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Accelerating Economywide Carbon Capture Deployment to Meet Midcentury Climate Goals

Presentation to Fargo-Morehead CLEAN

March 24, 2020

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Great Plains Institute
Ashley, North Dakota

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.*

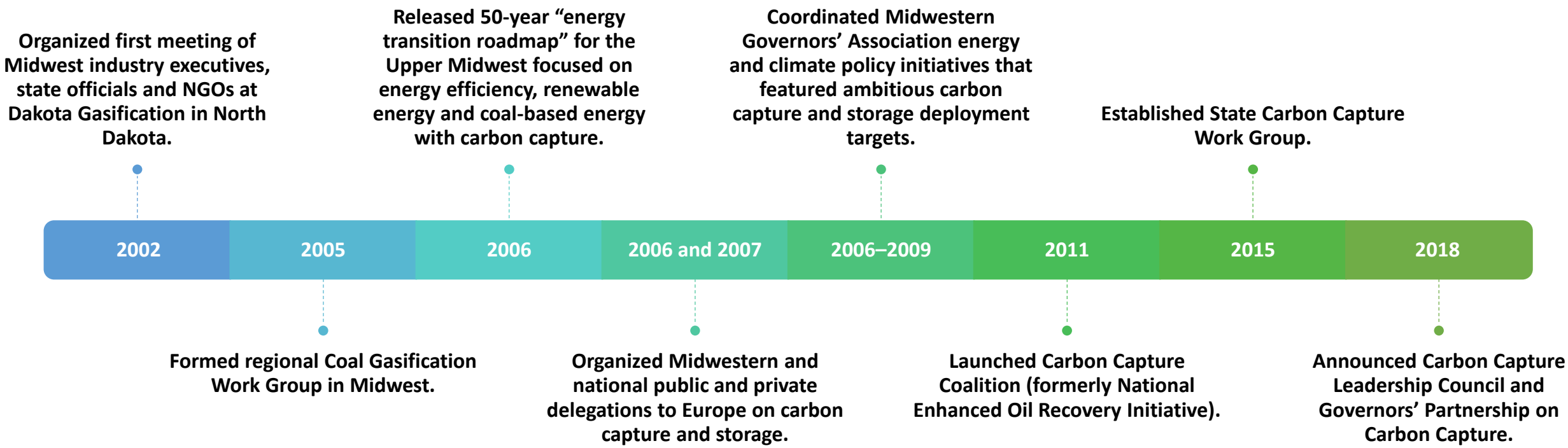
Objectives

- *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.***

Great Plains Institute: Nearly Two Decades Working on Carbon Capture, Transport, Use & Storage



1972: Val Verde Gas Processing Plants in Texas

1982: Koch Nitrogen Company Enid Fertilizer Plant in Oklahoma

1986: Exxon Shute Creek Gas Processing Facility in Wyoming

2000: Dakota Gasification's Great Plains Synfuels Coal Gasification Plant in North Dakota

2003: Core Energy/South Chester Gas Processing Plant in Michigan

2009: Chaparral/Conestoga Energy Partners' Arkalon Bioethanol Plant in Kansas

2010: Occidental Petroleum's Century gas processing plant in Texas

2012: Air Products Port Arthur Refinery Hydrogen Production in Texas

2012: Conestoga Energy Partners/PetroSantander Bonanza Bioethanol Plant in Kansas

2013: ConocoPhillips Lost Cabin Gas Processing Plant in Wyoming

2013: Chaparral/CVR Energy Coffeyville Fertilizer Gasification Plant in Kansas

2014: SaskPower Boundary Dam Coal Power Plant Post-Combustion Capture Retrofit in Saskatchewan

2015: Shell Quest hydrogen production at bitumen upgrader in Alberta

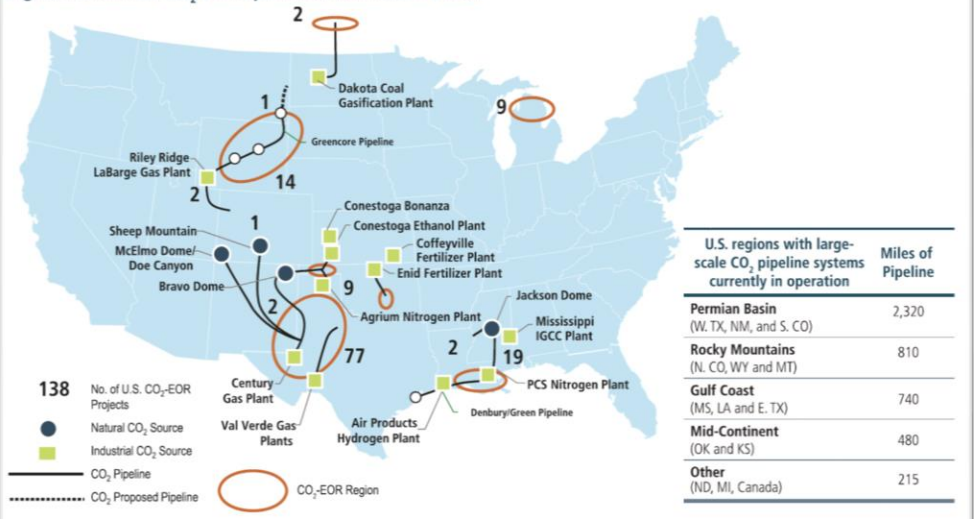
2016: Emirates Steel's Mussafah direct reduction iron plant in the United Arab Emirates

2017: NRG Petra Nova Coal Plant Post-Combustion Retrofit in Texas

2017: Archer Daniels Midland large-scale ethanol capture in Illinois

Carbon Capture Works:
Nearly 50 Years of Large-Scale Commercial Experience

Figure 7-8. Current CO_2-EOR Operations and Infrastructure[112]



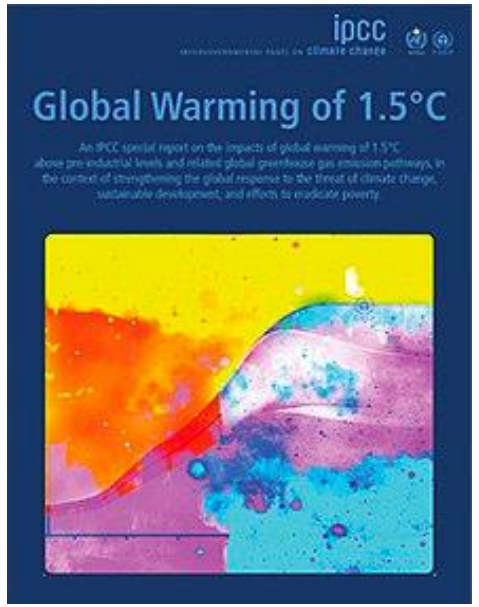
U.S. regions with large-scale CO_2 pipeline systems currently in operation	Miles of Pipeline
Permian Basin (W. TX, NM, and S. CO)	2,320
Rocky Mountains (N. CO, WY and MT)	810
Gulf Coast (MS, LA and E. TX)	740
Mid-Continent (OK and KS)	480
Other (ND, MI, Canada)	215

The current CO_2 pipeline system has been built to deliver CO_2 for CO_2-EOR to oil fields in the Permian Basin of west Texas and eastern New Mexico. This system spans across more than a dozen U.S. states and into Saskatchewan, Canada.

13 commercial-scale U.S. facilities capturing ~25 million metric tons of CO_2 per year.
~5,200 miles of U.S. CO_2 pipeline infrastructure.

Carbon Capture is Not Optional: It is Essential to Meeting Mid-Century Emissions Reduction Goals—and Doing So Affordably

- **IEA modeling of 2° C goal**: Carbon capture achieves 1/5th of reductions by midcentury; nearly half from industrial facilities.
- **IPCC 5th Assessment**: Meeting 2° C goal costs 138% more without carbon capture.



IPCC 1.5 C modeling: Atmospheric CO_2 removal through direct air capture and bioenergy with carbon capture needed—in addition to economywide power plant and industrial capture.

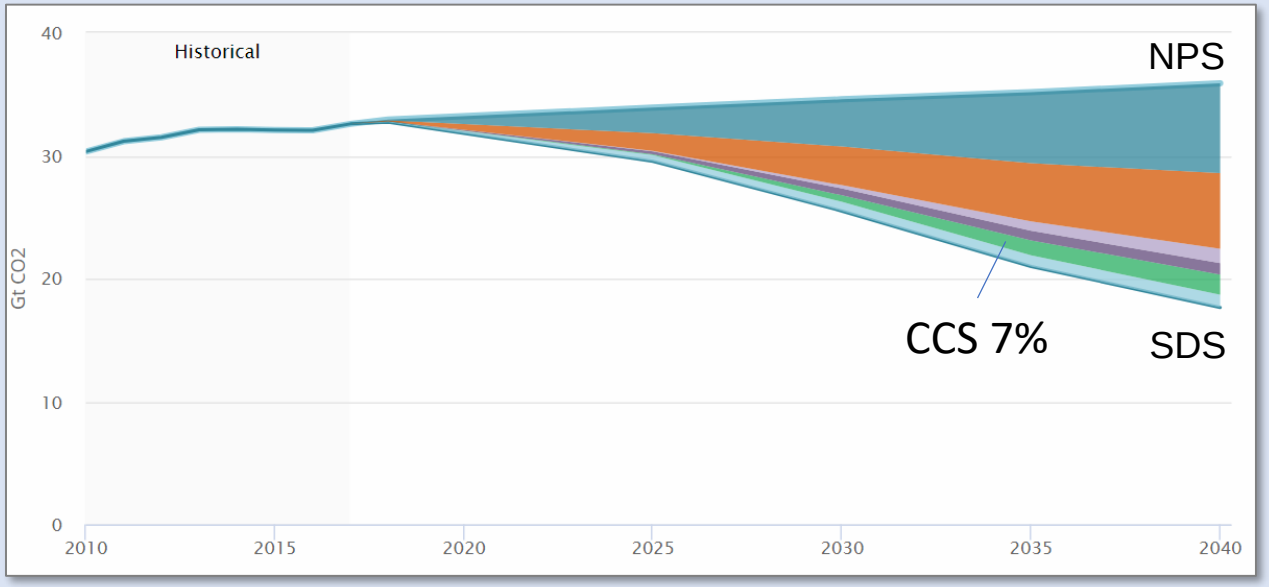
IEA World Energy Outlook Sustainable Development Scenario

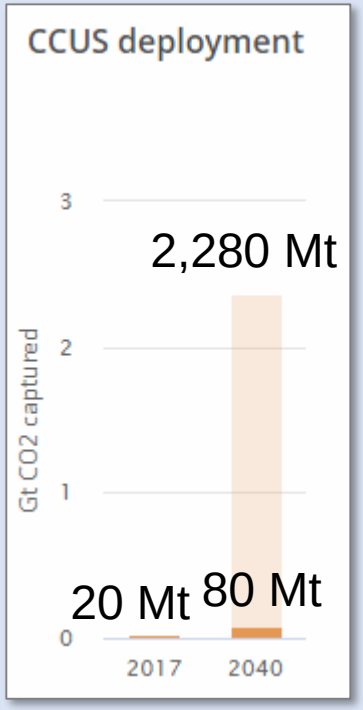
IEA & UN call for *economywide deployment of carbon capture by mid-century*

Carbon capture accounts for 7% of the cumulative global emissions reduction by 2040 and 20% annually by 2050 in the IEA Sustainable Development Scenario (SDS)

"**Rapid scale-up o deployment**, from around 30 million tonnes (MT) of CO2 currently captured each year to **2,300 Mt per year by 2040**."

Increased Emissions (NPS)
vs
Sustainable Development Scenario (SDS)



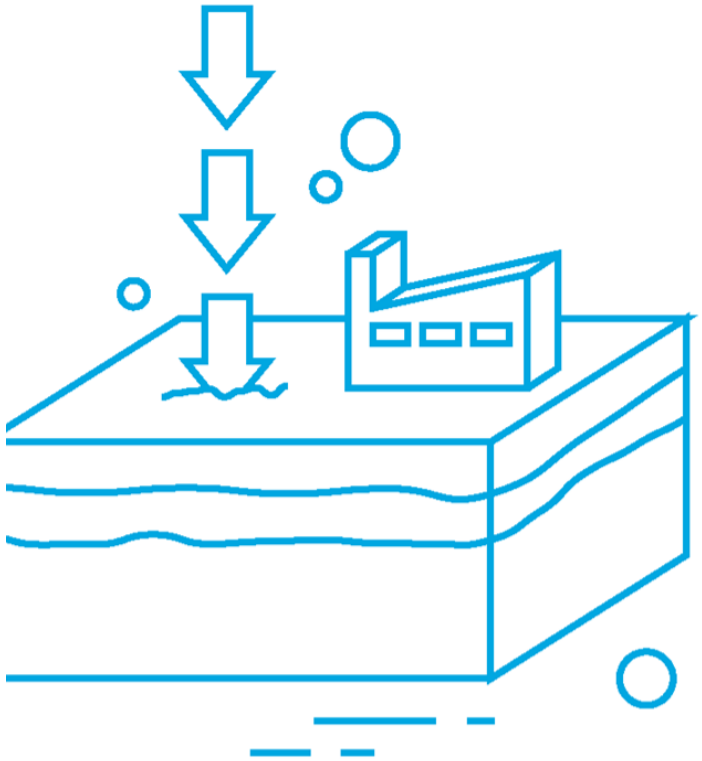


https://www.iea.org/weo2018/scenarios/

Carbon Capture in Industrial Sectors

- Roughly one-third of U.S. and global carbon emissions come from industrial sectors.
- Over half of industrial emissions occur in just three sectors: steel, cement and basic chemicals.
- Carbon capture is not optional: over half of emissions from these sectors are inherent to the chemistry of key industrial processes and cannot be eliminated through efficiency or decarbonization of energy inputs.

Carbon Capture is Much More than a Niche: It's Scalable to Meet Midcentury Climate Goals



- **U.S. oil industry has purchased, transported and injected nearly 1.5 billion tons of CO_2 over the past half century** with no fatalities or major environmental incidents (~65 million tons of CO_2 annually; ~ 3percent of U.S. oil production).
- **~37% net lifecycle emissions reductions achieved through geologically storing industrial and power plant CO_2 through enhanced oil recovery (EOR),** *including the additional oil produced* (IEA analysis).
- **Saline geologic storage of CO_2 has been demonstrated successfully at scale** (e.g. ADM in Illinois and Equinor in the North Sea) and achieves even greater lifecycle emissions reductions, including potentially atmospheric carbon removal for negative emissions.
- **Centuries to thousands of years' worth of geologic storage potential in U.S. geologic formations.**

Source: IEA

Carbon Capture is Cost-Effective in Comparison to Other Necessary Low and Zero-Carbon Options

Capture Category (CO2% is molar concentration)	Main Equipment Needed	Industrial Application	US$ per MT Captured/Compressed
Pure CO2 emissions	Compression & Dehydration only	Ethanol, Natural Gas Processing, Ammonia	$15-20/metric ton
CO2 emissions @ **16-50%** concentration	Amine CO2 separation equipment plus Compression	Hydrogen Plants, Cement, Fluidized Catalytic Cracking Unit (Refineries), Blast Furnace Gas Combustion (Steel)	$40-60
CO2 emissions @ **~13-15%** concentration		Pulverized Coal Power Plants	$55-65
CO2 emissions @ **~4%**		Natural Gas Combined Cycle Power Plants	$65-75

Source: Jeff Brown, Stanford University. These figures above are broad category summaries, and individual projects costs vary widely.
Key price assumptions: $50/MWh for electricity, $3.50/MMBtu natural gas, 10% Capital Recovery Factor.
Capture plant size: For amine solvent carbon capture systems cited above (all at 85% capacity factor) capture plant size for hydrogen is 350k MTPA (metric tons per annum), cement 1 million MTPA, FCCU 500k MTPA, Blast Furnace 3 million MTPA, Pulverized Coal Power 3 million MTPA, NGCC, 1.5 million MTPA. Pure emissions have compression/dehydration only.
Power and steam supply: Coal power plants and NGCCs can supply parasitic electric and steam loads from the power plants themselves, or can buy grid electricity and build separate steam boilers. The exact impact of this supply decision depends on power plant value, fuel costs, and the local grid.

