Building to Net-Zero

A U.S. POLICY BLUEPRINT FOR GIGATON-SCALE CO_2 TRANSPORT AND STORAGE INFRASTRUCTURE

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Foreword

We are pleased to release *"Building to Net-Zero: A U.S. Policy Blueprint for Gigaton-Scale CO_2 Transport and Storage Infrastructure,"* where we describe a comprehensive policy blueprint to enable the build out of CO_2 infrastructure to support gigaton scale emissions reductions in a manner that supports U.S. industry and its workforce, and creates new, good-paying jobs.

This report was prepared by the Labor Energy Partnership (LEP) between the Energy Futures Initiative and the AFL-CIO, which is guided by the following principles:

- Successful social solutions to climate change must be based on an "all-of-the above" energy source strategy that is regionally focused, flexible, preserves optionality, and addresses the crisis of stranded workers.
- An essential priority of all climate policy solutions is the preservation of existing jobs, wherever possible, and the creation of new ones that are equal to or better than those that are displaced.
- Climate policy represents an economic opportunity to the United States when the benefits of new technology deployment result in the creation of quality jobs and the creation of competitive domestic supply chains.

Translating these principles into action requires massive investments to mitigate climate change and policies that support the creation of new industries based on emerging clean-energy technologies, including carbon capture and storage (CCUS) systems. This study is a follow-on to a workshop we held last December. The study focuses on policies and regulations that can expedite the creation of carbon dioxide transportation and storage infrastructure to support rapid and deep decarbonization of both industry and power generation, as well as new technologies like direct air capture and bioenergy with CCUS.

We believe these are essential technologies and actions and look forward to working with industry, policymakers, and other stakeholders to translate the recommendations in this study into deep decarbonization actions for the nation.

Ernest Moniz	**Richard Trumka**
President & CEO,	*President,*
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About

About the Labor Energy Partnership
The Labor Energy Partnership (LEP) is based on a shared commitment of the American Federation of Labor and Congress of Industrial Organizations (AFL-CIO) and the Energy Futures Initiative to promote federal, regional, and state energy policies that address the climate crisis while recognizing the imperatives of economic, racial, and gender justice through quality jobs and the preservation of workers' rights.

About the Energy Futures Initiative
The Energy Futures Initiative (EFI) advances technically grounded solutions to climate change through evidence-based analysis, thought leadership, and coalition-building. Under the leadership of Ernest J. Moniz, the 13th U.S. Secretary of Energy, EFI conducts rigorous research to accelerate the transition to a low-carbon economy through innovation in technology, policy, and business models. EFI maintains editorial independence from its public and private sponsors. www.energyfuturesinitiative.org

About the AFL-CIO Energy Committee
The Energy Committee of the AFL-CIO Executive Council was formed in 2013. The committee is chaired by Cecil E. Roberts, who has been president of the United Mine Workers since 1995 and is a sixth-generation coal miner. The committee's vice-chair is Lonnie R. Stephenson, International President of the International Brotherhood of Electrical Workers, who began his IBEW career in 1975 as an apprentice wireman in Rock Island IL. The committee also includes the Laborers International Union of North America, the United Association of Plumbers, Fitters, Welders & Service Techs, the International Union of Operating Engineers, the United Steelworkers, the Utility Workers Union of America, the International Brotherhood of Boilermakers, the International Federation of Professional and Technical Engineers, the International Association of Bridge, Structural, Ornamental and Reinforcing Iron Workers Union, and North America's Building Trades Unions.

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Acronyms

Bioenergy with carbon capture and storage (BECCS)

Bureau of Land Management (BLM)

Bureau of Ocean Energy Management (BOEM)

Carbon capture, utilization, and storage (CCUS)

Carbon dioxide (CO_2)

Carbon Storage Assurance Facility Enterprise (CarbonSAFE)

Council for Environmental Quality (CEQ)

Carbon dioxide removal (CDR)

Competitive Renewable Energy Zone (CREZ)

Direct air capture (DAC)

Direct air carbon capture and storage (DACCS)

Department of Defense (DOD)

Department of Energy (DOE)

Department of the Interior (DOI)

Department of Labor (DOL)

Department of Transportation (DOT)

Environmental Assessment and Finding of No Significant Impact (EA/FONSI)

Enhanced oil recovery (EOR)

Environmental Impact Statement (EIS)

Environmental justice (EJ)

Environmental Protection Agency (EPA)

Front-end engineering and design (FEED)

Federal Energy Regulatory Commission (FERC)

Federal Highway Administration (FHWA)

Intergovernmental Panel on Climate Change (IPCC)

Internal Revenue Service (IRS)

International Energy Agency (IEA)

Memorandum of understanding (MOU)

Nationally Determined Contribution (NDC)

National Environmental Protection Act (NEPA)

National Energy Technology Laboratory (NETL)

National Technical Workgroup (NTW)

Outer Continental Shelf (OCS)

Pipeline and Hazardous Materials Safety Administration (PHMSA)

Regional Carbon Sequestration Partnership (RCSP)

Renewable Fuel Standard (RFS)

Rights-of-way (ROW)

State Departments of Transportation (SDOT)

Underground Injection Control (UIC)

U.S. Forest Service (USFS)

U.S. Fish and Wildlife Service (USFWS)

Wind Energy Area (WEA)

