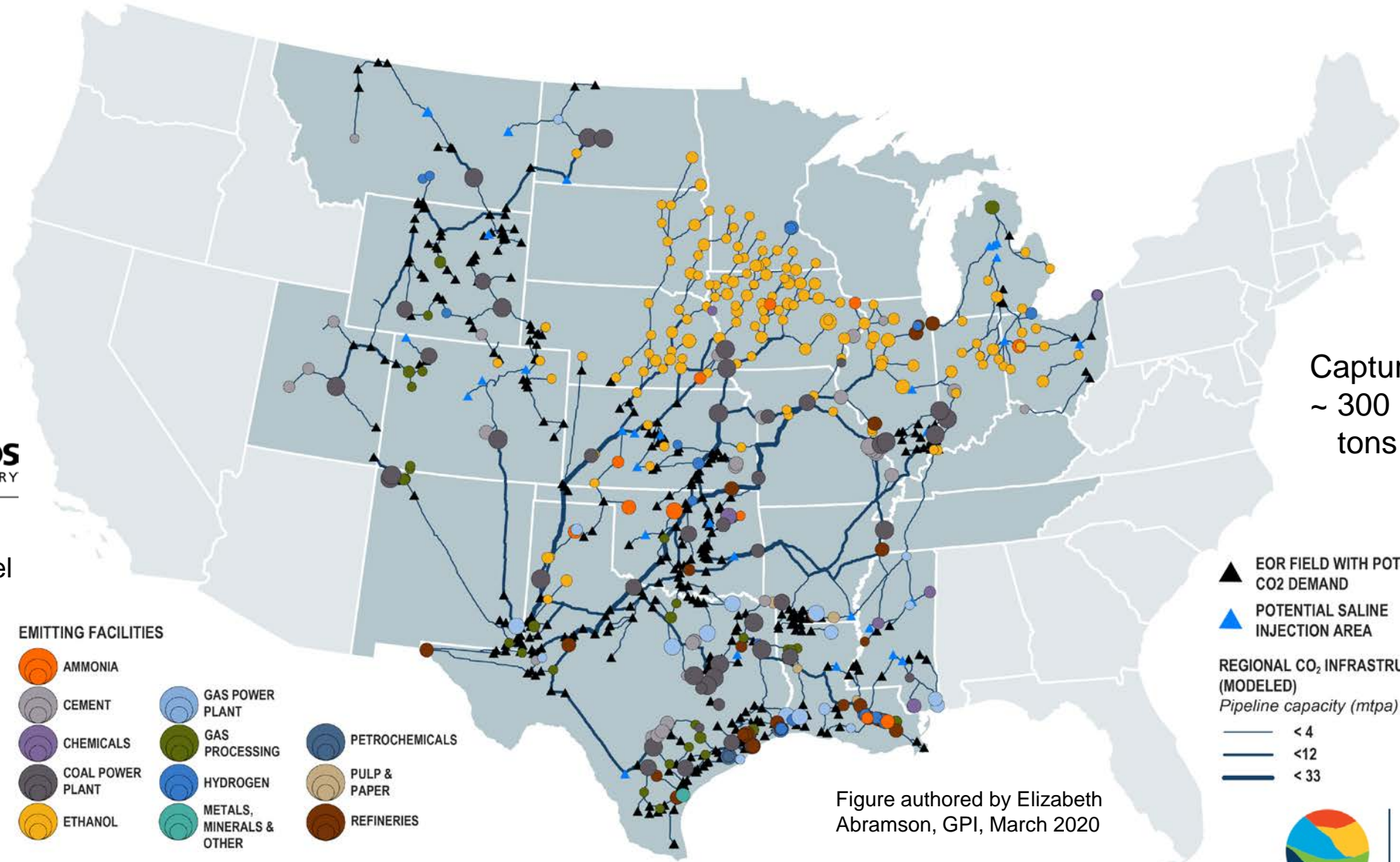
Industry	# of Facilities	Optimized Capture (mmt/year)	Average Estimated Cost \$/ton
Ethanol	150	50.6	\$17
Cement	45	32.7	\$56
Refineries	38	26.5	\$56
Steel	6	14.6	\$59
Hydrogen	34	14.4	\$44
Gas Processing	20	4.5	\$14
Petrochemicals	2	1.7	\$59
Ammonia	3	0.9	\$17
Chemicals	2	0.7	\$30
Coal Power Plant	58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

Source: Jeff Brown, 2019



**GREAT PLAINS
INSTITUTE**

Near- and Medium-Term Scenario: Optimized transport network for CO₂ capture and storage under 45Q