CARBON CAPTURE COALITION

STATE CARBON CAPTURE WORK GROUP

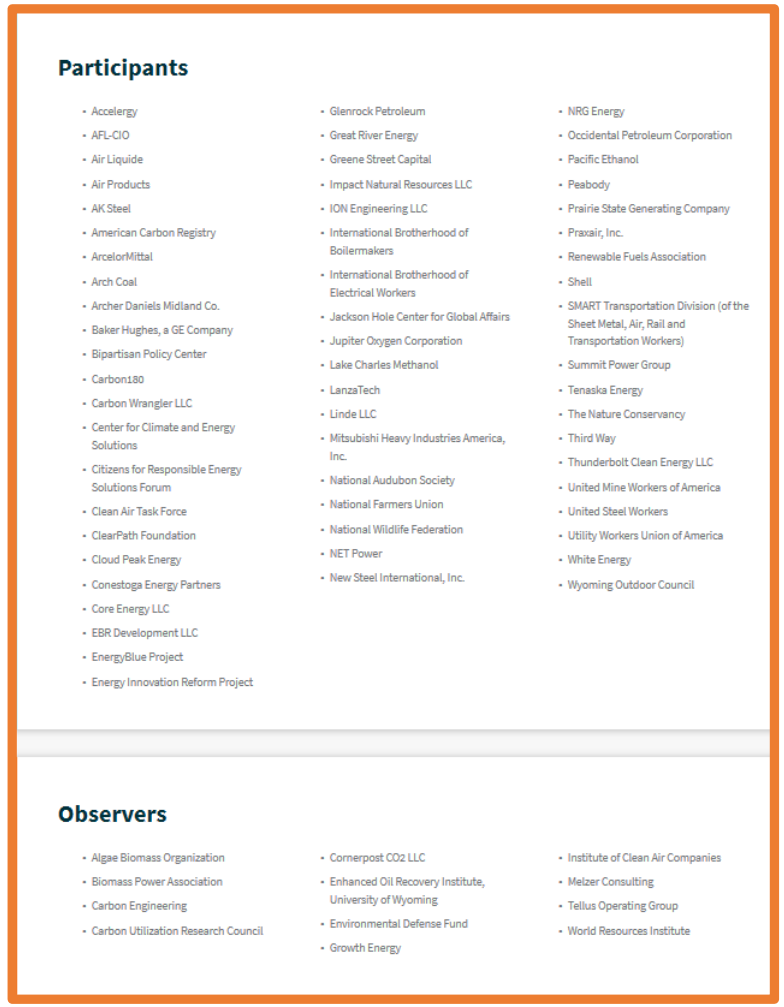
REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

"All hands on deck" to achieve economywide deployment of carbon capture in the U.S.

CARBON CAPTURE COALITION

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

- ~75 members, including industry, labor and environmental and clean energy NGOs.
- Climate, jobs and energy/industrial benefits unite diverse interests in a common purpose.
- **Goal**: economywide deployment of carbon capture to reduce emissions, foster domestic energy and industrial production, and support high-wage jobs.



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
- 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
- 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.
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- Occidental Petroleum Corporation
- Pacific Ethanol
- Peabody
- Prairie State Generating Company
- Praxair, Inc.
- Renewable Fuels Association
- Shell
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- Summit Power Group
- 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
- Cornerpost CO2 LLC
- Enhanced Oil Recovery Institute, University of Wyoming
- Environmental Defense Fund
- Growth Energy
- Institute of Clean Air Companies
- Melzer Consulting
- Tellus Operating Group
- World Resources Institute

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

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CARBON CAPTURE COALITION

Unparalleled Bipartisan Support for Reform of 45Q Tax Credit

Key Changes of Reformed 45Q Tax Credit

Increases credit values to US $35 and $50 per metric ton.

Expands eligibility to include other beneficial uses of captured carbon (in addition to EOR), projects that capture CO and direct air capture projects.

Creates **greater financial certainty** by lifting the credit cap and providing clear timing for eligibility

Expands eligibility to more industries by lowering the annual carbon capture threshold and expanding definitions for qualified facilities and qualified carbon.

Enables the owner of the capture equipment to transfer the credit to another party that stores the CO_2 or puts CO_2 or CO to beneficial use.

45Q Tax Credit Amount: Depends on Project Type

There is a 10-year ramp up to the following dollar per ton amounts, with the value depending on project type as shown below.

$35/ton

for CO_2 stored geologically through EOR.

$35/ton

for other beneficial uses of CO_2 or CO such as converting carbon emissions into fuels, chemicals, or useful products like concrete.

$50/ton

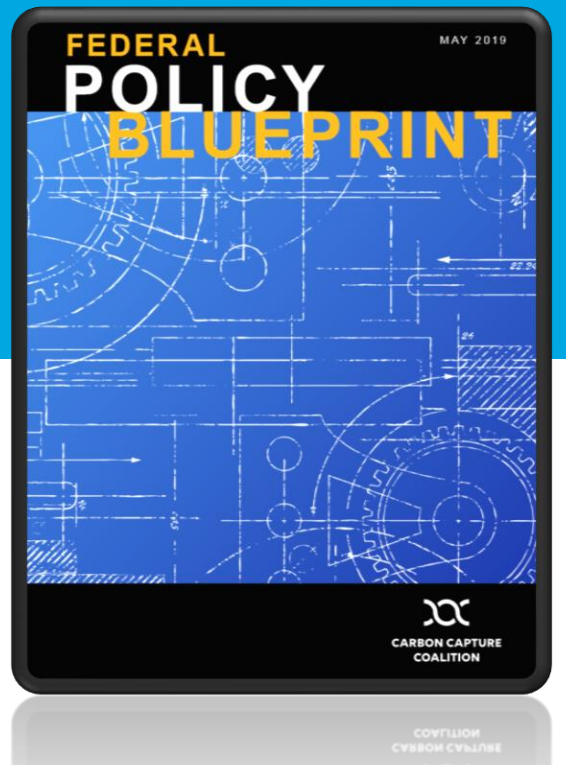
for CO_2 stored in other geologic formations and not used in EOR.

Federal Policy Agenda Going Forward

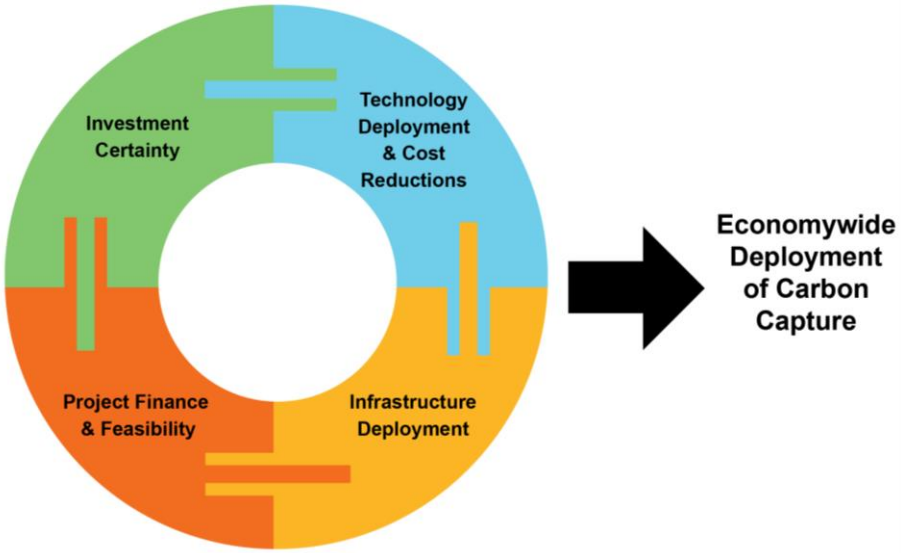
- Ensure effective implementation of 45Q by the U.S. Treasury to provide investment certainty and business model flexibility;
- Provide a portfolio of federal carbon capture policies to complement 45Q, similar to wind and solar;
- Incorporate CO_2 pipeline infrastructure into national infrastructure legislation, including measures for federal financing of extra capacity; and
- Increase prioritization of industrial sectors in federal carbon capture policy and eligibility of both CO_2 and CO emissions.
- Include measures in COVID 19-related stimulus to sustain carbon capture deployment during current economic crisis.

CARBON CAPTURE COALITION

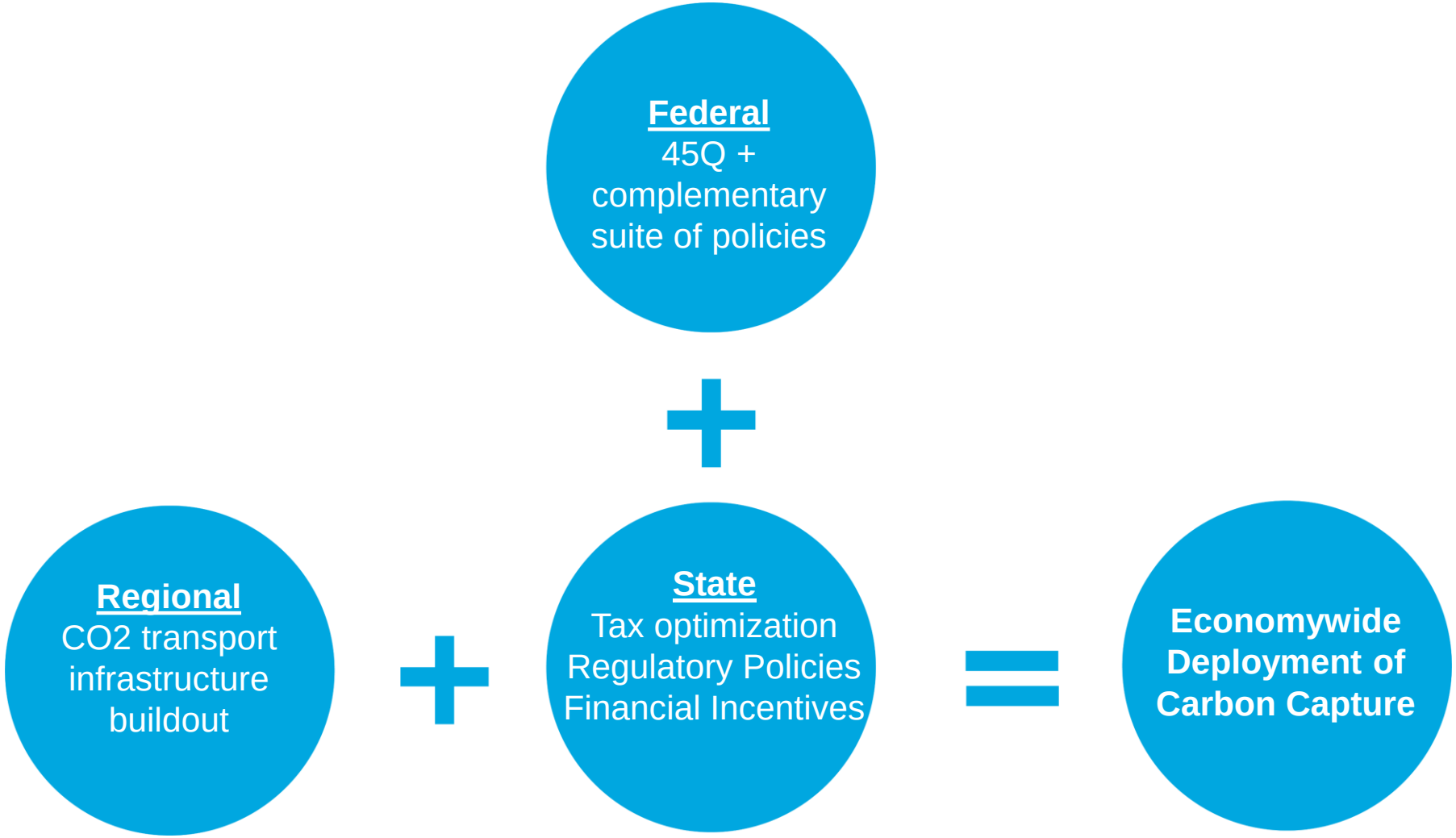
Carbon Capture Coalition's Federal Policy Blueprint



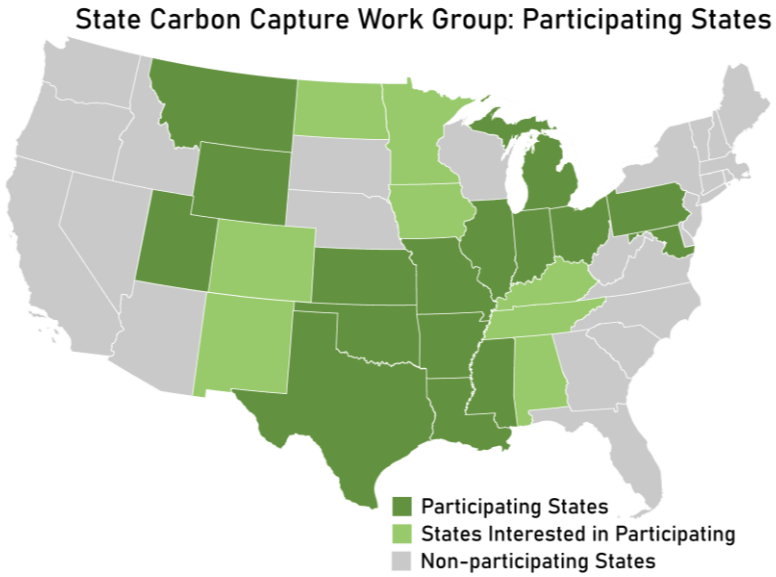
- ✓ Agenda for economywide deployment.
- ✓ Recommends full policy portfolio, similar to current support for wind, solar and other low and zero-carbon technologies.
- ✓ Consensus of Coalition's 75 companies, unions, and NGOs.



Integrated Federal, Regional & State Policy are Key to Success

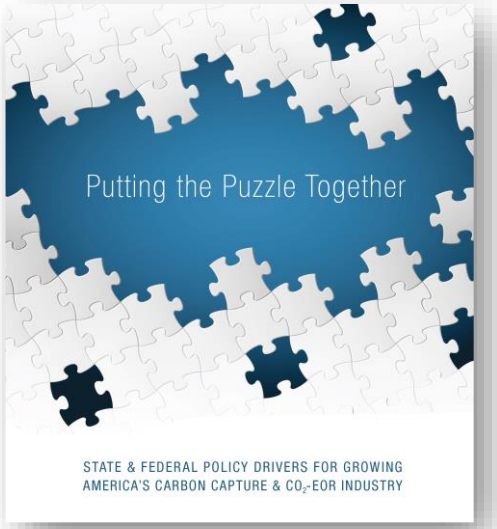


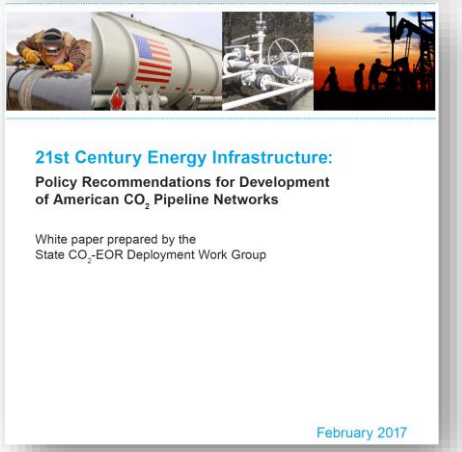
STATE CARBON CAPTURE WORK GROUP



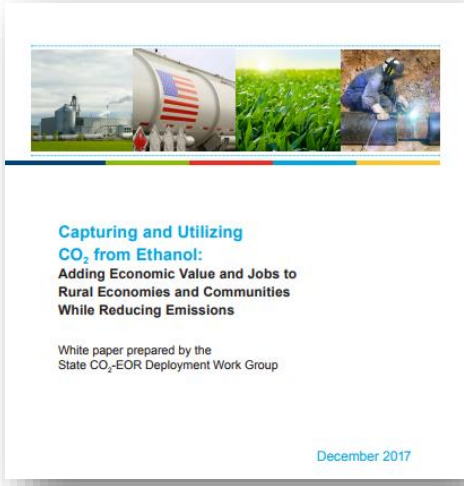
- Formed in 2015 by then Gov. Mead (R-WY) and Gov. Bullock (D-MT). Actively recruiting additional states (light green).
- Made comprehensive state and federal policy recommendations from 2015-2018.
- Now overseeing Midwestern and Western Regional Carbon Capture Deployment Initiatives.
- Modeled candidate capture and storage projects and CO_2 transport infrastructure (two-year effort).
- Forming state policy teams to develop state policy recommendations to complement the federal 45Q tax credit and make states “carbon-capture ready.”