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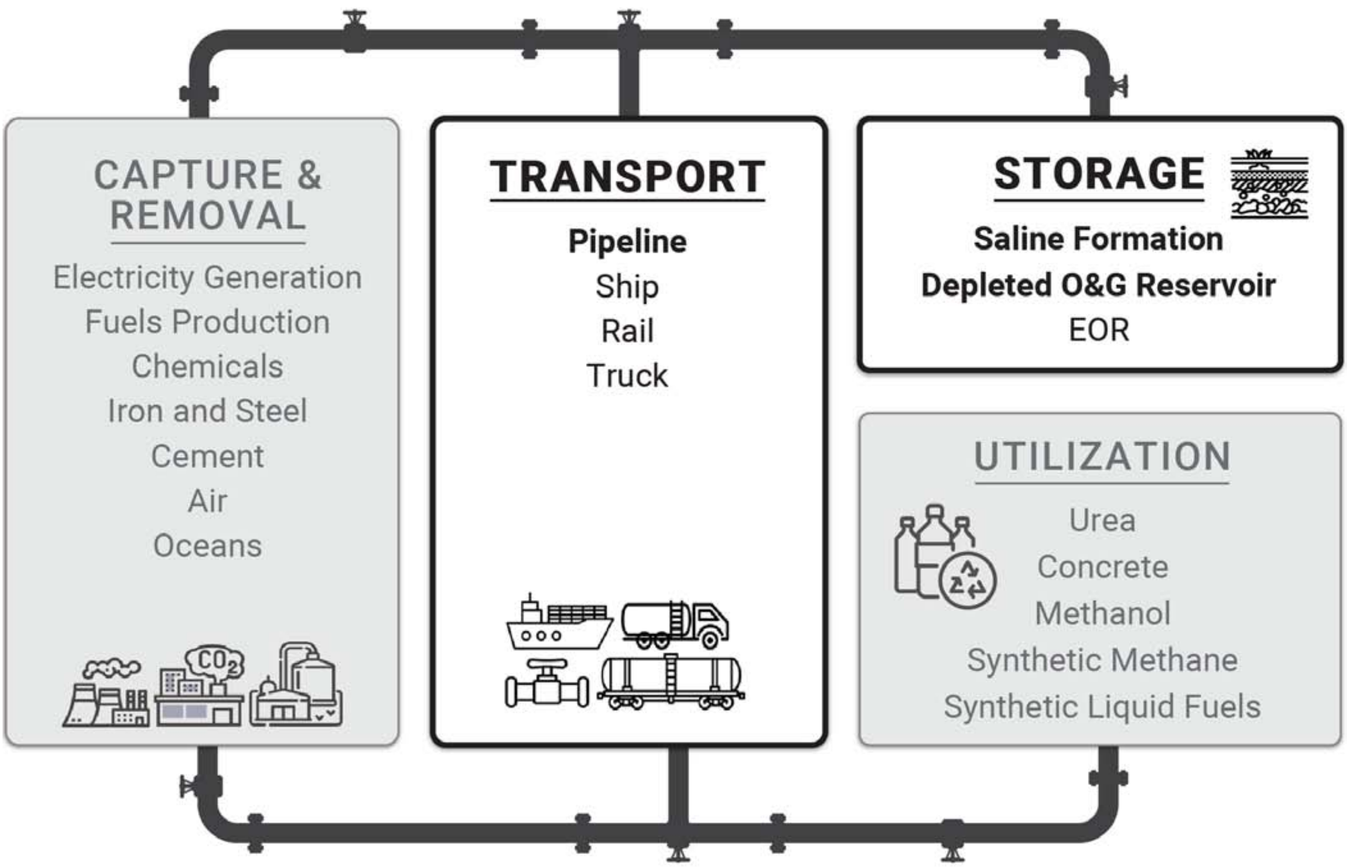
CHAPTER 1

Introduction

The Biden Administration's recent announcement of a U.S. Nationally Determined Contribution (NDC) of at least 50 percent economywide emissions reduction by 2030, and the longer-term goal of net-zero emissions by 2050, are a reminder of the urgent action required to avert the worst impacts of climate change. Exactly how the United States will reach these targets is yet unknown; what is certain, however, is that such ambitious targets can only be met by pursuing the widest possible suite of emission reduction pathways.

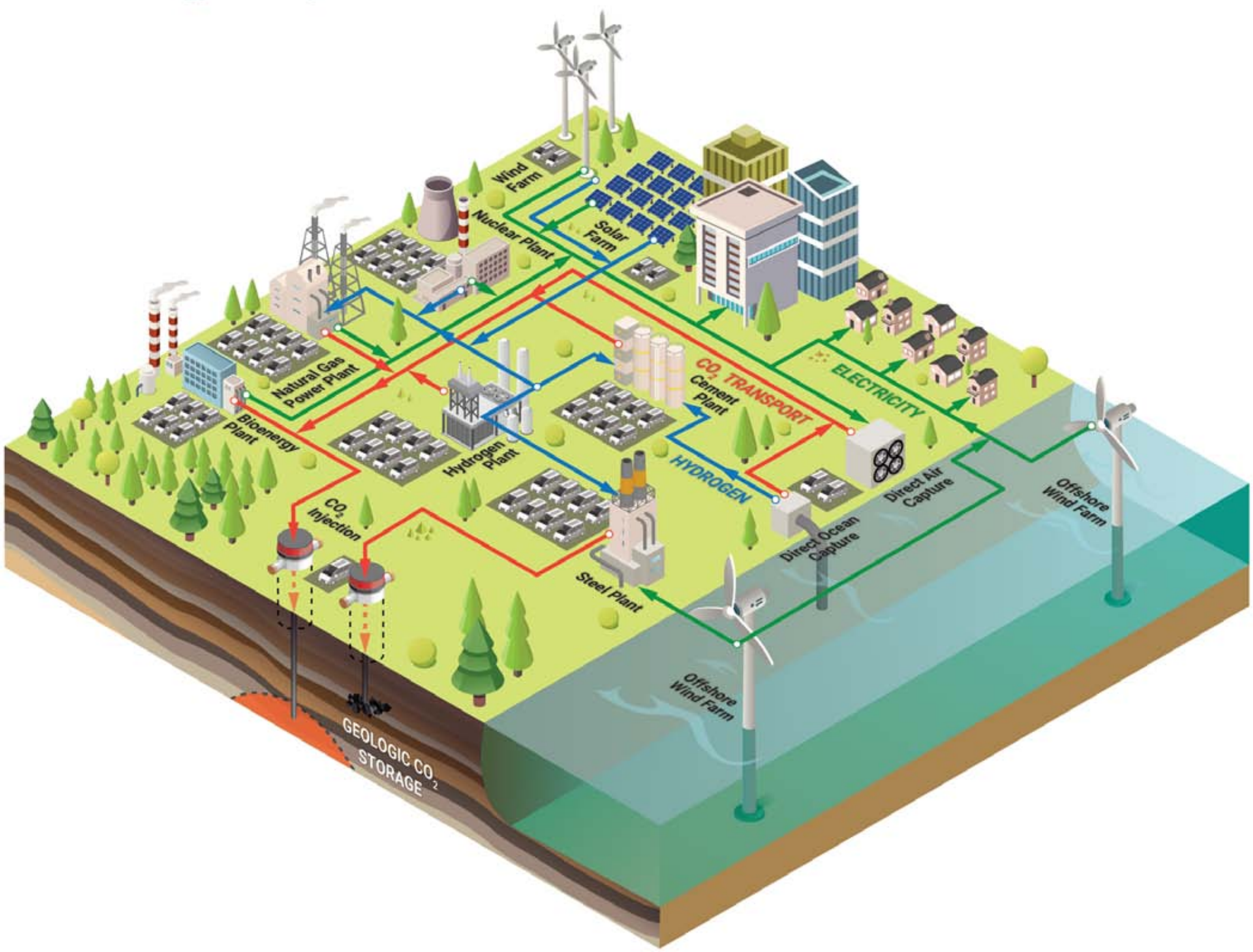
FIGURE 1
Overview of CO_2 Capture, Removal, Transport, Storage, and Utilization Pathways



CO_2 capture, transport, storage, and utilization includes several technologies, sectors, and processes. This report focuses on CO_2 transport and storage infrastructure, primarily pipelines and geologic storage in saline formations and depleted oil and gas (O&G) reservoirs.

Among that suite of options is point source carbon dioxide (CO_2) capture, utilization, and storage (CCUS) as well as carbon dioxide removal (CDR) from the atmosphere and oceans that are enabled by CO_2 transport and storage infrastructure (Figure 1). Combined, these pathways can support gigaton-scale CO_2 emissions reduction by midcentury; preserve jobs in hard-to-decarbonize sectors; and create new industries and additional, good-paying jobs.