Capture and storage:
~ 300 million metric
tons per year



SimCCS CO₂
transport model

EMITTING FACILITIES

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

- ▲ EOR FIELD WITH POTENTIAL CO₂ DEMAND
- ▲ POTENTIAL SALINE INJECTION AREA

REGIONAL CO₂ INFRASTRUCTURE (MODELED)

Pipeline capacity (mtpa)

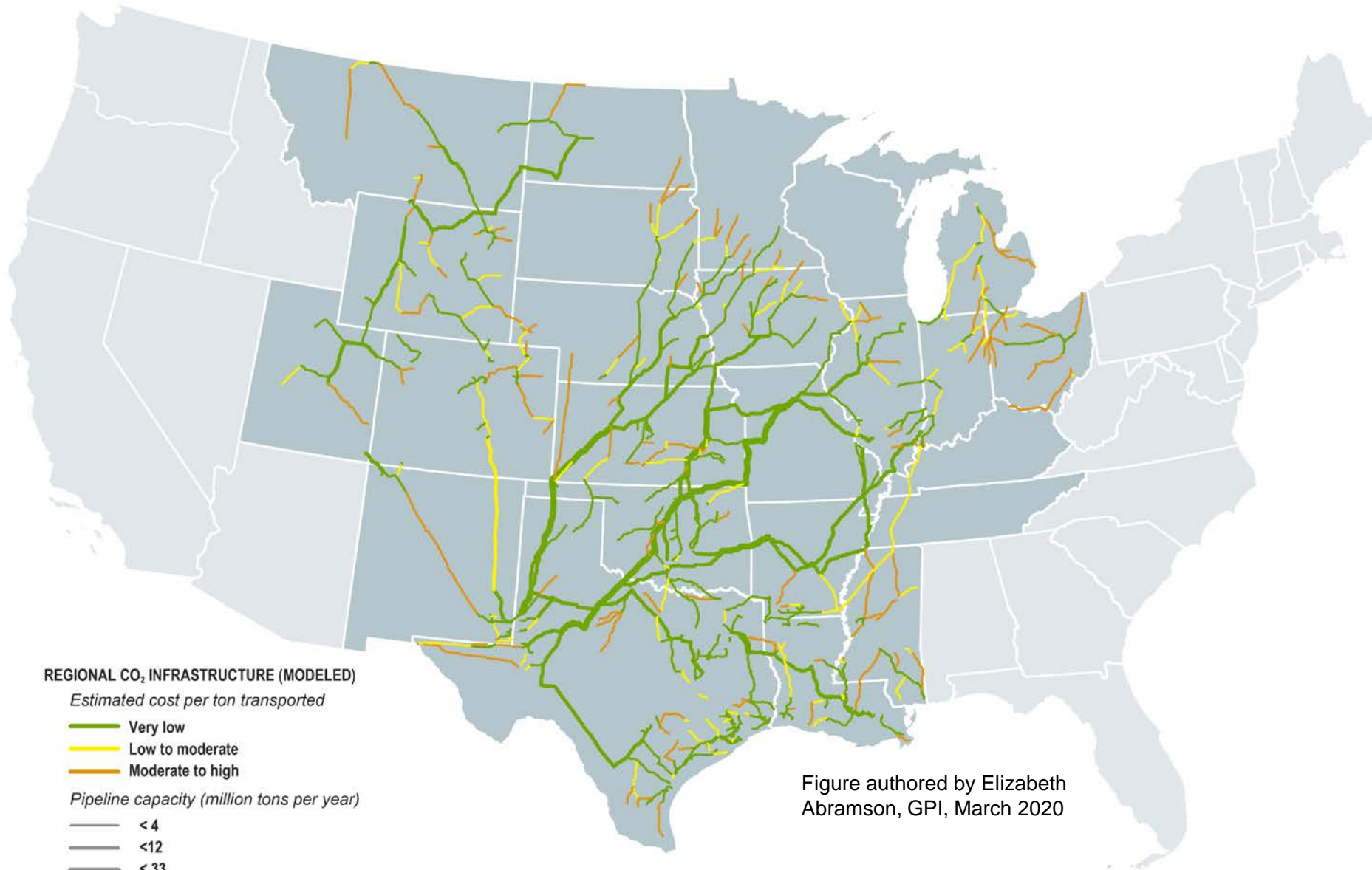
- < 4
- < 12
- < 33

Figure authored by Elizabeth Abramson, GPI, March 2020



**GREAT PLAINS
INSTITUTE**

Near- and Medium-Term Scenario: Relative transport cost of network segments



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