Four Major Work Group Deliverables To Date





- ***Putting the Puzzle Together: State and Federal Policy Drivers for Growing America's Carbon Capture and CO_2-EOR Industry***
- ***21st Century Energy Infrastructure: Policy Recommendations for Development of American CO_2 Pipeline Networks***
- ***Electricity Market Design and Carbon Capture Technology: The Opportunities and the Challenges***
- ***Capturing and Utilizing CO2 from Ethanol: Adding Economic Value and Jobs to Rural Economies and Communities While Reducing Emissions***



Governors' Partnership: Providing State Leadership for Carbon Capture Policy and Project Deployment

GOVERNORS' PARTNERSHIP FOR CARBON CAPTURE

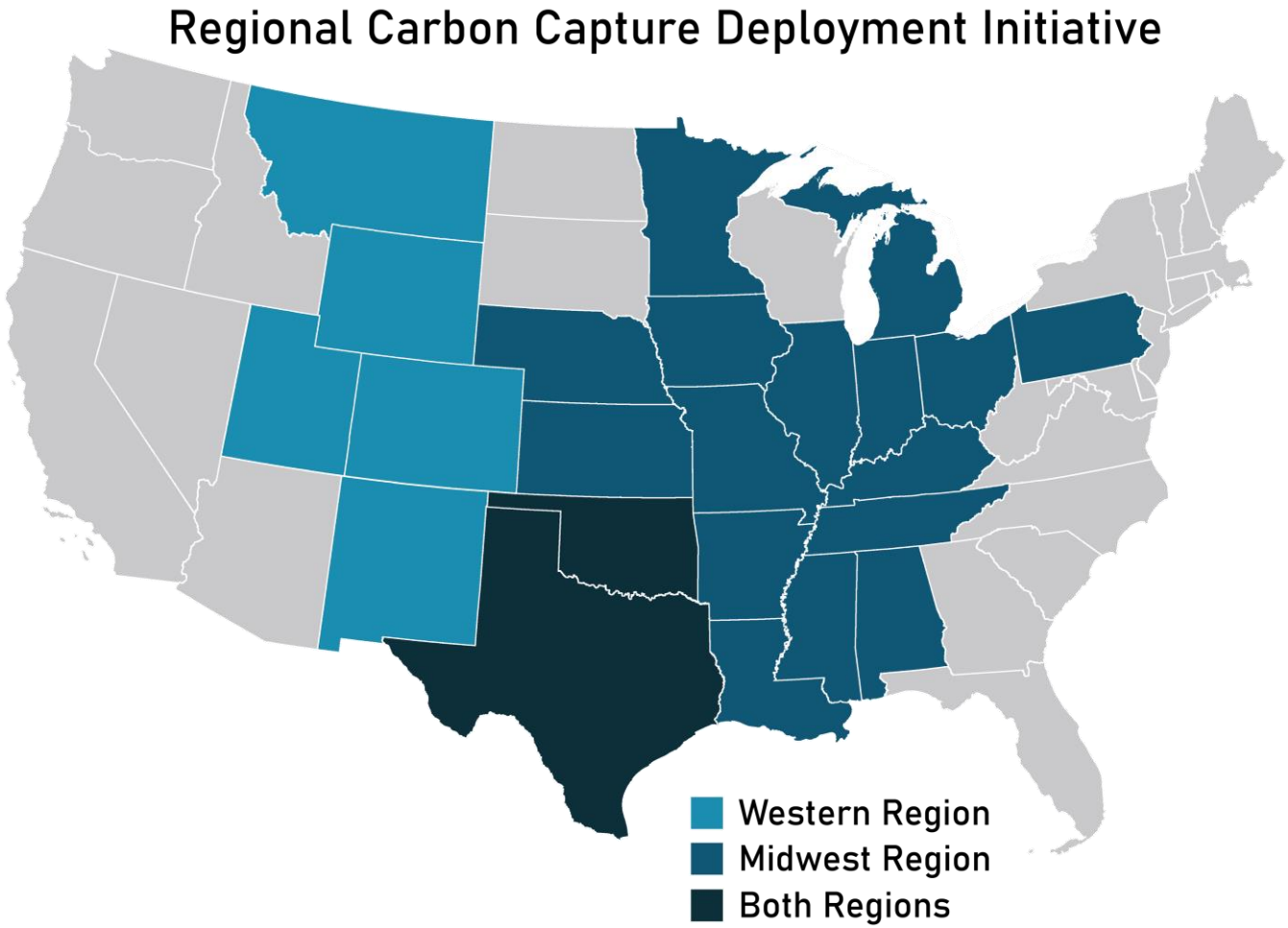
Objectives:

- Elevate carbon capture, its beneficial use and storage as a national priority;
- Encourage congressional and presidential action to expand the portfolio of federal policies; and
- Foster carbon capture policy and CO_2 transport infrastructure deployment in states and regions.

Current Governors:

- Governor Steve Bullock (D-MT)
- Governor John Bel Edwards (D-LA)
- Governor Mark Gordon (R-WY)
- Governor Gary Herbert (R-UT)
- Other Governors being invited.

Regional Deployment Initiatives: Western & Midwestern Regions



REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

Regional Deployment Initiatives: Where We are in the Process

Phase I

Preliminary Analysis (Jan-Sep 2018)

Mapping industrial facilities, power plants and CO_2 storage opportunities, initial cost analysis, and preliminary pipeline modeling.

Phase II

Convening State Officials and Stakeholders (October 2018)

Launched Initiatives in Columbus, OH and Salt Lake City, UT.

Phase III

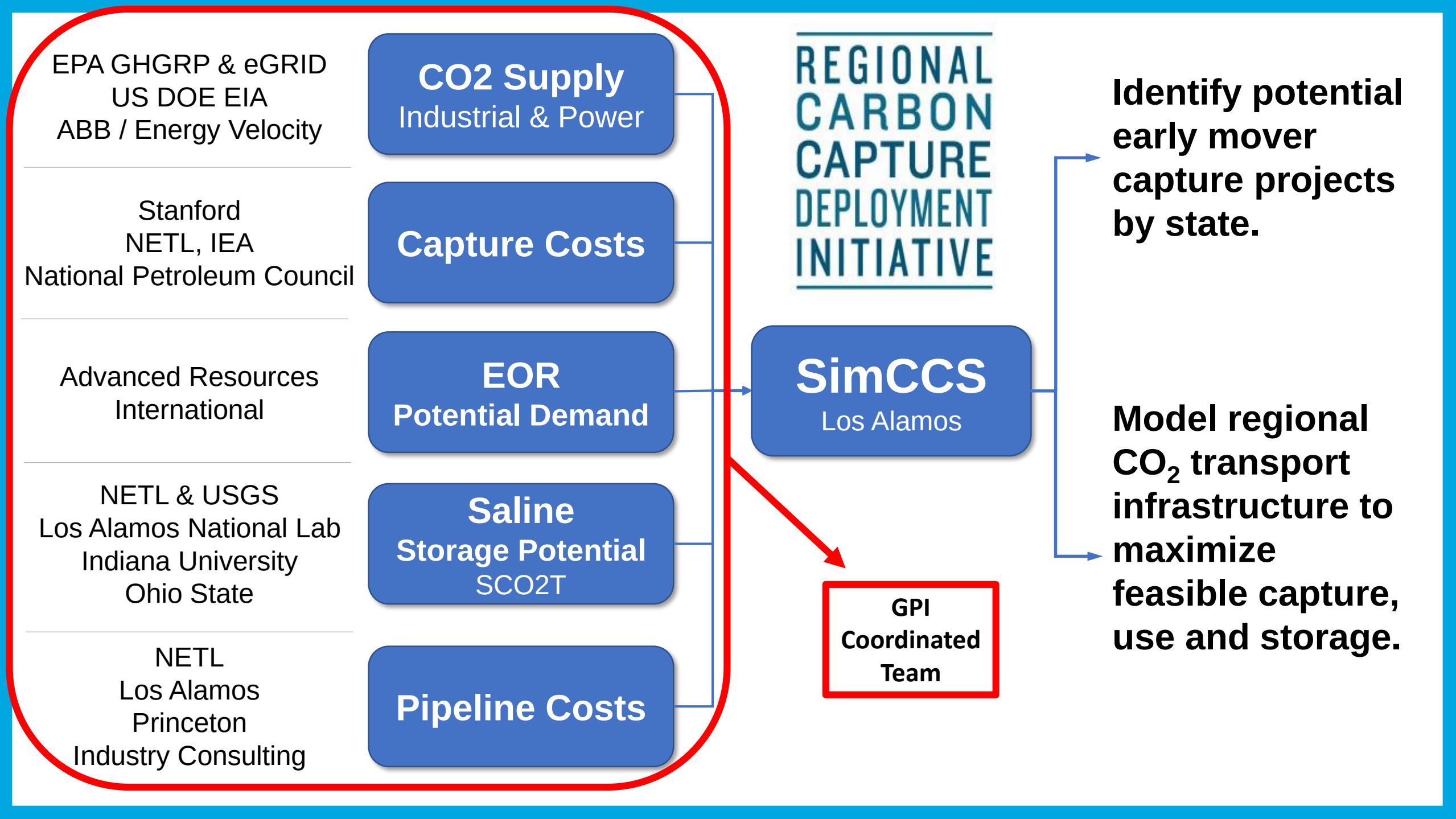
Supporting State Policy Development and Projects (Underway)

Advancing state policies to complement 45Q credit.

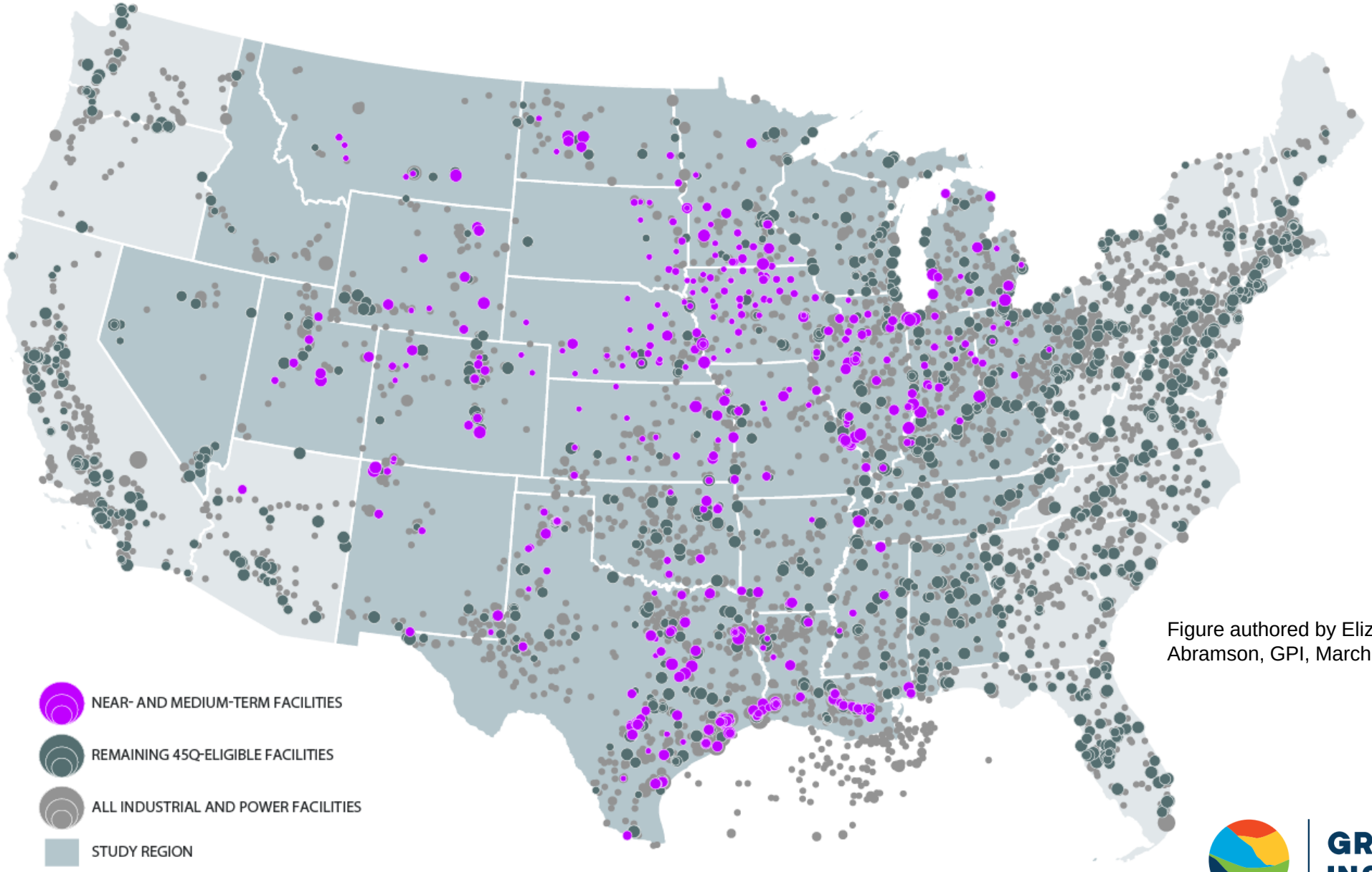
Engaging in 2020 state legislative sessions and preparing for 2021.

Cooperating regionally on CO_2 transport infrastructure and development of carbon hubs.

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE


EPA GHGRP & eGRID
US DOE EIA
ABB / Energy Velocity
CO2 Supply
Industrial & Power
Stanford
NETL, IEA
National Petroleum Council
Capture Costs
Advanced Resources
International
EOR
Potential Demand
NETL & USGS
Los Alamos National Lab
Indiana University
Ohio State
Saline
Storage Potential
SCO2T
NETL
Los Alamos
Princeton
Industry Consulting
Pipeline Costs
REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE
SimCCS
Los Alamos
GPI Coordinated Team
Identify potential early mover capture projects by state.
Model regional CO_2 transport infrastructure to maximize feasible capture, use and storage.