FIGURE 2
Large-Scale CO_2 Transport and Storage Infrastructure Supporting Multiple Sectors and Clean Energy Pathways



CO_2 transport and storage infrastructure could connect multiple CO_2 capture and removal sites, supporting multiple clean energy pathways across multiple economic sectors. The number of cars at respective sites notionally represents the relative number of jobs that the facility supports.

CO_2 capture, removal, transport, storage, and utilization pathways are complementary to other abatement strategies and can accelerate the pace at which other sectors reduce emissions. For example, carbon capture in the electricity sector can support both increased renewable energy generation and support grid reliability by enabling low-carbon firm power generation. Fuels produced with carbon capture have lower lifecycle emissions, helping to decarbonize transportation and industrial end uses that are difficult to electrify (e.g., heavy-duck trucks, aviation, steel, and iron). Cleaner materials production (e.g., carbon capture for cement production or CO_2 utilization in concrete) can lower emissions associated with infrastructure and the built environment; while important, utilization options are not adequate for removing, transporting, and sequestering CO_2 at the gigaton scale. CDR can remove CO_2 emissions already in the atmosphere, helping to enable net-zero emissions and avoid the most catastrophic climate impacts. Across these sectors, CO_2 infrastructure enables U.S. industry to provide goods and services while also sustaining and creating good-paying jobs (Figure 2).

Like so many sectors of the U.S. economy, infrastructure is the foundation of widespread deployment of CCUS and CDR yet is among the most challenging components of project development. A 2020 analysis from the Energy Futures Initiative and Stanford University found that issues related to siting, permitting, and long-term liability of geologically stored CO_2 are some of the key impediments to CCUS project development, slowing the deployment of capture facilities for lack of places to transport and store the captured CO_2.[1]

This report focuses on the CO_2 transport and storage infrastructure that collects CO_2 from any source and moves it to a location where it is used or permanently stored.

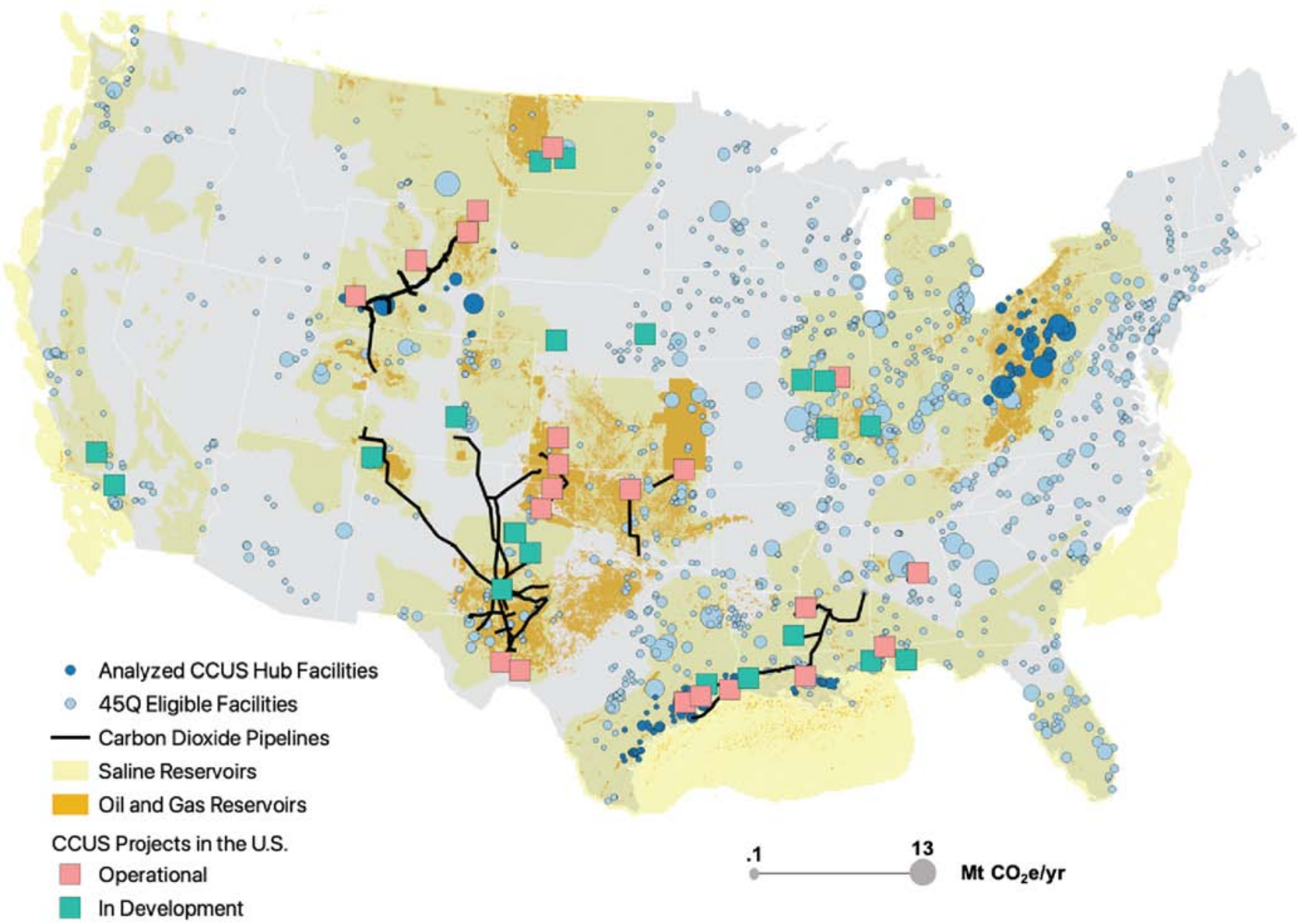
This report presents a strategic policy framework for federal action to support the development of the necessary infrastructure, the associated jobs, and robust pathways to net-zero emissions by midcentury. It focuses on the CO_2 transport and storage infrastructure that collects CO_2 from any source—for example, from CO_2 captured at an industrial plant or through direct air capture (DAC)—and moves it to a location where it is used or permanently stored deep underground. Capturing and removing carbon at a large scale will require support from existing industries and workers to build and operate infrastructure while helping to create new businesses and opportunities for workers in transition.

Current Status of Carbon Capture, Removal, Transport, Storage, and Utilization Projects

CCUS technologies are commercially-ready decarbonization pathways. As of June 2021, there were 70 commercial-scale CCUS projects operating or in development around the world.[a,2] In the United States, there were 12 commercial and seven demonstration carbon capture facilities in operation, capturing CO_2 from a wide variety of sources including hydrogen production via steam methane reforming, ethanol production, natural gas processing, fertilizer production, and power generation (Figure 3). Many of these facilities are near the country's 4,500 miles of CO_2 pipelines,[3] and all but one use CO_2 for enhanced oil recovery (EOR), in which CO_2 is injected underground to release crude oil and in so doing is permanently stored there.