Shared CO₂ Transport Infrastructure: Beneficial Economies of Scale

Higher capacity achieves lower costs per ton

Infrastructure investment by capacity \$ per inch-mile

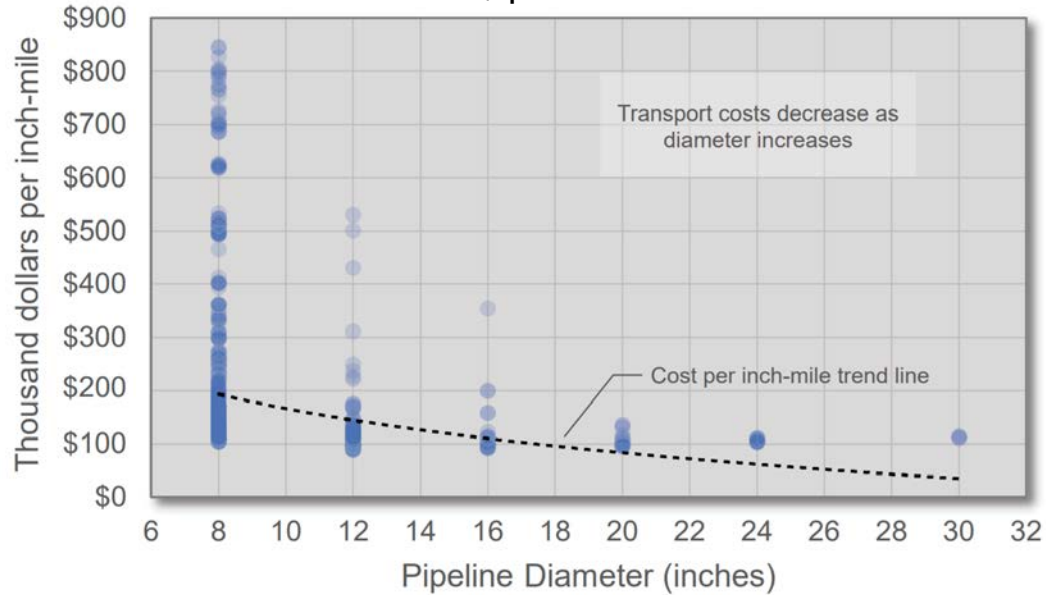


Figure authored by GPI based on calculations performed using the NETL CO₂ Transport Cost Model.

Transport tariff by capacity \$ per ton

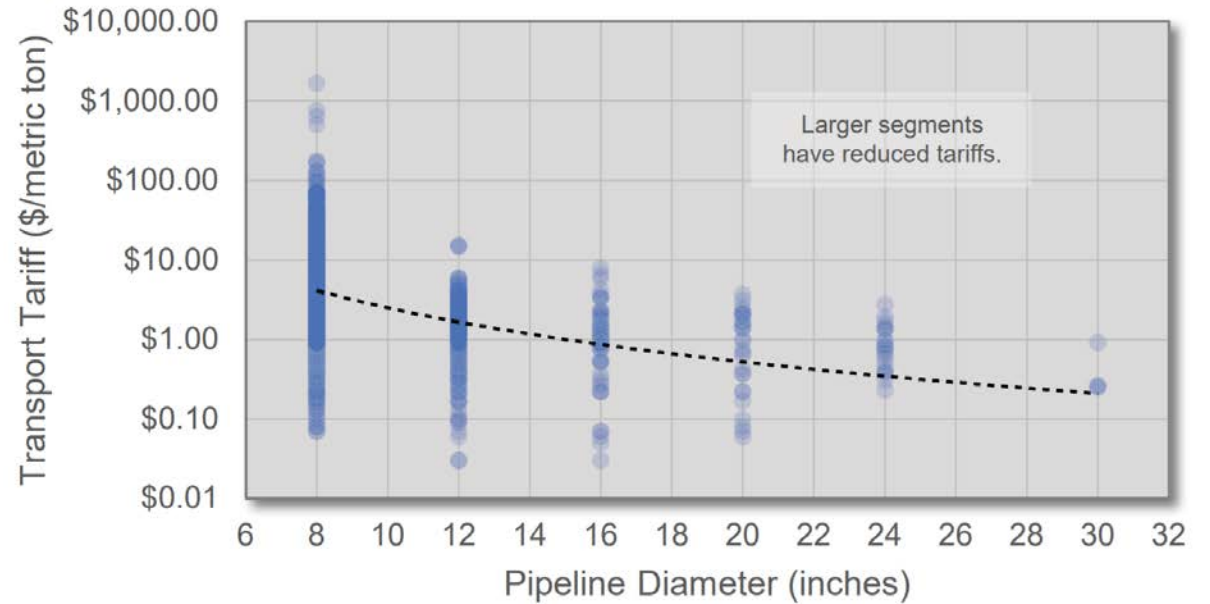


Figure authored by GPI based on calculations performed using the NETL CO₂ Transport Cost Model, as modified by McFarlane, Dubois, and Edwards, 2018.