Emitting Facilities: 45Q Eligibility and Near-Term Capture Opportunities



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Near- and medium-term facilities, capture targets, and cost estimates

Industry	# of Facilities	Optimized Capture (mmt/year)	Share of Total Capturable Estimate	Average Estimated Cost $/ton	Range of Cost Estimates $/ton
Ethanol	150	50.6	14.1%	$17	$12 - $30
Cement	45	32.7	9.1%	$56	$40 - $75
Refineries	38	26.5	7.4%	$56	$43 - $68
Steel	6	14.6	4.1%	$59	$55 - $64
Hydrogen	34	14.4	4.0%	$44	$36 - $57
Gas Processing	20	4.5	1.3%	$14	$11 - $16
Petrochemicals	2	1.7	0.5%	$59	$57 - $60
Ammonia	3	0.9	0.3%	$17	$15 - $21
Chemicals	2	0.7	0.2%	$30	$19 - $40
Coal Power Plant	58	143.4	40.1%	$56	$46 - $60
Gas Power Plant	60	67.9	19.0%	$57	$53 - $63
Grand Total	**418**	**357.8**	**100.0%**	**$39**	**$11 - 75**

All emissions are in million metric tons

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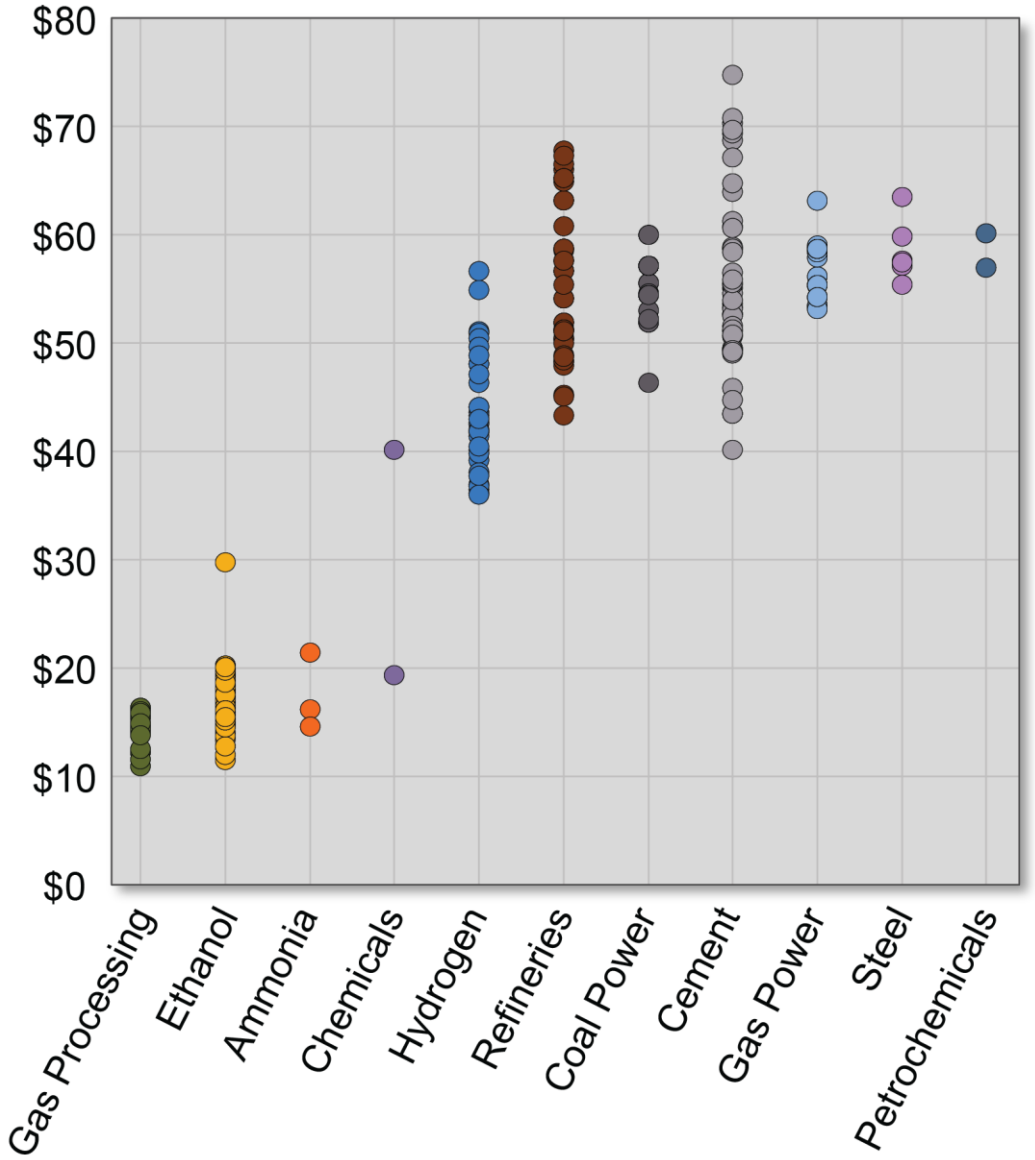
Estimated cost of capture per industry for near-term facilities in study area



Industry	Average Estimated Cost $/ton	Range of Cost Estimates $/ton
Gas Processing	$14	$11 - $16
Ethanol	$17	$12 - $30
Ammonia	$17	$15 - $21
Chemicals	$30	$19 - $40
Hydrogen	$44	$36 - $57
Refineries	$56	$43 - $68
Coal Power Plant	$56	$46 - $60
Cement	$56	$40 - $75
Gas Power Plant	$57	$53 - $63
Steel	$59	$55 - $64
Petrochemicals	$59	$57 - $60

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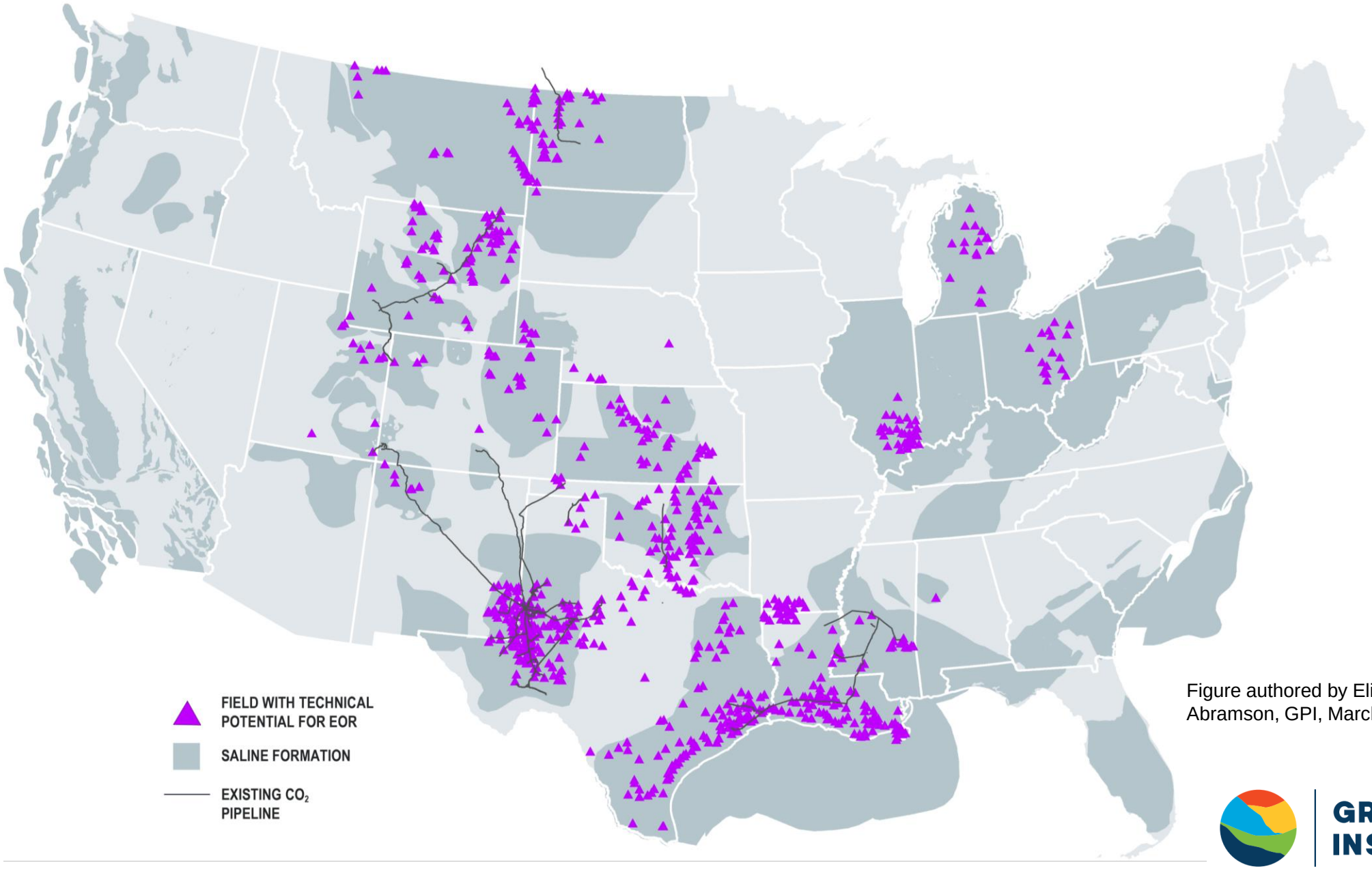
Deep Saline Formations & Oil Fields with CO2 Injection Potential



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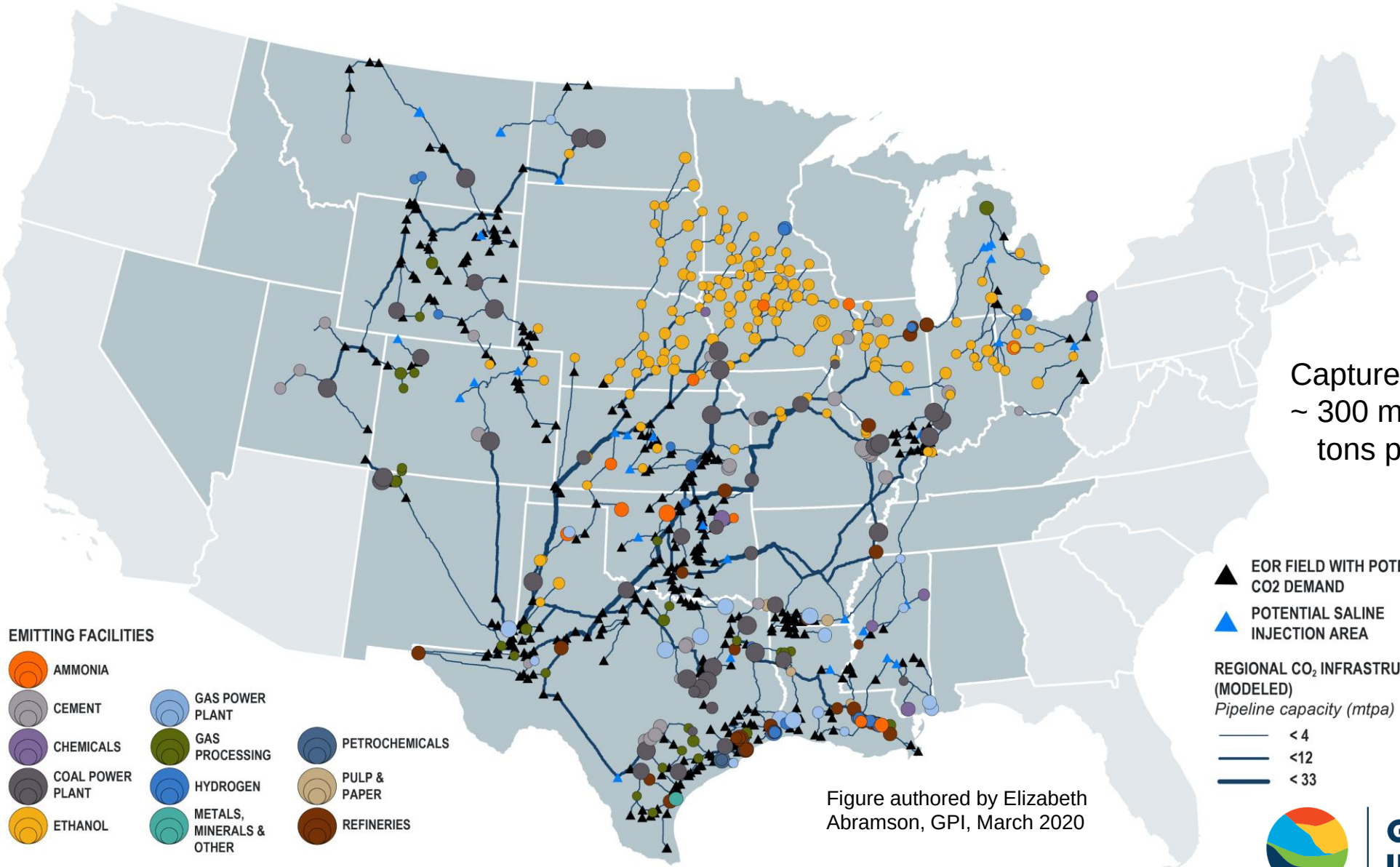
Base Scenario:
Optimized transport network for CO2 capture and storage under 45Q



Capture and storage:
~ 300 million metric tons per year

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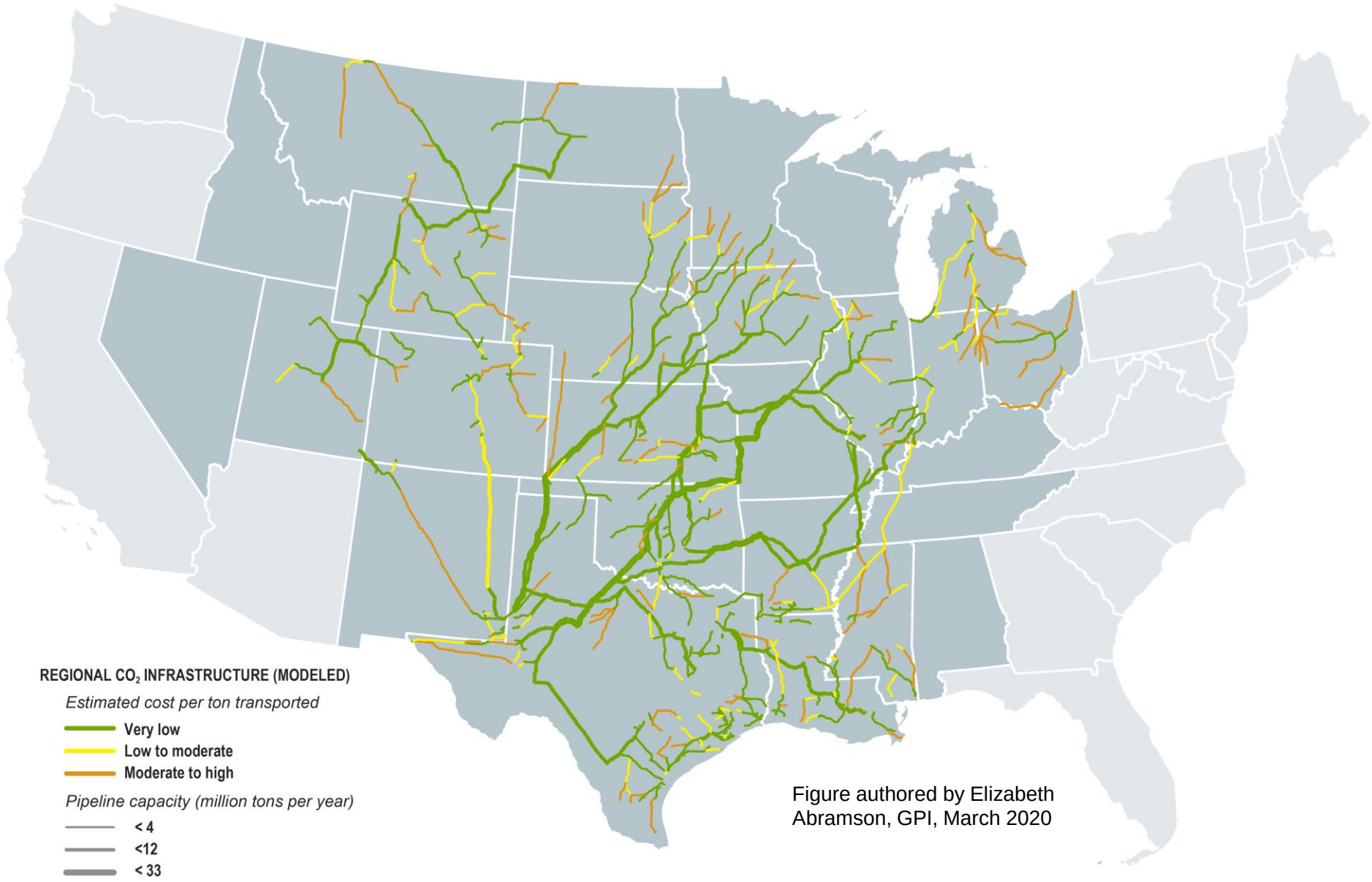
Base Scenario:
Relative transport cost of network segments