[a] Of these facilities 28 are operational, 21 are in advanced development (i.e., under construction or in an advanced planning stage), and 21 are in early development (i.e., early planning). Only 10 of the projects in development have clarified they are using the CO_2 via EOR. At least 26 projects in development have clarified they intend to store CO_2 in permanent geologic storage.

FIGURE 3
Major CO_2-Emitting Facilities, CCUS Projects, and CO_2 Pipelines in the United States



There are 19 operational CCUS projects, more than 4,500 miles of CO_2 pipelines, and approximately 1,500 facilities eligible for the Section 45Q tax credit (i.e., industrial facilities emitting at least 100,000 metric tons of CO_2 emissions each year and power generators emitting at least 500,000 metric tons).[b,4] Another 22 CCUS projects are in development, three of which are hubs intended for the storage of multiple surrounding emitting facilities. The facilities shown in dark blue are further examined in callout boxes below as a part of a regional CO_2 hubs analysis.[5]

[b] Pipelines are estimated based on a 2015 DOE Report, "A Review of the CO_2 Pipeline Infrastructure in the U.S."

Most CCUS projects to date have stored CO_2 using EOR because the produced oil provides a source of revenue, but project developers are increasingly pursuing CO_2 storage in saline formations; of 22 CCUS projects in development in the United States, at least eight are pursuing storage in saline formations, with the remainder focused on EOR.[6] Saline formations—rock formations deep underground that contain highly saline water unsuitable for drinking or other uses—provide a much greater total storage capacity than do oil and gas reservoirs and must be prioritized for CCUS projects to reach meaningful scale.

Technological CDR[c] is at an earlier stage of development compared to CCUS, though there are several deployed projects and more underway: there are 15 DAC projects across the United States, Canada, and Europe, with the world's first large-scale plant (storing more than one million metric tons of CO_2 annually) under development in West Texas; four bioenergy with carbon capture and storage (BECCS) projects in the United States alone, including one large-scale plant in Illinois, with two more in development; and multiple demonstrations of carbon mineralization using captured CO_2 in the United States and Canada.[7,8,9]

[c] U.S. researchers and companies are developing both natural and technological CDR solutions. Natural CDR includes afforestation, reforestation, and soil carbon management; technological solutions include direct air capture (DAC), direct ocean capture, enhanced carbon mineralization, and bioenergy with carbon capture and storage (BECCS).

CHAPTER 2

Opportunities for CO_2 Infrastructure Deployment

CO_2 capture, removal, transport, storage, and utilization pathways are a critical complement to other emission reduction strategies and an integral component of a net-zero carbon economy. While these pathways have received recent legislative support (Box 1), additional federal actions are required to fully realize the potential contributions of large-scale CO_2 transport and storage infrastructure deployment to national climate policy objectives:

- Deploying CO_2 transport and storage infrastructure supports **near-term, economywide emissions reduction and removal of CO_2 from the atmosphere.** CO_2 capture and removal infrastructure can be built in most regions of the country, is highly scalable, is commercially proven across a range of industries, and can be tailored to each region's natural and human resources.

- CO_2 capture **preserves jobs in hard-to-decarbonize sectors** that underpin the nation's clean industrial development. While decarbonizing any aspect of the economy presents significant challenges—including cost, technology readiness, and consumer behavior, among others—some industries that are critical to our economy simply do not have other decarbonization technology options. CO_2 capture provides avenues to create clean domestic supply chains that preserve jobs in industries such as iron and steel, cement, dispatchable power generation, aviation, shipping, and heavy-duty transportation.[10]

- Building and operating large-scale CO_2 infrastructure **creates new industries and additional good-paying jobs** for U.S. workers, often relying on the skillsets common to existing emissions-intensive industries.

BOX 1

Support for CO_2 Infrastructure from the 116th U.S. Congress

The Energy Act of 2020 (Division Z of the Consolidated Appropriations Act of 2020) authorized federal cost-shared funding of over $4 billion for CO_2 capture and storage projects, with $1 billion for commercial-scale pilot projects and $2.6 billion for demonstration projects.[11] In addition to new funding authorizations, the omnibus increased the accessibility of tax equity financing by extending eligibility for projects to receive the 45Q tax credit by two years.[12] The omnibus also included the USE IT Act, which lowered regulatory hurdles by making CCUS projects eligible for permitting reviews under the FAST Act and directing the Council on Environmental Quality to issue guidance.[13]

While these measures will provide significant incentive to deploy CO_2 capture and related CO_2 transport and storage infrastructure, additional policy support and immediate actions across the federal government can accelerate the pace and increase the scale of deployment.

Support Near-term, Economywide Emissions Reduction and CO_2 Removal

With a range of commercially available and near-commercial options for capturing, removing, storing, and using a large portion of U.S. CO_2 emissions, large-scale CO_2 transport and storage infrastructure could enable emissions reduction on a gigaton scale. A gigaton (one billion metric tons) of CO_2 captured or removed each year would be equivalent to eliminating a third of electricity and industrial sector emissions in the United States in 2019 or removing over 200 million cars from the road.[14]

U.S. economywide greenhouse gas emissions totaled nearly 6.6 gigatons of carbon dioxide equivalent ($GtCO_2e$) in 2019. CO_2 accounted for 80 percent of these emissions, methane accounted for 10 percent, and the remaining 10 percent is attributable to other greenhouse gases.[15] Roughly 40 percent came from large stationary sources (i.e., industrial facilities and power plants), while the remaining emissions came from smaller stationary sources and non-point sources (e.g., transportation, building energy use, and non-energy sources). Of those stationary sources, more than 1,500 large facilities with significant emissions across several sectors—including power generation, metals, oil and gas, and chemicals—are eligible for the U.S. Tax Code Section 45Q tax credit (Figure 3).[d,e] In total, these facilities emit more than two $GtCO_2e$ annually, approximately 36 percent of U.S. emissions in 2019.

Global emissions need to reach net-zero and even net-negative levels this century to limit warming to 1.5 degrees Celsius (°C). All scenarios that meet the Intergovernmental Panel on Climate Change (IPCC) 1.5 °C target require removing 100 to 1,000 $GtCO_2$ by 2100.[16] Achieving these levels of emissions reductions will require both CCUS and robust CDR deployment, in which emissions already released into the atmosphere and oceans are removed.[17,18,19,20,21] CDR can compensate for the emissions from difficult-to-decarbonize sectors, such as agriculture, waste, heavy industry, and aviation, that have limited mitigation options.[22]

Two prominent CDR pathways—bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS)—will often require CO_2 transport and storage infrastructure, though these requirements could be smaller for pathways that utilize instead of store captured CO_2. This infrastructure is also crucial for other CDR pathways that require CO_2 offtake or input, such as electrochemical seawater carbon extraction and subsurface carbon mineralization. Such infrastructure can also enable CO_2 utilization for useful products, helping to defray the costs of CDR and CCUS.