Investment by owner/operator



Cost to user/customer

Calculated with:



CO₂ Transport Cost Model



GREAT PLAINS INSTITUTE

Midcentury: Long-term Economy-Wide Deployment

Expanded storage in saline formations and petroleum basins

Capture and storage:
~ 670 million metric
tons per year

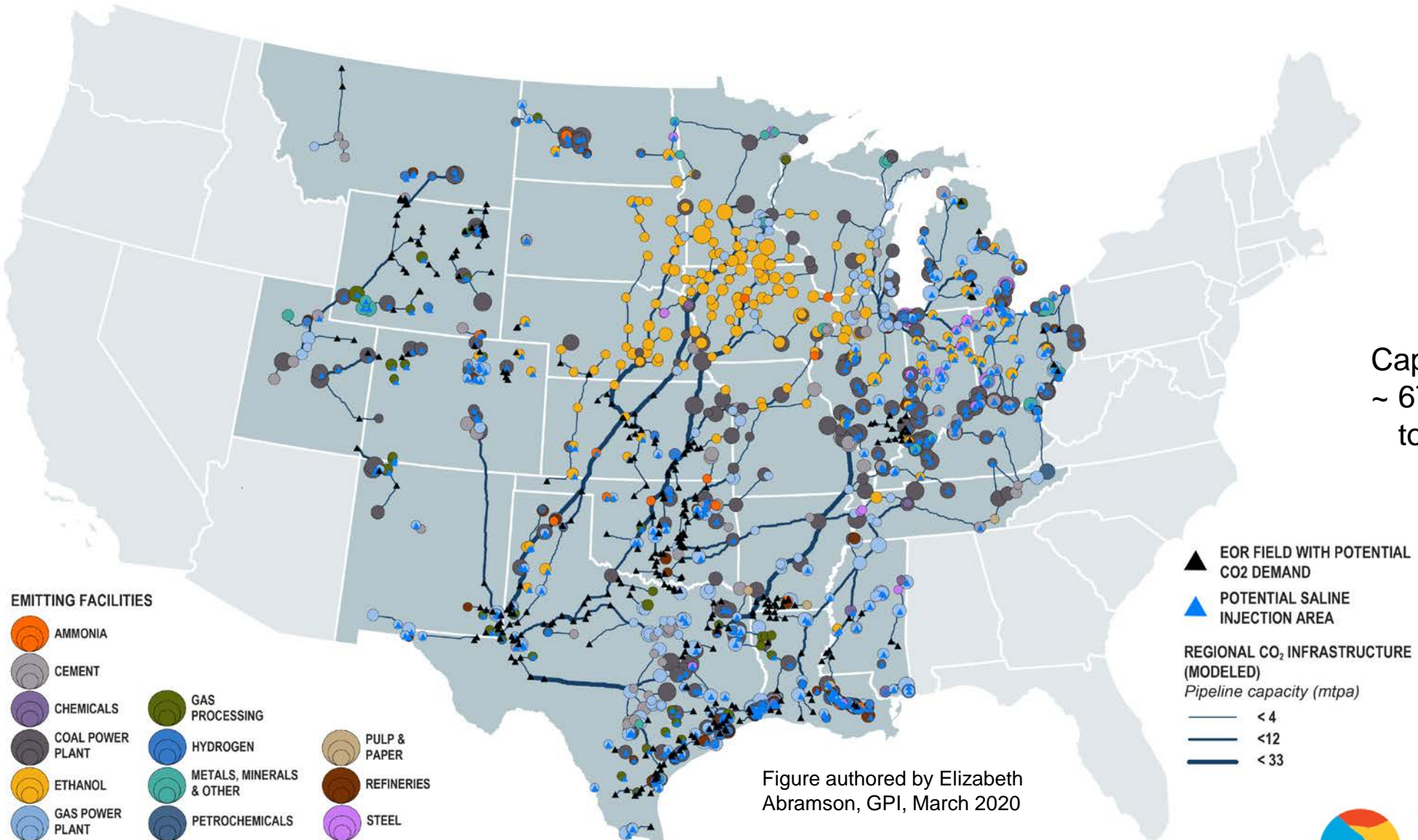


Figure authored by Elizabeth Abramson, GPI, March 2020



Planning for Near-Term versus 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
Near- and Medium-Term	281 million metric tons	29,710 miles	\$16.6 billion	\$14.3 billion	\$252 million
Midcentury	669 million metric tons	29,922 miles	\$19.3 billion	\$15.3 billion	\$254 million
Midcentury scenario increase over Near- and Medium-Term scenario	x 2.38 more CO ₂ stored	+0.7%	16.3%	7.0%	0.8%



Analytical Report

Published June 30, 2020




Transport Infrastructure for Carbon Capture and Storage


WHITEPAPER ON REGIONAL INFRASTRUCTURE FOR MIDCENTURY DECARBONIZATION

Authored by
Elizabeth Abramson and Dane McFarlane
Great Plains Institute

Jeff Brown
University of Wyoming



GREAT PLAINS INSTITUTE



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, the 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 SINO2 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.