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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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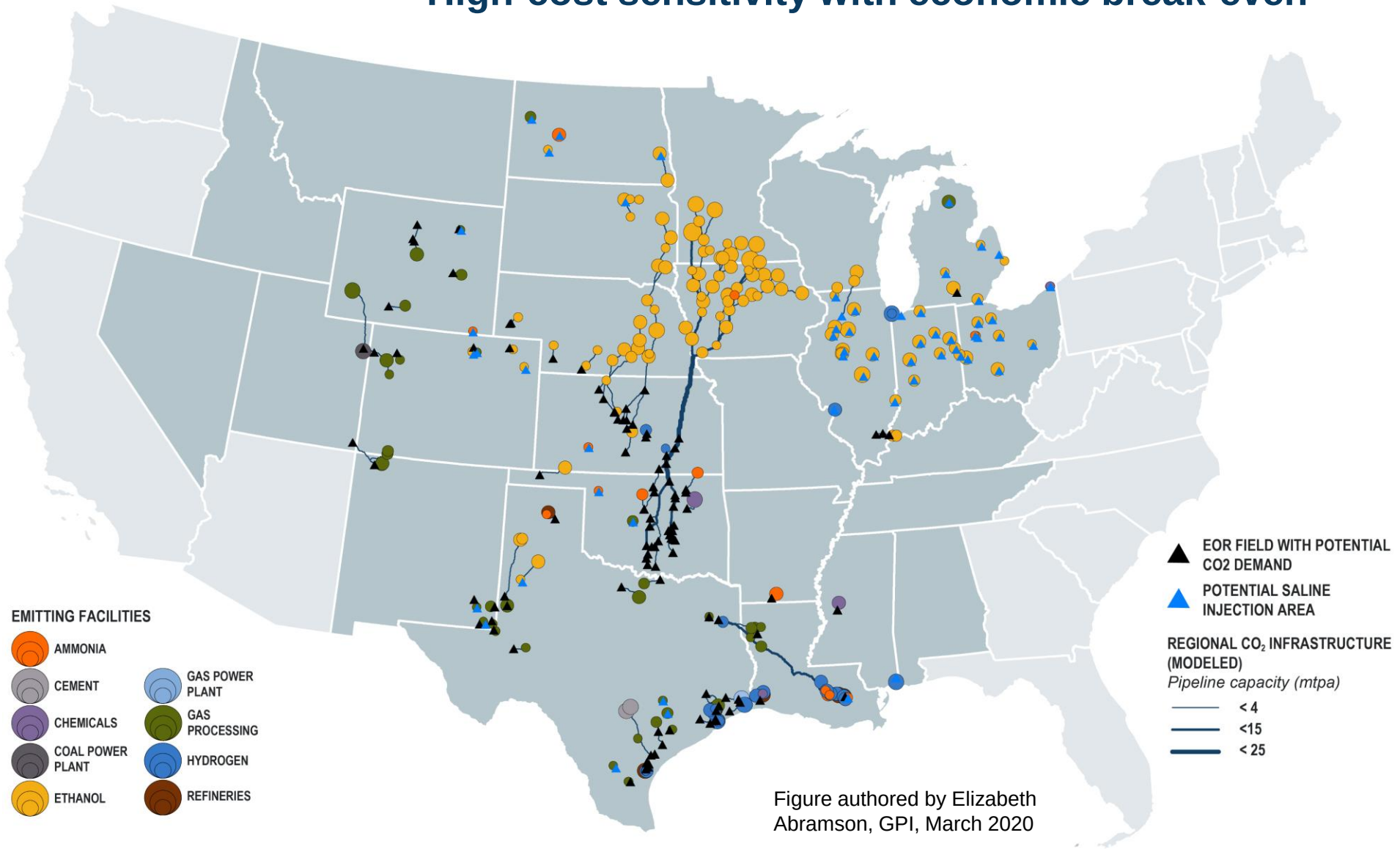
Sensitivity Scenario:
High-cost sensitivity with economic break-even



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

High-purity industrial sources choose local saline storage.

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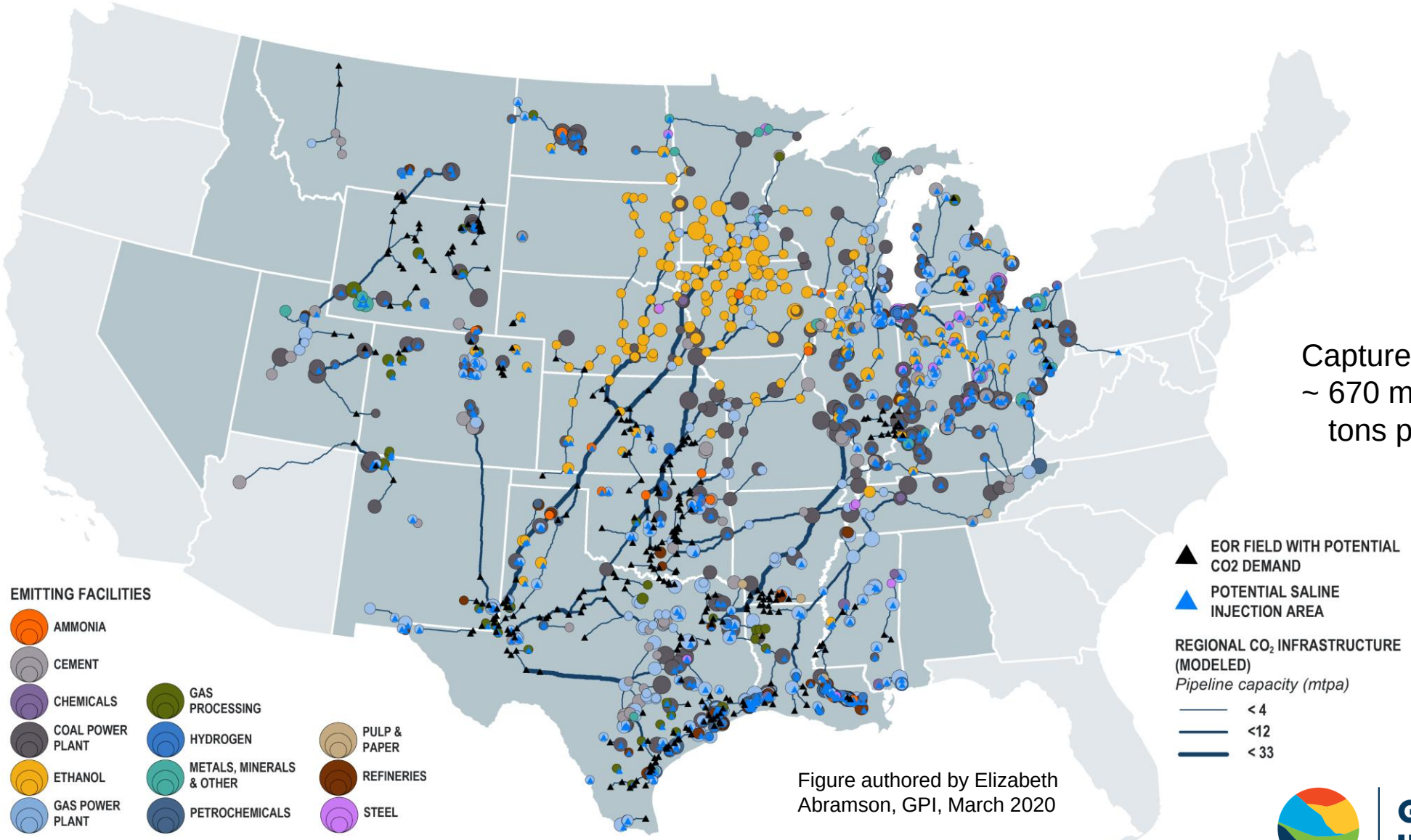
Long-term economy-wide deployment: Expanded storage in deep saline formations and petroleum basins



Capture and storage: ~ 670 million metric tons per year

Figure authored by Elizabeth Abramson, GPI, March 2020

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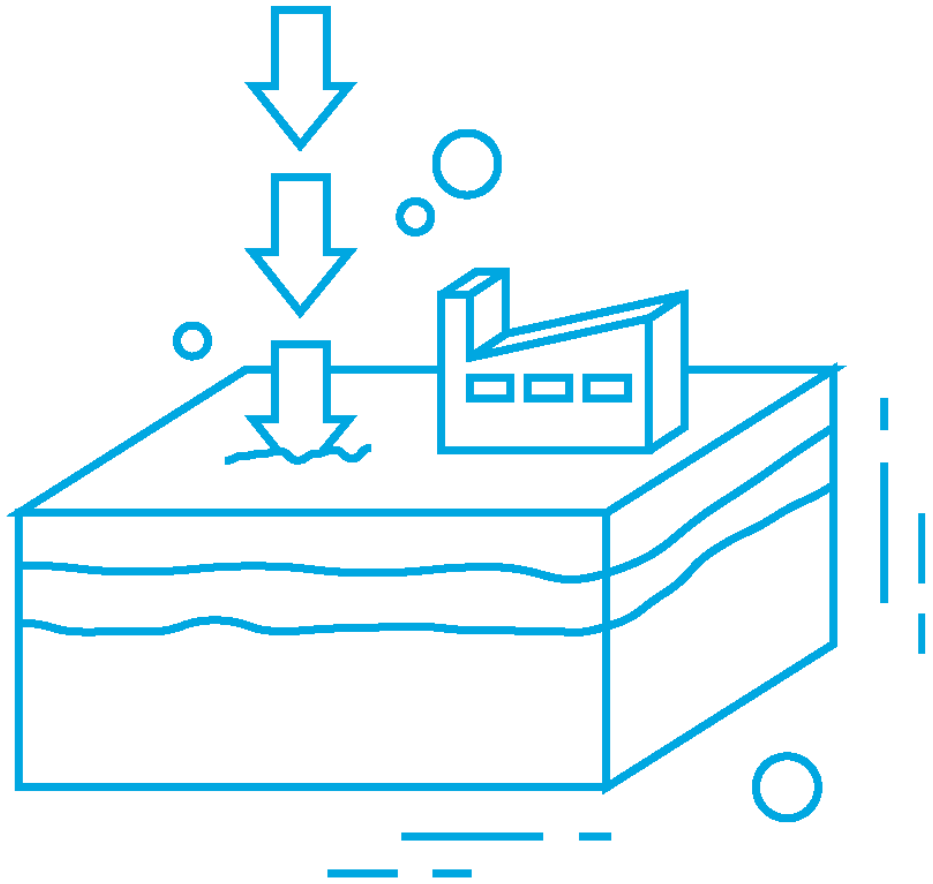
Setting the Stage for Regional Carbon Hubs: Enabling Large-Scale Carbon Management

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

- Modeling of regional capture, transport and storage networks is increasing awareness among state officials and industry, labor and NGO stakeholders of the opportunity presented by the 45Q tax credit to establish carbon hubs.
- **Strategy**: Advance state and regional planning, policy and project development in conjunction with federal legislative effort.
- **Reframing the challenge as opportunity**: Building a new carbon economy for emissions reductions, domestic energy and industrial production and high-wage jobs.



Carbon Capture Ready

Next Step: Help States Become "Carbon Capture Ready" and Take Economic Advantage of Available 45Q Tax Credit Before End of 2023

- Developing state policy frameworks to complement 45Q and other federal policies:
  - ✓ Delegation of EPA authority for permitting saline storage projects (federal UIC Class VI) to states
  - ✓ Rules for long-term CO_2 storage
  - ✓ Rules for CO_2 transport and storage space
  - ✓ Rules for clarifying the purpose of CO_2 injection
  - ✓ Financial incentives for carbon capture
  - ✓ Optimization of state taxes to incentivize capture, transport, use and storage
- Establishing state policy teams to develop legislative and other policies for their states, based on modeling and analysis.

CO2 Deployment Fact Sheets: Tailored to Each State

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE

Indiana

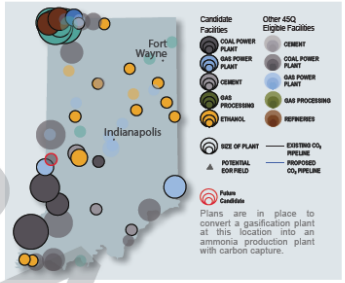
IMPLEMENTING CARBON CAPTURE AND STORAGE TECHNOLOGY

Carbon capture can play a vital role in the future of Indiana's energy system as support grows within the state for this technology. Indiana has fifty-six facilities qualifying for the expanded 45Q federal tax credit, twenty-eight of which are also identified as potentially economically feasible candidates for carbon capture. With large storage potential in the Illinois Basin and a diverse set of clean energy legislation, Indiana is strategically positioned to adopt this economically valuable technology enabling the state to meet its growing environmental and energy needs.

Figure 1 (Right) : Indiana has many facilities large enough to qualify for the 45Q carbon capture tax credit, including coal and gas power plants, gas processing facilities and petroleum refineries. Facilities identified by the Regional Carbon Capture Deployment Initiative as potential early candidates for capture retrofit based on emissions, equipment, and estimated capture cost, are shown with outlines and darker colors. Details on these facilities are listed below.