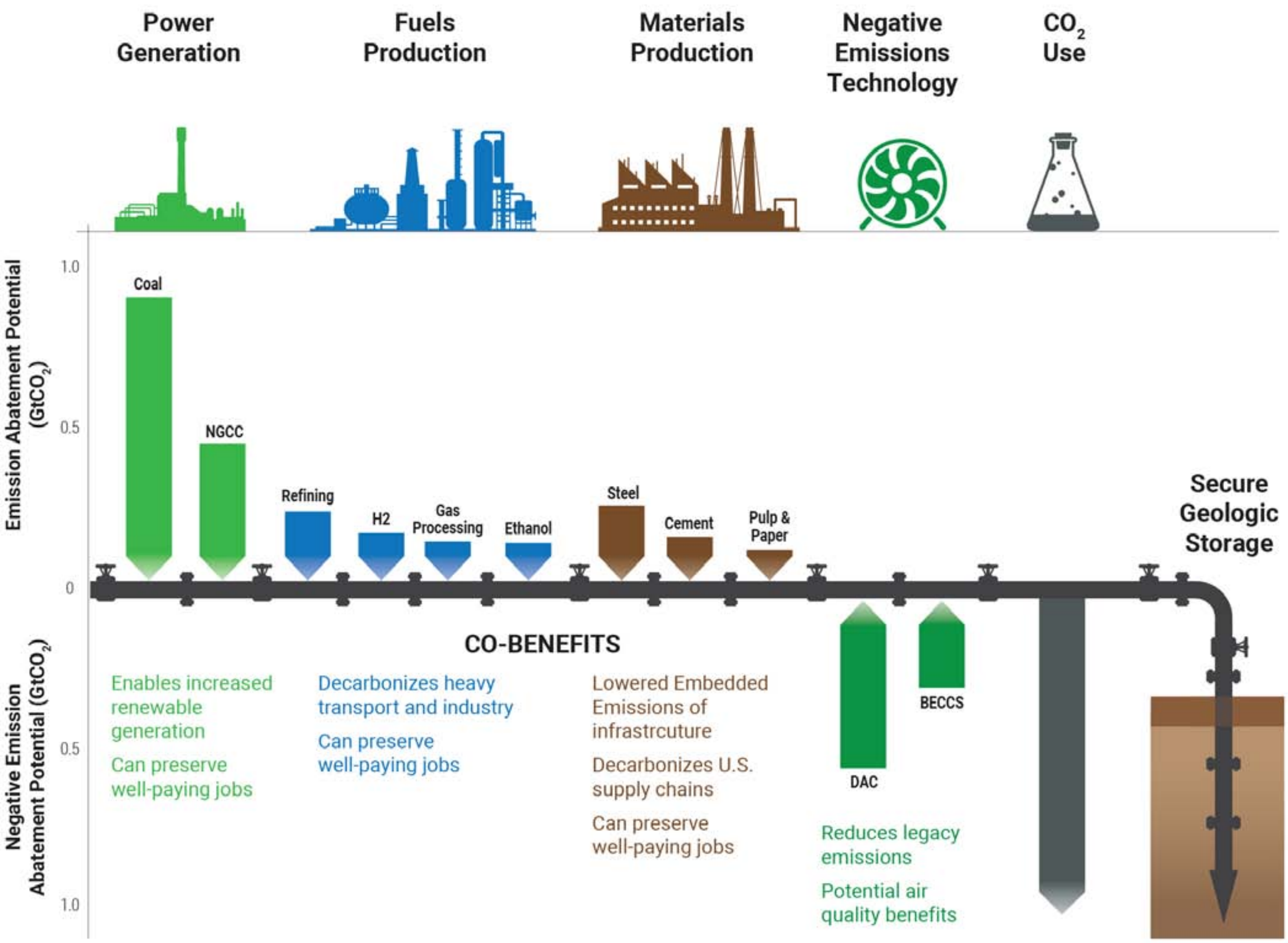
The potential gigaton scale of emissions abatement and negative emissions opportunities unlocked by CO_2 transport and storage infrastructure is illustrated in Figure 4. CO_2 carried by shared pipelines can deliver CO_2 for utilization as well as permanent geologic storage and unlock co-benefits for jobs and economywide decarbonization.

[d] Originally established in 2008, the U.S. Tax Code Section 45Q Tax Credit is a tax incentive for dedicated geological CO_2 storage, CO_2 for EOR, and CO_2 utilization.

[e] According to the 2019 EPA Greenhouse Gas Reporting Program data, approximately 1,500 facilities meet the eligibility threshold for the Section 45Q tax credit for carbon sequestration: 100,000 metric tons of CO_2 emissions annually for industrial facilities and 500,000 metric tons annually for power generators.

FIGURE 4

Emissions Abatement and Negative Emissions Opportunities Unlocked by CO_2 Infrastructure



Emissions abatement for power generation, fuels production, and materials production is based on multiplying current U.S. emissions levels in these sectors by a reasonable capture percent (65-95 percent, depending on the emissions source). Negative emissions potential for BECCS is based on lifecycle emissions (not total CO_2 captured at BECCS plants) and the potential for DAC is based on potential deployment by 2030. The CO_2 use estimate assumes that the CO_2 is not used for EOR based on National Academies estimates in 2019. Sources and methodology for estimates in the figure are provided in the appendix.

The nine sectors and three negative emissions and CO_2 reduction pathways shown in Figure 4 were evaluated as potential options enabled by the deployment of large-scale CO_2 infrastructure, described in Table 1. The 2020 emissions were determined for each sector, based on publicly available data, and the CO_2 capture rates and CO_2 use and removal potential were based on a review of the literature.

TABLE 1

Emissions Abatement and Negative Emissions Opportunities Unlocked by CO_2 Infrastructure

Technology	2020 Emissions ($MtCO_2e$)	Estimated Capture Rate (Percent)	Carbon Use/Removal Potential ($GtCO_2e$)
Natural Gas Combined Cycle Facilities	560[a]	85[e]	
Coal Power Plants	952[a]	90[e]	
Ethanol Plants	44[a]	60[f]	
Refining	178[b]	65[g]	
Pulp & Paper	26[b]	75[g]	
Cement	67[b]	88[h]	
Gas Processing	58[b]	99[g]	
Hydrogen Production	95[c]	90[h]	
Steelmaking	191[d]	86[g]	
Direct Air Capture			0.5[i]
CO_2 Use			1.0[j]
Bioenergy with CO_2 Capture			0.25[k]

[a] U.S. Energy Information Administration, "Frequently Asked Questions (FAQS): How much carbon dioxide is produced per kilowatthour of U.S. electricity generation?" December 15, 2020, https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

[b] U.S. EPA, "Greenhouse Gas Reporting Program (GHGRP): GHGRP Refineries," September 26, 2020, https://www.epa.gov/ghgreporting/ghgrp-refineries

[c] U.S. Department of Energy, "DOE Hydrogen and Fuel Cells Program Record," October 1, 2019, https://www.hydrogen.energy.gov/pdfs/19002-hydrogen-market-domestic-global.pdf

[d] U.S. Steel, "Sustainability Report 2019," May 2020. p. 42. https://www.ussteel.com/documents/40705/43725/U.+S.+Steel+2019+Sustainability+Report_web.pdf/52f7fb7e-a2aa-c80b-7d72-202afc5ab5ff?t=1603766679756,

[o] World Steel Association, "Global crude steel output increases by 3.4% in 2019," January 27, 2020, https://www.worldsteel.org/media-centre/press-releases/2020/Global-crude-steel-output-increases-by-3.4--in-2019.html.