and international temperature targets, shared regional CO₂ transport infrastructure will minimize investment requirements, transport costs, and land use. Los Alamos National Laboratory's SINO2 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




Figure 8 shows the optimized network for the full CO₂ model.

Diameter	4"	8"	12"	16"	20"	24"	30"
Length (miles)	4,712	6,363	8,560	8,824	2,275	1,700	59

The difference in built-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 compared with the value of tax credits in the current 452 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 U.S. 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 U.S.

networks for economy-wide deployment of carbon capture and storage. By midcentury, local, regional, 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 interstate CO₂ transportation corridors, interconnected pipeline networks owned 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.

10

38

Download the paper at:

carboncaptureready.org/analysis



GREAT PLAINS INSTITUTE

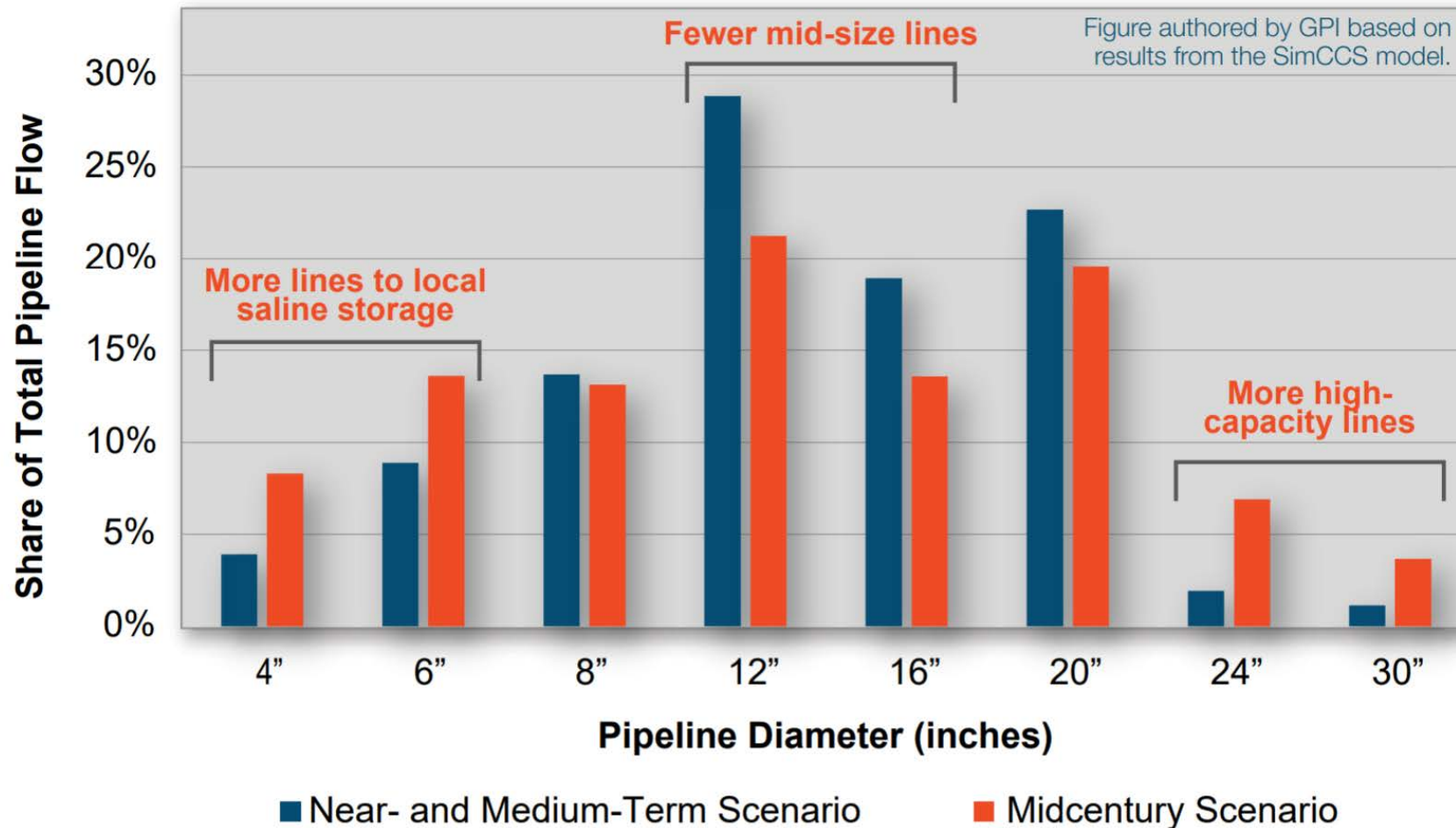
End of presentation.