Source: GPI 2019; EPA 2018

SOURCES BY INDUSTRY & VOLUME

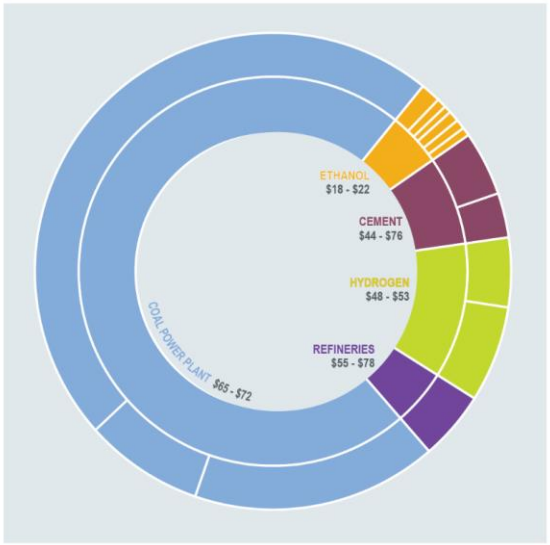


POTENTIAL CANDIDATE FACILITIES FOR CAPTURE WITH ANNUAL EMISSIONS

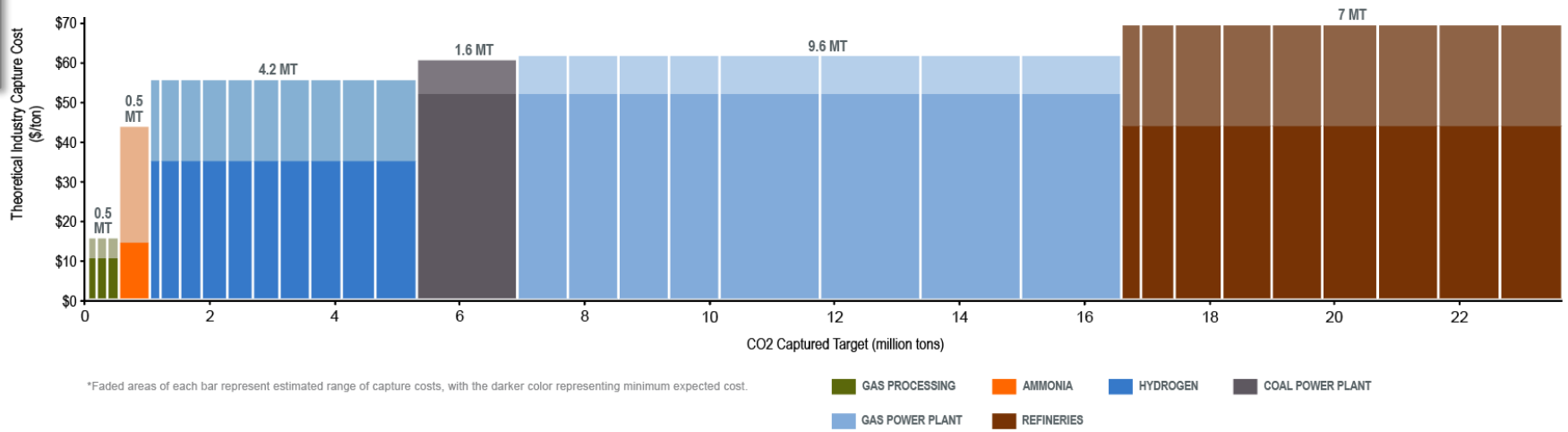
Facility Name	Location	Industry	Total Facility CO2 Emissions thousand tons	CO2 Captured Target thousand tons	Theoretical Capture Cost $/ton (Draft - Do Not Cite)
Gibson	Owensville	Coal Power Plant	16,332	6,400	$53
Mittal Steel USA	East Chicago	Metals & Minerals	6,971	4,373	$57
Merom	Sullivan	Coal Power Plant	4,834	3,200	$56
Edwardsport	Edwardsport	Coal Power Plant	3,430	3,043	$56
Arcelormittal Burns Harbor	Burns Harbor	Metals & Minerals	10,131	2,885	$58
11 Ethanol Plants	Multiple	Ethanol	3,133	2,787	$16 (Average)
US Steel Corp	Gary	Metals & Minerals	9,215	2,621	$59
Lawrenceburg Energy	Lawrenceburg	Gas Power Plant	2,857	2,574	$55
Arcelormittal Indiana Harbor	East Chicago	Metals & Minerals	4,684	2,571	$59
BP Business Unit 1	Whiting	Refineries	4,694	1,042	$47
BP Business Unit 2	Whiting	Refineries	4,694	955	$48
Lone Star Industries	Greencastle	Cement	1,056	952	$49
Praxair - Whiting	East Chicago	Hydrogen	1,610	900	$36
IPL Eagle Valley	Martinsville	Coal Power Plant	1,107	800	$61
Sugar Creek	West Terre Haute	Gas Power Plant	1,397	800	$61
Lehigh Cement	Speed	Cement	531	478	$57
Carmeuse Lime Buffington	Gary	Cement	873	462	$58
Lehigh Cement	Mitchell	Cement	626	318	$64

Table 1: The Regional Carbon Capture Deployment Initiative estimated theoretical facility capture costs based on published capture equipment costs, facility-specific operational patterns, existing equipment, and level of emissions. Most states have a large number of facilities eligible for 45Q. Of those facilities, the above table lists likely economically feasible candidates based on estimated capture cost. This list is not meant to be definitive. Commercial decisions by participating companies, and policy and regulatory decisions by state governments, will ultimately determine if a project is feasible for carbon capture. Captured Emissions refers to the amount of carbon dioxide that can be expected to be captured at a facility considering relevant technological and economic constraints. Source: GPI 2019; EPA 2018.

POTENTIAL CANDIDATE FACILITIES FOR CAPTURE, BY CO2 EMISSIONS AND COST RANGE



POTENTIAL CANDIDATE FACILITIES FOR CAPTURE, BY CAPTURE TARGET AND COST RANGE



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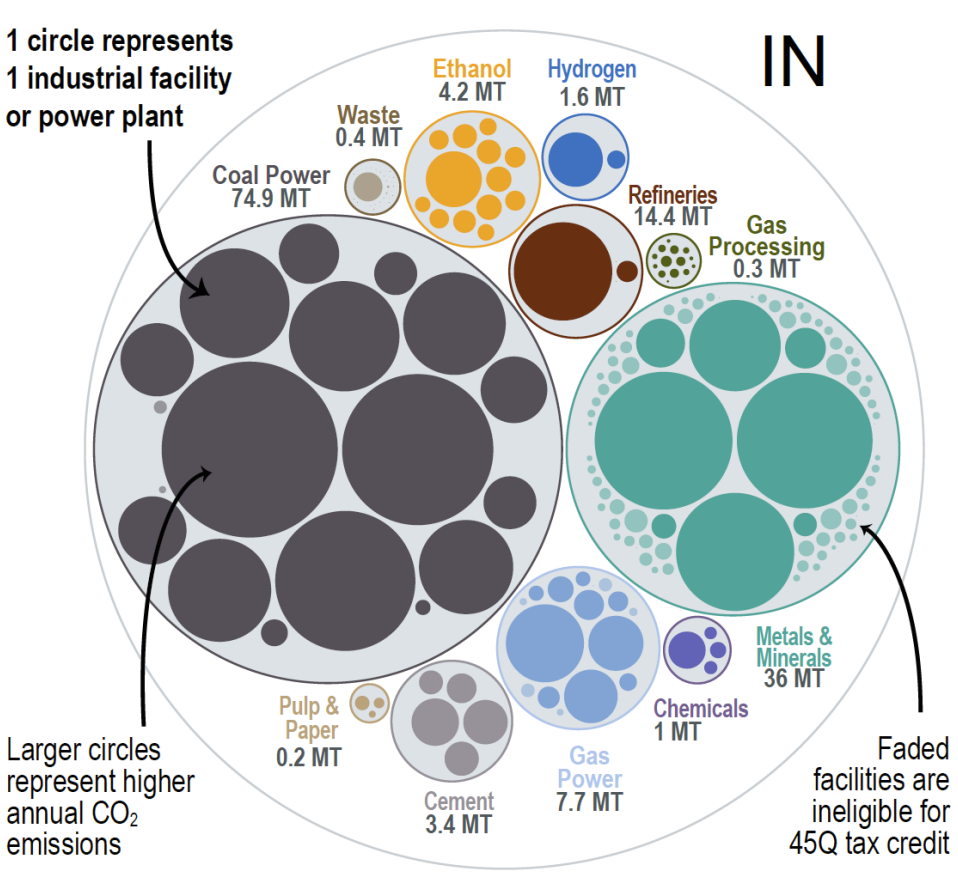
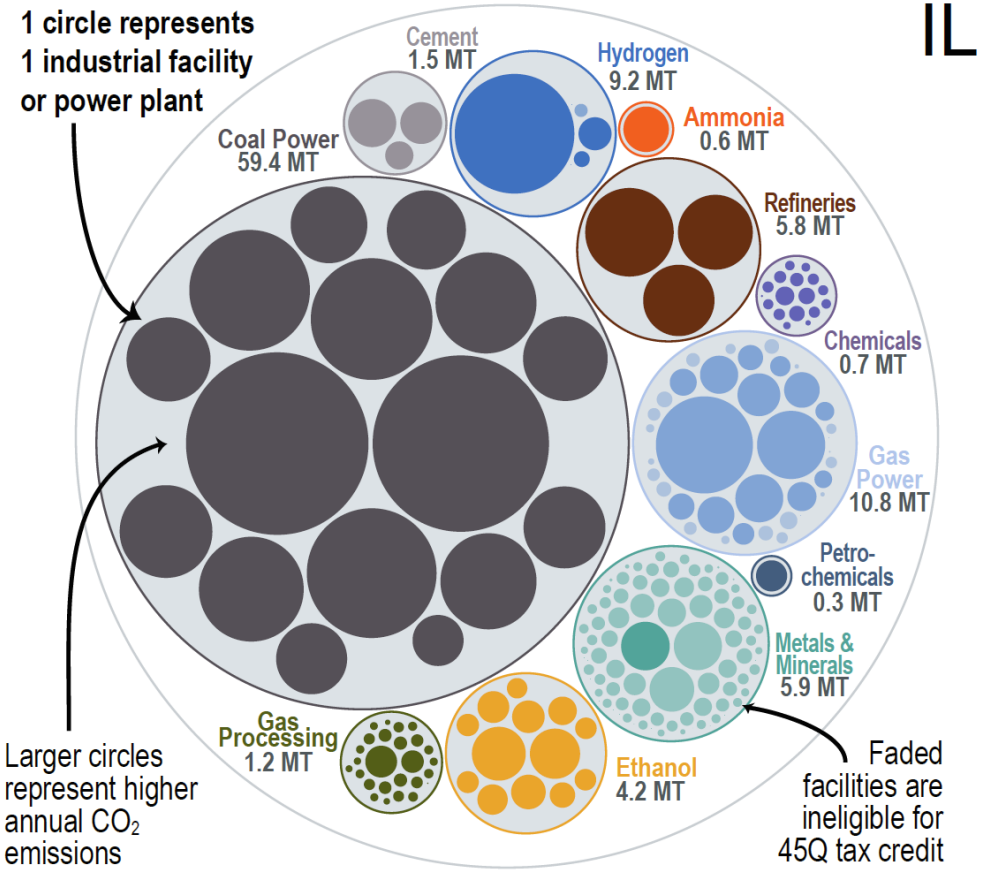
CO2 Deployment Fact Sheets: Tailored to Each State





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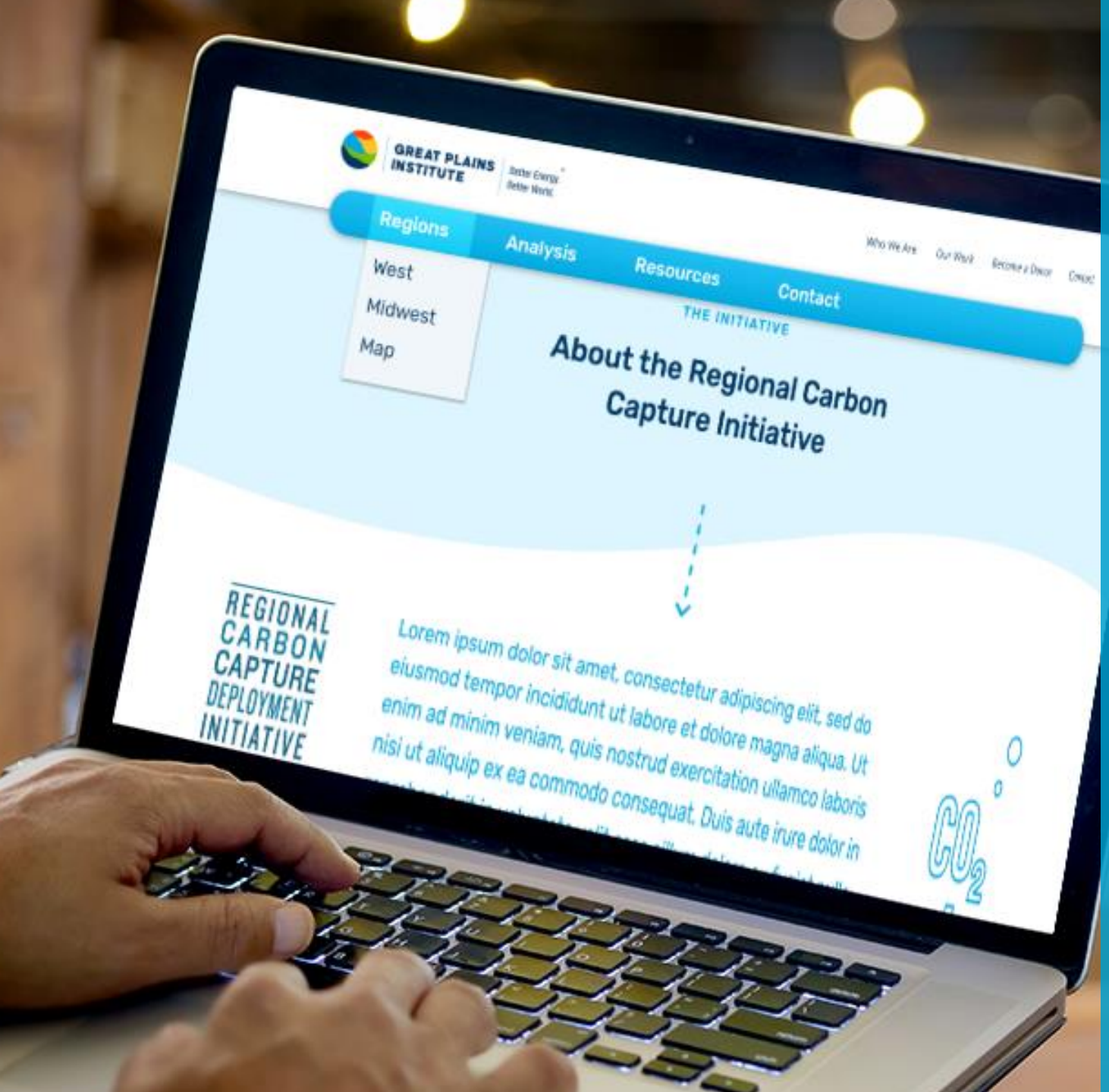
Figures authored by Elizabeth Abramson, Great Plains Institute, 2019



Building Out Web Presence and Tools for State Policymakers and Stakeholders

www.carboncaptureready.org

Forthcoming: Economic Impacts & Jobs Analysis

Jobs and Private Sector Investment from Carbon Capture, Transport and Deployment

Phase 1

- National level
- Carbon capture deployment necessary to meet midcentury temperature targets of 2^{o} and 1.5 ^{o} C

Phase 2

- States in Regional Deployment Initiative scenarios
- Retrofits made feasible with 45Q and other major candidates

Phase 3

- Expand analysis to include more states
- Industrial and electric power retrofits and new builds

Thank You

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Extra Slides

Carbon Capture is Cost-Effective in Comparison to Other Necessary Low and Zero-Carbon Options

Capture Category (CO2% is molar concentration)	Main Equipment Needed	Industrial Application	US$ per MT Captured/Compressed
Pure CO2 emissions	Compression & Dehydration only	Ethanol, Natural Gas Processing, Ammonia	$15-20/metric ton
CO2 emissions @ **16-50%** concentration	Amine CO2 separation equipment plus Compression	Hydrogen Plants, Cement, Fluidized Catalytic Cracking Unit (Refineries), Blast Furnace Gas Combustion (Steel)	$40-60
CO2 emissions @ **~13-15%** concentration		Pulverized Coal Power Plants	$55-65
CO2 emissions @ **~4%**		Natural Gas Combined Cycle Power Plants	$65-75

Source: Jeff Brown, Stanford University. These figures above are broad category summaries, and individual projects costs vary widely.
Key price assumptions: $50/MWh for electricity, $3.50/MMBtu natural gas, 10% Capital Recovery Factor.
Capture plant size: For amine solvent carbon capture systems cited above (all at 85% capacity factor) capture plant size for hydrogen is 350k MTPA (metric tons per annum), cement 1 million MTPA, FCCU 500k MTPA, Blast Furnace 3 million MTPA, Pulverized Coal Power 3 million MTPA, NGCC, 1.5 million MTPA. Pure emissions have compression/dehydration only.
Power and steam supply: Coal power plants and NGCCs can supply parasitic electric and steam loads from the power plants themselves, or can buy grid electricity and build separate steam boilers. The exact impact of this supply decision depends on power plant value, fuel costs, and the local grid.