[e] Babaee, S. and Loughlin, D.H., "Exploring the role of natural gas power plants with carbon capture and storage as a bridge to a low-carbon future," *Clean Technologies and Environmental Policy* 20, 2018: 379–391. https://doi.org/10.1007/s10098-017-1479-x.

[f] Sanchez, D. L. et al., "Near-term deployment of carbon capture and sequestration from biorefineries in the United States," *Proceedings of National Academy of Science of the United States of America*, May 8, 2018, 4875-4880. https://www.pnas.org/content/115/19/4875

[g] Leeson, D. et al., "A Techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the iron and steel, cement, oil refining and pulp and paper industries, as well as other high purity sources," *International Journal of Greenhouse Gas Control*, Volume 61. 2017: 71-84. https://doi.org/10.1016/j.ijggc.2017.03.020

[h] Collodi, G. et al., "Techno-economic Evaluation of Deploying CCUS in SMR Based Merchant H_2 Production with NG as Feedstock and Fuel," *Energy Procedia*, 114, 2017: 2690-2712. https://doi.org/10.1016/j.egypro.2017.03.1533,

[i] Fasishi et al., "Techno-economic assessment of CO_2 direct air capture plants," *Journal of Cleaner Production*, Volume 224, July 1, 2019. https://www.sciencedirect.com/science/article/pii/S0959652619307772

[j] National Academies of Sciences, Engineering, and Medicine. *Gaseous Carbon Waste Streams Utilization: Status and Research Needs*. Washington, DC: The National Academies Press. 2019. https://doi.org/10.17226/25232

[k] National Academies of Sciences, Engineering, and Medicine. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: The National Academies Press. 2019. https://doi.org/10.17226/25259

Many regions in the United States have subsurface geology suitable for permanent CO_2 storage. There are two subsurface geologic features required to securely store CO_2. The first is a thick reservoir with sufficient porosity (like the many holes of a sponge) to hold large volumes of CO_2, with enough permeability (i.e., the ease with which CO_2 flows between the holes of the sponge) to handle large-scale injections. The second required geologic feature is a strong rock layer above the storage reservoir with low permeability that can effectively cap the storage reservoir and prevent the CO_2 from migrating back to the surface.[23] Suitable formations for permanent geologic CO_2 storage include deep (>800 meters) salt water-containing saline formations and depleted oil and gas reservoirs.[24] While local characterization is needed to determine the actual feasibility of any geologic storage project, one estimate of the U.S. geologic storage potential of CO_2 in saline formations alone is more than 2,000 gigatons, including offshore reservoirs in the Outer Continental Shelf (OCS).[25]

There are several factors assessed to determine the suitability of a site for CO_2 storage, including the absence of permeable faults, low seismicity, geo-mechanical conditions, and compatibility with existing above-ground land use. The potential for CO_2 leakage is minimal, and the immediate environmental risk of a CO_2 release is much lower than an uncontrolled oil or gas release.

According to an analysis by the IPCC, it is *very likely* that 99 percent of CO_2 injected for underground storage would be secure for 100 years and *likely* that it would be safely stored for 1,000 years.[26] The IPCC further stated that "with appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities;" the safe storage of CO_2 underground from two decades of CCUS projects supports this conclusion.[27]

Reduce Emissions and Preserve Jobs in Hard-to-Decarbonize Sectors

America's industrial workforce is the lifeblood of the economy; without the millions of individuals making concrete, chemicals, steel, and fuels—or producing the electricity that enables all facets of the economy—the nation's economic base could be undermined. Some industrial sectors, however, are particularly difficult to decarbonize without CCUS. Emissions from hard-to-abate sectors, including iron and steel production, cement production, aviation, and marine transportation, accounted for roughly 20 percent of U.S. emissions in 2018.[28] Additionally, a share of U.S. electricity emissions that come from load-following resources and from capacity that supports seasonal demand shifts may also be considered difficult to replace, absent technology innovations and large-scale deployment of long-duration storage. One study estimates that 12 percent of global emissions come from load-following electricity resources.[29]

In many small towns and rural communities across the country, an industrial facility or power plant can underpin the entire local economy. When these facilities shut down, as has occurred across the country, there are few other job opportunities, property values decrease, and funding for key public services like schools and public safety are diminished. Few emissions reduction pathways besides CCUS can so directly preserve and enhance the prosperity of communities while contributing to national climate ambitions.

"CCUS will be key for maintaining good manufacturing jobs as the global economy decarbonizes. It will be particularly important for industries like steel, cement, chemicals, and refining where United Steelworker members work."

—United Steel Workers

As the United States prepares to invest $580 billion or more to revitalize its infrastructure, CCUS provides an opportunity to decarbonize supply chains for new infrastructure projects. Similar to local economies, industries that could reduce their emissions through CCUS are critical for the nation's economy as well. Retrofitting industrial facilities with CO_2 capture equipment lowers the lifecycle emissions of steel, cement, and chemicals; low-carbon products can then be used to domestically produce cleaner energy-efficient equipment, renewable power, transmission lines, roads, and bridges. CO_2 utilization could even result in net negative emissions from industrial products: new types of cement, for example, can lock away captured CO_2 for the life of the materials.

A study of a CCUS and hydrogen hub in the United Kingdom found that over the next decade, the Net Zero Teesside hub could support and safeguard between 8,000 and 16,000 jobs in the chemicals, food products, basic metals, and other energy-intensive trade-exposed industries.[30] The Net Zero Teesside hub could further enable up to 7,000 jobs for industries such as fabrication, metal processing, and battery manufacturing that could use the low-carbon fuels produced by the hub.

As shown in Table 2, CO_2 transport and storage infrastructure enables emissions abatement opportunities from several currently emitting sectors in the United States, in turn sustaining and creating significant job opportunities. The development of robust CO_2 infrastructure provides additional co-benefits to economywide decarbonization that are often overlooked.