Appendix: Additional slides below.

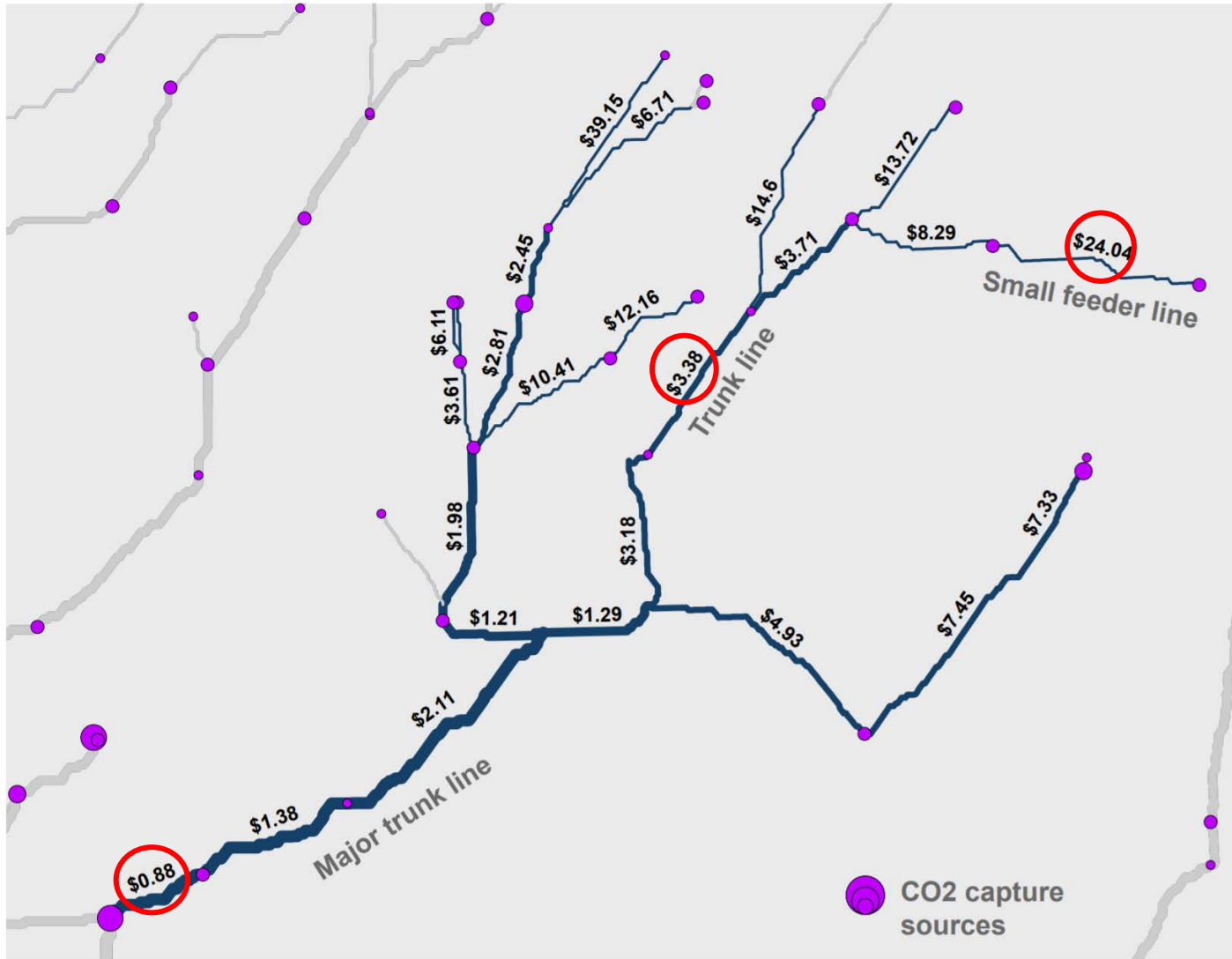


Achieving lower costs through shared high capacity infrastructure

Type of infrastructure built in each scenario