Illustrative Comparison of Carbon Mitigation Costs on a Per-Ton Basis

Source: Kenneth Gillingham and James H. Stock, "The Cost of Reducing Greenhouse Gas Emissions," *Journal of Economic Perspectives*, Volume 32, Number 4, Fall 2018

Table 2

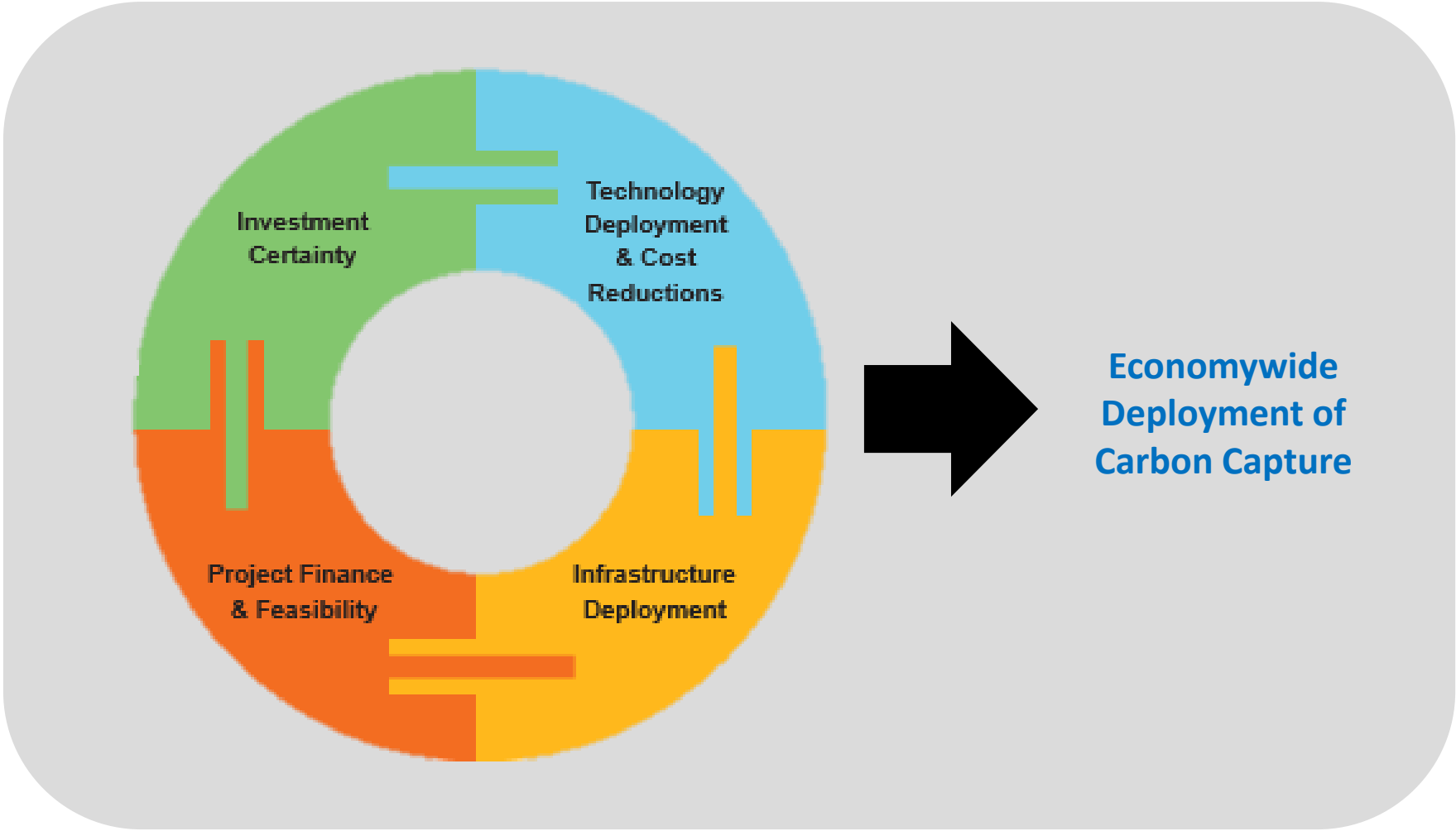
Static Costs of Policies based on a Compilation of Economic Studies

(ordered from lowest to highest cost)

Policy	*Estimate ($2017/ton CO_{2e})*
Behavioral energy efficiency	–190
Corn starch ethanol (US)	–18 to +310
Renewable Portfolio Standards	0–190
Reforestation	1–10
Wind energy subsidies	2–260
Clean Power Plan	11
Gasoline tax	18–47
Methane flaring regulation	20
Reducing federal coal leasing	33–68
CAFE Standards	48–310
Agricultural emissions policies	50–65
National Clean Energy Standard	51–110
Soil management	57
Livestock management policies	71
Concentrating solar power expansion (China & India)	100
Renewable fuel subsidies	100
Low carbon fuel standard	100–2,900
Solar photovoltaics subsidies	140–2,100
Biodiesel	150–250
Energy efficiency programs (China)	250–300
Cash for Clunkers	270–420
Weatherization assistance program	350
Dedicated battery electric vehicle subsidy	350–640

Note: Figures are rounded to two significant digits. We have converted all estimates to 2017 dollars for comparability. See Appendix Table A-1 for sources and methods. CO_{2e} denotes conversion of tons of non-CO_2 greenhouse gases to their CO_2 equivalent based on their global warming potential.

Federal Carbon Capture Policy Puzzle



CARBON CAPTURE COALITION

Investment Certainty

Schweikert-Wenstrup proposal

- Ends 45Q commence construction window
- Increases direct air capture credit 25%; lowers DAC thresholds
- Included in House GOP climate package

Sewell proposal

- 1-year commence construction extension
- Included in House Green Act

Capito-Whitehouse proposal

- 5-year extension to commence construction
- Offered as amendment to Senate energy package

CARBON CAPTURE COALITION

Project Finance & Feasibility

Direct Pay

- Cash payment at a discount relative to 45Q credit
- Green Act includes direct pay for renewables
- No similar provision for carbon capture

BEAT Tax Fix

- Prevent disallowance of 45Q under BEAT, similar to treatment afforded wind and solar

CARBON CAPTURE COALITION

Project Finance & Feasibility

Enhanced Transferability

- Allows 45Q to be transferred more broadly to entities with tax liability to monetize the credit
- Expands the pool of eligible tax equity investors for carbon capture projects
- The Renewable Energy Transferability Act (S. 3032)

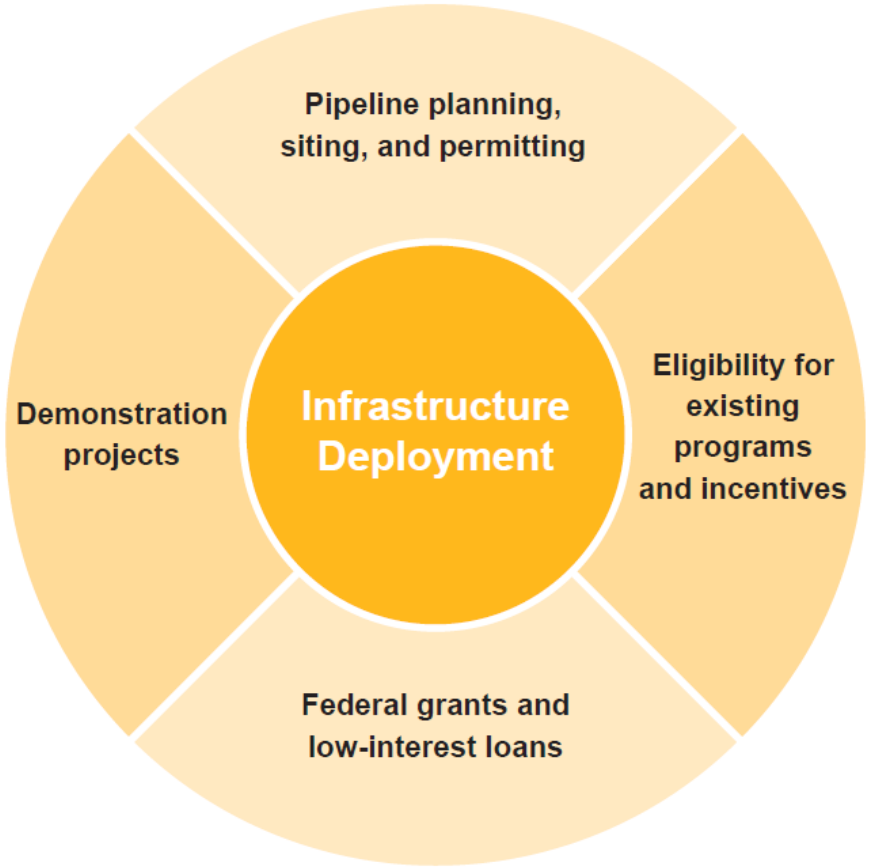
48A Fix

- Adjusts heat rate requirements for 48A tax credits to enable carbon capture retrofits on coal power plants
- Unlocks $2 billion in available financing
- Carbon Capture Modernization Act (S. 407, H.R. 1796)

Infrastructure Deployment

INVEST CO_2 Act – Bustos (H.R. 4905)

- Low-interest federal loans to expand CO_2 pipeline capacity.
- Development of trunk and feeder lines to build out CO_2 management system.
- Encourages state and local governments to designate anthropogenic CO_2 pipelines as “pollution control devices” to enable tax abatement.



Technology Deployment & Cost Reductions

Update and Expand Technology R&D and Demonstration

Passed Senate

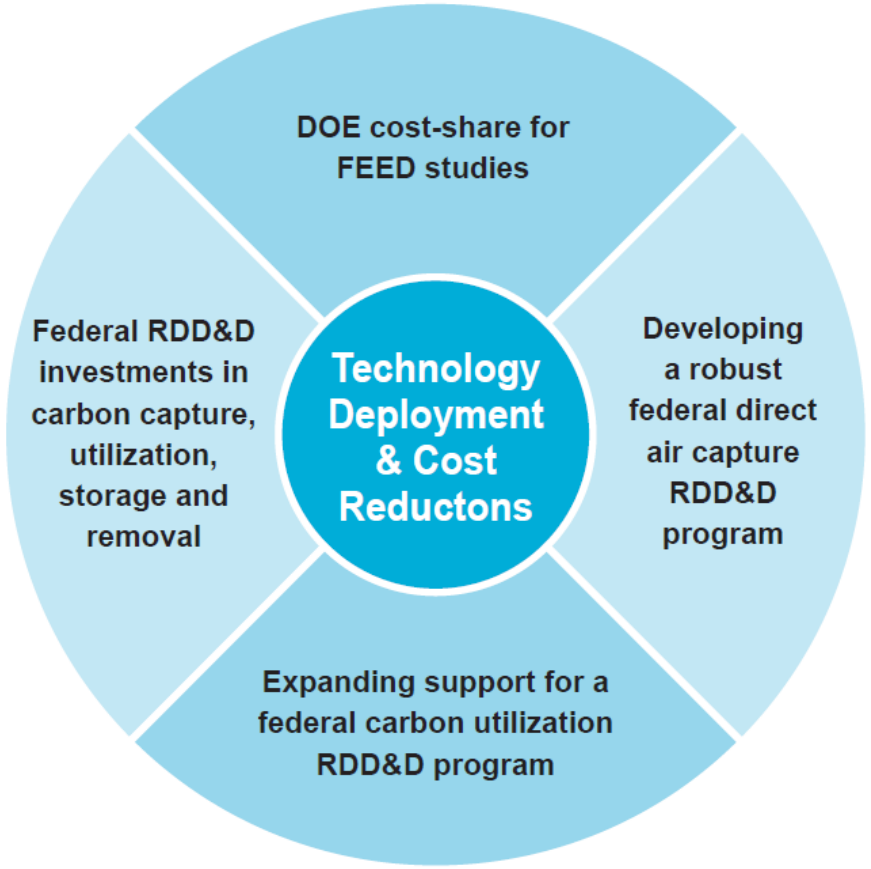
- USE IT Act (S. 383, H.R. 1166)

Included in Current Senate Energy Package:

- The EFFECT Act (S. 1201)
- LEADING Act (S. 1201)
- Clean Industrial Technology Act (S. 2300)

Reported out of House Committees:

- Fossil Energy R&D Act (H.R. 3607)
- Companion Clean Industrial Technology Act (H.R. 3978)



CARBON CAPTURE COALITION

Rapid Response on Carbon Capture Provisions for COVID 19-Related Economic Stimulus Legislation

- Three and possibly four tranches of response/stimulus:
  - First and second completed
  - Third focused on workers, key industries and economic stimulus being debated and voted on now
  - Fourth on further economic stimulus anticipated for April.
- Affected industries, including clean/low-carbon energy sectors mobilizing to provide input.
- Importance of ensuring component for carbon capture, transport, use, removal and storage.

Rapid Response on Carbon Capture Provisions for COVID 19-Related Economic Stimulus Legislation

- Development of proposed carbon capture provisions underway through Carbon Capture Coalition to restore certainty and confidence and enable projects to proceed faster to sustain economic activities and jobs:
  - **Tax component**: 5-year extension & direct pay for 45Q, plus 48A and BEAT tax fixes
  - **Infrastructure component**: Cost-share for CO2 transport development to enable carbon capture projects and associated economic activity to proceed in near term with 45Q (especially lower cost industrial facilities)
  - **Demonstration component:** Targeted resources for technology demonstration and projects in sectors with higher costs and less commercial deployment that will otherwise stall out in current economic environment.
- Coalition's proposed tax measures released to Congress and the media last week.

CLEAN AIR TASK FORCE

Geologic CO_2 Storage Senate Staff Briefing

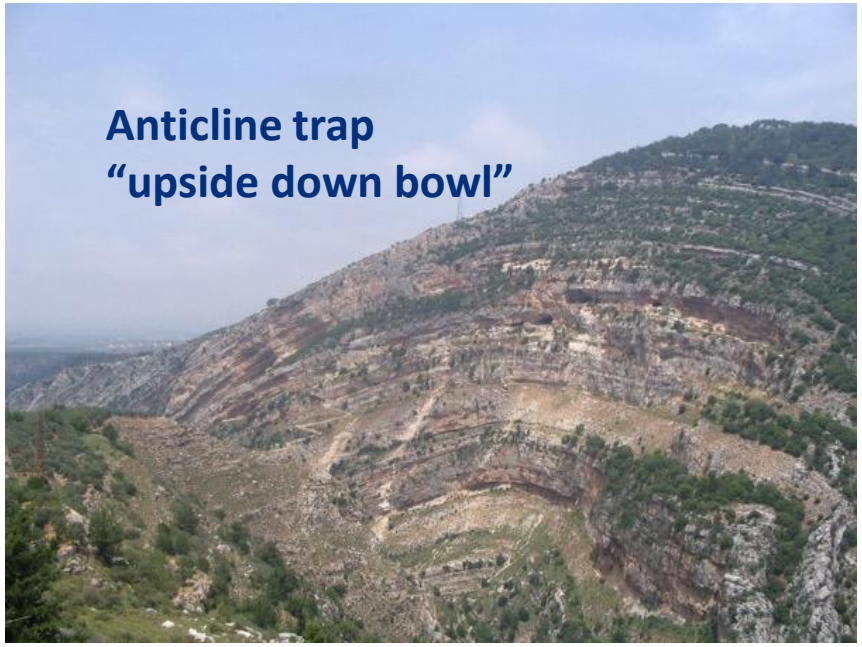
Bruce Hill, Ph.D., Chief Geologist |
January 24, 2020

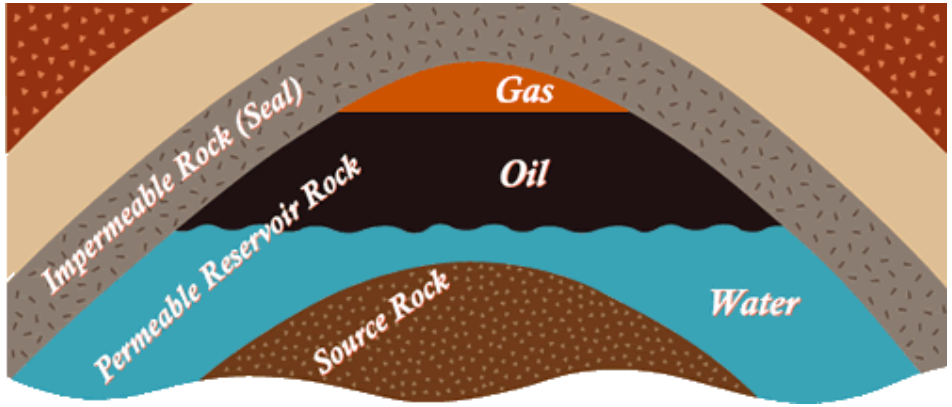
Thousands of Feet of Rock Beneath Our Feet!