> **"In our view, CCUS technologies can help preserve good jobs and create new ones. And those technologies can do so while reducing carbon emissions from essential industries that ensure U.S. economic health and global competitiveness."**
>
> *—International Brotherhood of Boilermakers*

TABLE 2

Benefits of CO_2 Infrastructure Across Industries[c]

	Potential CO_2 Sources	Emissions ($MtCO_2$, % of 2019 U.S. Total)[31] & 2019 Employment[32]	Primary Benefit	Co-Benefit(s)
Power Generation	Natural gas power plants	560 $MtCO_2$,[33] 9% 122,000 jobs	Provides low-carbon, dispatchable power	• Reduces the carbon intensity of firm power generation • Enables greater penetration of variable renewable energy • Preserves high-paying utility sector jobs (even with lower capacity factors)
Power Generation	Coal power plants	952 $MtCO_2$,[34] 15% 80,000 jobs	Reduces carbon intensity of firm power generation	• Can reduce co-pollutants and improve air quality • Preserves good-paying utility sector jobs (even with lower capacity factors)
Power Generation	Bioenergy (Power)	[no emissions data available] 13,000 jobs	Can provide net-zero or net-negative electricity	• Potential to repurpose traditional energy generation assets • Air and water quality benefits assuming sustainable biomass supply/forest management

	Potential CO_2 Sources	Emissions ($MtCO_2$, % of 2019 U.S. Total) & 2019 Employment	Primary Benefit	• Co-Benefit(s)
Fuels Production	Bioenergy (Fuels)	~50 $MtCO_2$,[35] 1% 55,000 jobs (ethanol production), 18,000 jobs (other biofuels)	Reduces carbon intensity of fuels for transportation	• Air and water quality benefits assuming sustainable biomass supply/forest management • Potential monetization of waste products (for second- and third-generation biofuels) • Can transition traditional fossil-powered energy jobs
	Refineries	178 $MtCO_2$, 3% 615,000 jobs (oil and petroleum refineries)	Reduces CO_2 emissions and carbon intensity for fuels and other products	• Reduces carbon intensity of traditional fossil energy
	Gas processing plants	57 $MtCO_2$, 1% 276,000 jobs (traditional gas production)	Reduces CO_2 emissions	• Reduces carbon intensity of traditional fossil energy
	Hydrogen producers	44 $MtCO_2$, 1%*	Reduces carbon intensity of fuels	• Enables decarbonization of industrial sectors • Can produce other low-carbon fuels • Can transition traditional fossil-powered energy jobs
	Ammonia producers	35 $MtCO_2$, <1%*	Reduces CO_2 emissions	• Lowers carbon intensity of fertilizer production
Materials Production	Cement plants	67 $MtCO_2$, 2% 198,300 jobs	Reduces CO_2 emissions that lack alternative abatement pathways	• Lowers embedded carbon of buildings, roads, etc. • Preserves good-paying industrial sectors
	Steel plants	42.6 $MtCO_2$, 1% 86,500 jobs	Reduces CO_2 emissions that lack alternative abatement pathways	• Lowers embedded carbon of buildings, infrastructure, etc. • Preserves good-paying industrial sectors
	Pulp and paper	35.2 $MtCO_2$, <1% 96,300 jobs	Reduces CO_2 emissions that lack alternative abatement pathways	• Lowers embedded carbon of various consumer products • Preserves good-paying industrial sectors

	Potential CO_2 Sources	Emissions ($MtCO_2$, % of 2019 U.S. Total) & 2019 Employment	Primary Benefit	• Co-Benefit(s)
CO_2 Removal	Direct Air Capture	NA*	Removes legacy emissions in the atmosphere	• Potential to use captured CO_2 for fuels, materials, etc. • Negative emissions are secure and easily verifiable
	Direct Ocean Capture	NA*	Removes legacy emissions in the ocean	• Deacidification • Potential to use captured CO_2 for fuels, materials, etc.
	Mineralization (via looping)[f]	NA*	Removes legacy emissions in the atmosphere	• Scalable CO_2 removal at lower cost than DAC • Possible synergies with decarbonization of mining, cement • Potential to use captured CO_2 for fuels, materials, etc.

*No employment data available

Create New Industries and Additional Good-Paying Jobs

Employment in emissions-intensive industries has ebbed and flowed with structural changes in the economy; the imperatives of climate change and the need to reduce carbon emissions will require yet another structural change. Fortunately, the buildout and operation of large-scale CO_2 transport and storage infrastructure provides an opportunity to use the skillsets of workers in emissions-intensive industries that anticipate shrinking workforces in the years ahead. With targeted policy support for the labor force, the buildout of CO_2 infrastructure can help facilitate an equitable and just clean energy transition.

Workers in industries that have declining demand—whether a result of climate mitigation policies or continued structural changes in the global economy—often have the skills necessary for new, clean industries. Implementing CO_2 infrastructure requires boilermakers and construction trades to build capture facilities; pipeline workers and welders to build or repurpose the network of pipes moving CO_2 from emission source to sink; and subsurface engineers, welders, rig operators, and roustabouts to build the wells to permanently store CO_2 underground. These trades stand to gain significant work in new industries and increased demand for their skilled labor; many of these are permanent jobs New low-carbon industries hold enormous promise for wealth creation and job growth, especially for employees located outside of urban areas where job growth over recent years was highest.[36]

The Alberta Carbon Trunk Line, a hub of three CCUS projects in Canada, for example, is estimated to create over 6,000 jobs for those three projects over the four-year construction period.[37] In the United States, NET Power developed an innovative technology for oxygen combustion with CO_2 capture technology for gas-fired power generation and recently initiated the development process for commercial-scale plants in Colorado and Illinois. These projects were estimated to each create 1,000 jobs over the construction and implementation phase.[38,39] While the number of jobs to operate and maintain these facilities is substantially

[f] Only some mineralization pathways, such as magnesium or calcium oxide looping, require CO_2 transport and storage infrastructure for offtake. Other mineralization pathways that could harness CO_2 infrastructure, such as subsurface injection or carbonation of mineral wastes, instead are a source of permanent storage for CO_2 captured from point sources or DAC.

lower, sustained growth of the industry can maintain a high number of construction and related jobs for many years to come.

CO_2 Infrastructure Hubs: A Key Opportunity for Reaching Gigaton-Scale Emissions Reduction

Around the world, many CO_2 capture projects in development are part of hubs, where geographically clustered emissions sources share CO_2 pipelines and geologic storage sites. Shared CO_2 transport and storage infrastructure takes advantage of economies of scale to reduce costs and complexity for individual facilities considering CO_2 capture. Hub development can also lower risks for infrastructure project developers by diversifying the number and sources of captured CO_2.

In the United States, regional hubs are an essential step toward gigaton-scale CO_2 capture and removal. Given the proximity of many stationary emitting facilities to robust permanent geologic storage resources, developing local networks of CO_2 infrastructure can underpin significant regional emissions reduction, job opportunities, and economic activity. Aggregating emitters to form hubs can also align CO_2 sources with companies and entities capable of transporting and storing CO_2. Such strategic alignments can pave the way for business innovations—forming new industry consortia, sharing risk across actors, and leveraging skills from multiple industries. For example, a CCUS hub in development in Norway is planning to form a joint industry venture that will share costs, responsibility, and liability across multiple companies.[41] This venture includes companies from cement, oil and gas, and waste management industries.