Shared CO₂ Transport Infrastructure: Beneficial Economies of Scale



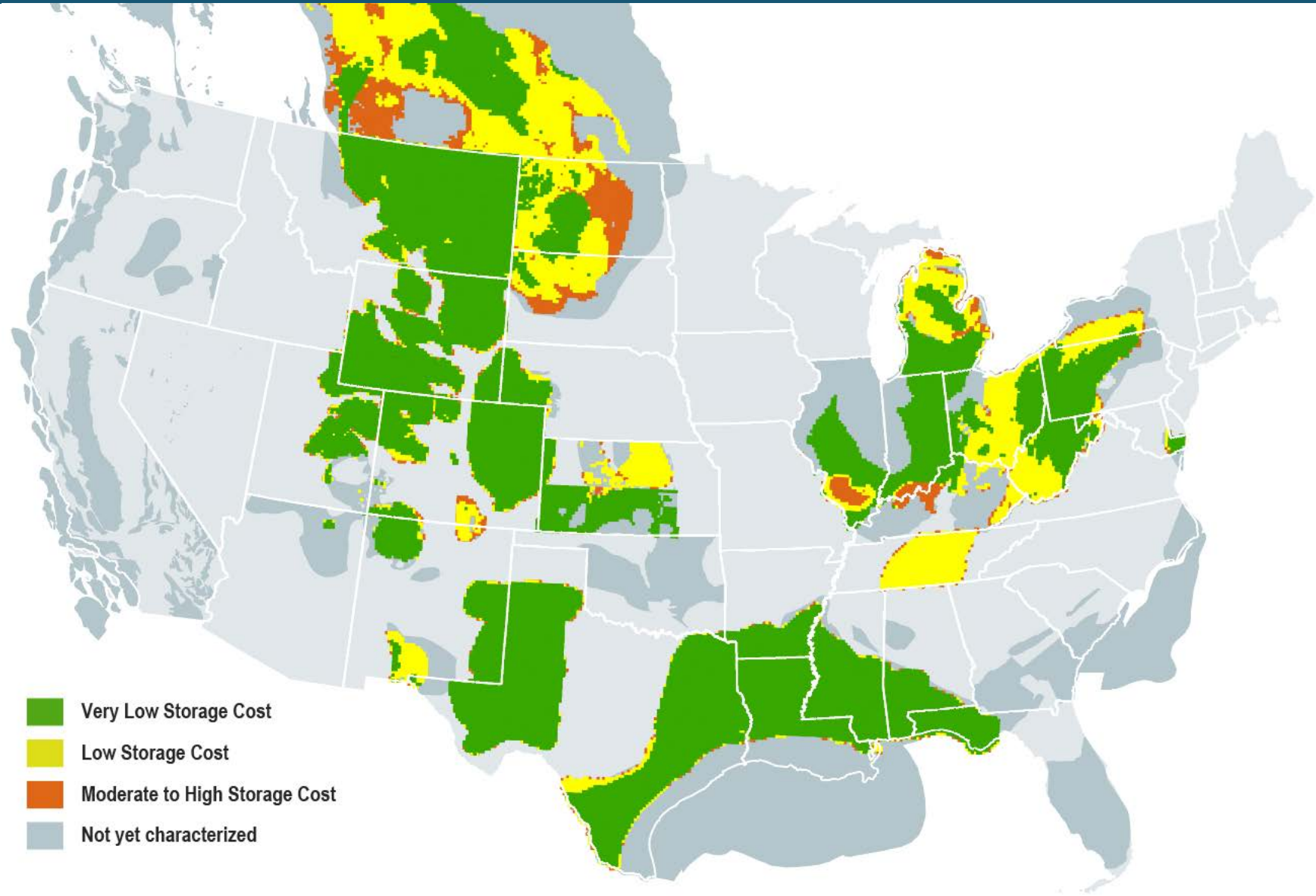
Small feeder lines have a higher per-ton cost because they deliver less CO₂.