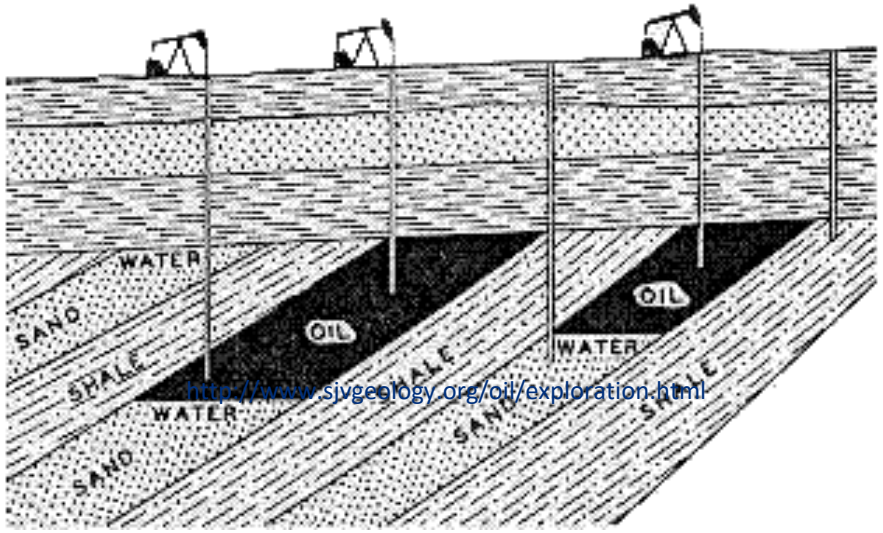
Permeable Sandstone Wall Illustrates Thickness and Volume of High-Quality Storage Formations

Caprock Seal: Overlying Impermeable Shale

Traps: Sealing in The CO_2







http://www.sjvgeology.org/oil/exploration.html

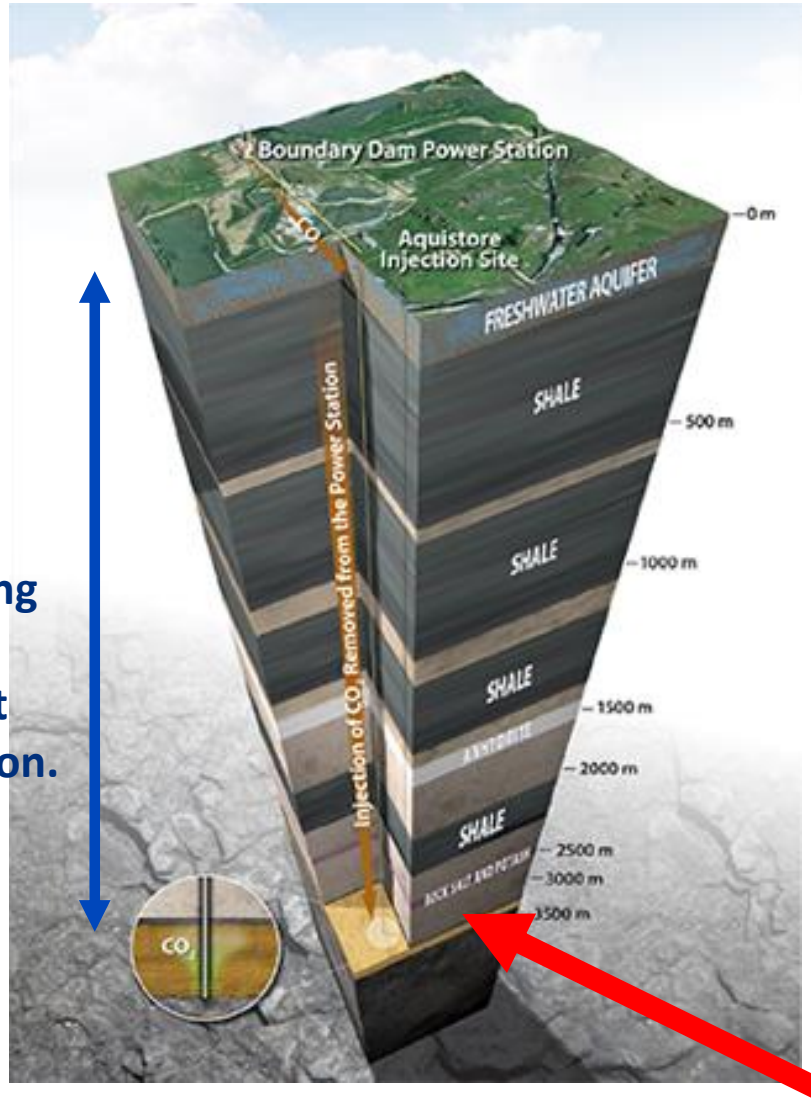
U.S.G.S Geologic Carbon Storage: 2,400-3,700 GT*

For Reference: U.S. EGUs 2 GT per year // U.S. Total CO_2 5 GT per year.

* https://www.usgs.gov/faqs/how-much-carbon-dioxide-can-united-states-store-geologic-sequestration?qt-news_science_products=0#qt-news_science_products

1. Deep Continental “Saline” Storage

Lots of rock to with confining zones prevent migration.



Source: Aquistore

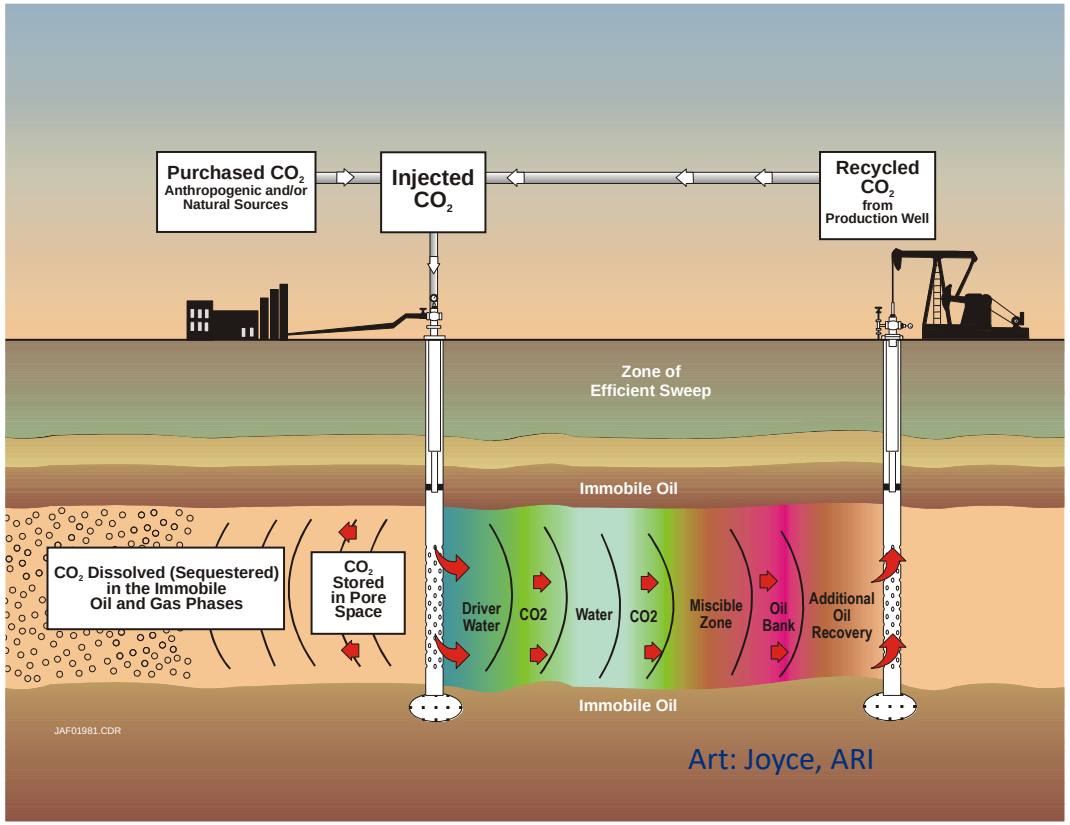
Compressed “supercritical” (dense phase) CO_2 is injected into porous formations (e.g. sandstone, carbonate) containing non-potable saltwater brine. Some of the CO_2 is immediately trapped in the rock pores by capillary forces.

The saline formation is at great depth, far below drinking water.

CO_2, trapped by overlying sealing rocks, then dissolves into the brine and may eventually form carbonate minerals such as calcite.

DEEP SALINE

2. Enhanced Oil Recovery & Storage (EOR)



Art: Joyce, ARI

Exhibit 3 Permian Basin CO_2 pipeline infrastructure

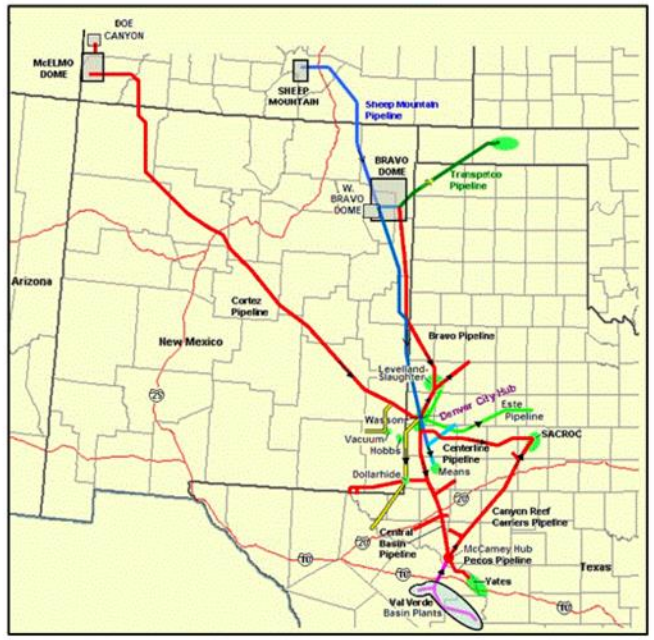
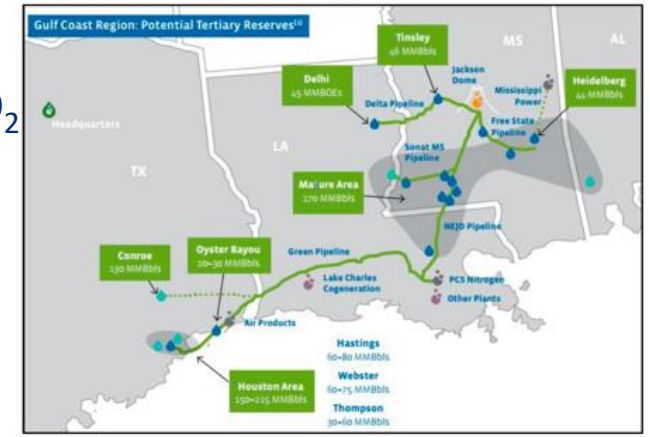


Exhibit 5 Gulf Coast CO_2 pipeline infrastructure



Where Sequestration Technology Started: Half a century of CO_2 injection technology developed through EOR. Injected CO_2 is never released into the atmosphere. Instead CO_2 is recycled & progressively trapped in rock pores, And, its hard to remove!

Advantages: Injections are into known formations with known seal that has kept HCs in place for millions of years. Existing pipeline and injection infrastructure in brownfield environment.

What EOR-Storage Looks Like

North Ward Estes Field-Permian Basin

Reinject

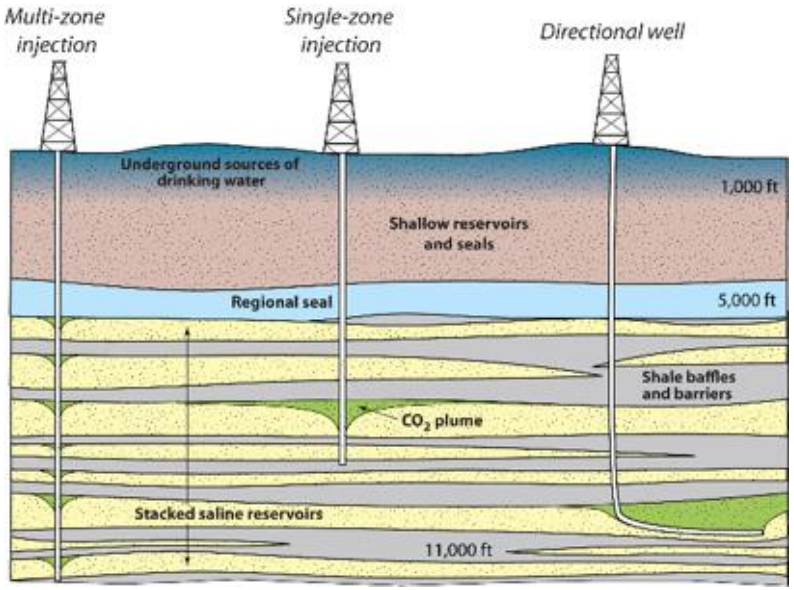
Photos: B Hill/CATF

“Stacked” Storage: Repetition of Storage Formation Rock

Repetitive marine geologic sequences are formed by the rise and fall of sea level over millions of years.

“Stacks” of storage formations are separated by repetitive/redundant trapping formations.

This means secure storage resources could be accessed in both a) saline storage-only sequences and b) in saline formations beneath oil fields where CO_2 infrastructure currently exists.



System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
	Miocene	Undifferentiated		Freshwater Aquifer
			Chicasawhay Fm.	Base of USDW
	Oligocene	Vicksburg Group	Bucatunna Clay	Local Confining Unit
	Eocene	Jackson Group		Minor Saline Reservoir
		Claiborne Group	Talahatta Fm.	Saline Reservoir
		Wilcox Group	Hatchetigbee Sand	Saline Reservoir
	Paleocene		Bashi Marl	
			Salt Mountain LS	
		Midway Group	Porters Creek Clay	Confining Unit
Cretaceous	Upper	Selma Group		Confining Unit
		Eutaw Formation		Minor Saline Reservoir
		Tuscaloosa Group	Upper Tusc.	Minor Saline Reservoir
			Mid. Tusc. Marine Shale	Confining Unit
			Lower Tusc. Pilot Sand / Massive sand	Saline Reservoir
Cretaceous	Lower	Washita-Fredericksburg	Dantzler sand / Basal Shale	Saline Reservoir / Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	Proposed Injection Zone
		Mooringsport Formation		Confining Unit
		Ferry Lake Anhydrite		Confining Unit
		Donovan Sand	Rodessa Fm. 'Upper'	Oil Reservoir
			'Middle'	Minor Saline Reservoir
			'Lower'	Oil Reservoir

Illustrations: J. Pashin.