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.

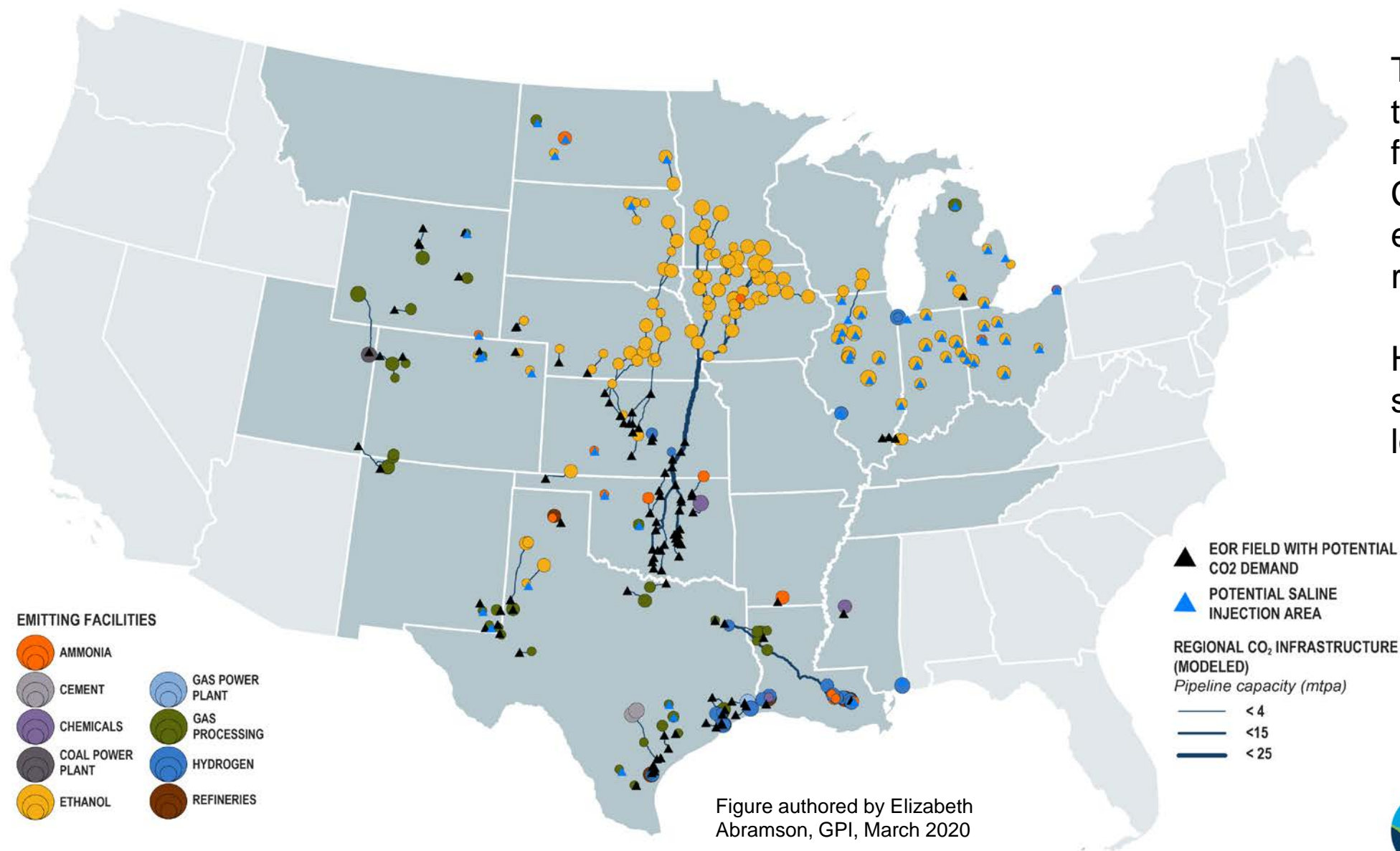
SCO₂T Model: Nation-wide geologic storage potential



INDIANA UNIVERSITY



Sensitivity Analysis: High-cost sensitivity with economic break-even required



Transport segments that essentially “pay for themselves”.
Capital investment easily paid for by revenue.

High-purity industrial sources choose local saline storage.

Figure authored by Elizabeth Abramson, GPI, March 2020

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**



GREAT PLAINS INSTITUTE