"Already, our Canadian Boilermakers have built CCUS facilities at Shell Quest in Edmonton, Alberta, SaskPower's Boundary Dam in Estevan, Saskatchewan, and the NWR Sturgeon Refinery - part of the Alberta Carbon Trunk Line."

—International Brotherhood of Boilermakers

Hub concepts in development around the world have benefitted from significant public funding and public-private partnerships to align various industrial players (Table 3). The Alberta Carbon Trunk Line, for example, is an operational hub that captures emissions from a refinery and a fertilizer plant.[42] Earlier in 2021, the project reached one million metric tons of CO_2 ($MtCO_2$) captured and stored.[43] Currently, the emissions that are transported via a shared pipeline are used for EOR. The Longship project in Norway is another CCUS hub that is transitioning from the planning process into implementation.[44] Finally, the Net Zero Teesside hub in the United Kingdom, described earlier, is in the pre-study phase and will feature a first-of-a-kind natural gas combined cycle plant with carbon capture.[45] The Net Zero Teesside hub is intended to decarbonize an emissions-intensive region and preserve jobs in industrial sectors.

TABLE 3
CO_2 Infrastructure Hub Projects Around the World

Transport/ Storage Project	Alberta Carbon Trunk Line	Longship/Northern Lights	Net Zero Teesside
Location	Canada	Norway	United Kingdom
Status	Operational; CO_2 used for EOR; 1 million metric tons of CO_2 delivered as of March 2021	Implementation Phase; engineering and design studies completed; verification well drilled; plans for transport, development, installation, and operations are developed	Study Phase; partnerships formed; engineering and design studies underway
Transport Capacity	1.6 $MtCO_2$/year (used today) 14.6 $MtCO_2$/year (total potential)	1.5 $MtCO_2$/y (Phase 1) 5.0 $MtCO_2$/y (Phase 2)	0.8 $MtCO_2$/y (Phase 1) 10 $MtCO_2$/y (at scale)
Storage Capacity	TBD	100 $MtCO_2$	>1 $GtCO_2$
Storage Type	Mature gas field, onshore	Sandstone reservoir, offshore	Saline reservoir, offshore
Funding	• US$520 million (2020$) from the Government of Alberta in 2009 • US$73 million (2020$) from the Government of Canada in 2011 • US$240 million (2020$) from Canadian Pension Investment Board in 2018	• US$1.2 billion for transport and storage in Phase 1 • US$1.6 billion for two capture projects • State covers 80% of transport and storage investment costs • State covers 95% of transport and storage operation costs in year 1, declines to 80% for years 4-10 • State covers 50% of costs for additional ships/wells	• US$68 million awarded via UK Innovation fund with about 2:1 matching funds from industry • US$1 billion pledged by UK government to establish two capture projects • Additional US$260 million investment pledged by UK government
Liability	Liability assumed by owner/operator; can be transferred to the government after closure; operator required to contribute to stewardship fund	State assumes 80% of costs of “extraordinary events” without a sunset date; Northern Lights DA will share liability among partners	TBD
Transport and Storage Ownership Structure	Wolf Midstream owns and operates pipeline and compression site; Enhance Energy owns and operates the utilization and storage of CO_2 for EOR and permanent storage	Equinor will be licensee and operator until Northern Lights DA (a new general partnership between Equinor, Shell, and Total) is established; Northern Lights DA will share liability, development, and operation of the project; profits will be based on future additions to the project	Operated by BP; OGCI members BP, Eni, Equinor, Shell, and Total form consortium that support project; 3 MOUs signed between Net Zero Teesside and potential capture sites
Scaling Strategy/ Potential	Unspecified	7 MOUs signed with other emissions sources, 11 projects in EU expecting to rely on Northern Lights for storage	Additional industrial emissions sources in Teesside; connecting Humber industrial cluster (2027-2030)

This study explores hub concepts for three regions in the United States—the Ohio River Valley, Wyoming, and the Texas/Louisiana Gulf Coast—using SimCCS, a high-level software screening tool to evaluate the techno-economic opportunities of building co-located and shared CO_2 pipeline and storage facilities. SimCCS provides notional pipeline routes to inform integrated system designs ranging from single facilities to large, regional networks involving multiple CO_2 emissions sources and geologic CO_2 storage sinks. Sink data from various studies was used to identify potential CO_2 storage locations, which were chosen based on proximity to the selected hub facilities analyzed. Sinks were placed strategically on top of suitable geologic storage and away from population dense areas. This analysis finds that in each region studied, a CO_2 infrastructure hub could dramatically lower each region's overall emissions (Table 4).

TABLE 4
Modeled CCUS Hub Projects, CO_2 Volumes, and Infrastructure Needs

Region	Total Emissions Reduction	Hub Facilities	Description
Ohio River Valley	123 $MtCO_2$	**Sources:** 29 power generation, 19 iron and steel/aluminum, 5 chemicals manufacturing & production, 2 refinery, and 1 mineral plant **Sink:** 8 geologic storage sites, 855 miles of CO_2 pipelines	The Ohio River Valley has highly emissions-intensive industrial and power generation facilities. Additionally, many communities in this region face an energy transition toward cleaner technologies. CCUS could play a role in preserving good-paying jobs.
Wyoming	43 $MtCO_2$	**Sources:** 10 power generation, 4 refinery, 2 chemicals manufacturing and production, and 1 mineral plant **Sink:** 4 geologic storage sites, 443 miles of CO_2 pipelines	Wyoming has a robust regulatory environment supporting CO_2 infrastructure, several large power generating plants, and the highest per capita energy consumption in the country, all of which promote the development of CCUS projects.
Texas and Louisiana Gulf Coast	171 $MtCO_2$	**Sources**: 47 chemicals manufacturing and production, 31 power generation, 25 refinery, 23 gas processing, 21 hydrogen and ammonia production, 3 iron and steel/aluminum production, and 2 paper and pulp production plants **Sinks:** 5 geologic storage sites, 1,462 miles of CO_2 pipelines	The Texas and Louisiana Gulf Coast is the most energy-intensive part of the country with a variety of industrial and power generation plants along the coast. The region has extensive oil and gas infrastructure and large storage potential for CO_2 under the Gulf of Mexico seafloor.

Facilities evaluated across these three regions emit 337 $MtCO_2e$ per year from a range of sources, including power generation, manufacturing, and fuels production. At the same time, the profile of emitting facilities differs across the regions. The Texas and Louisiana Gulf Coast has many refineries and is the only of the studied regions with hydrogen and ammonia production facilities, among the lowest cost opportunities for capture. The Ohio River Valley has a large concentration of iron, steel, and aluminum facilities, along with several coal-fired power plants. Wyoming, a state with one of the most comprehensive regulatory frameworks supporting CO_2 infrastructure, is home to several large coal-fired power plants. Another important distinction between the regions is existing CCUS projects and CO_2 infrastructure. The Gulf Coast and Wyoming have hundreds of miles of existing CO_2 pipelines, and the Gulf Coast is already home to four carbon capture projects. These regional characteristics and their implications for the formation of CO_2 infrastructure hubs are discussed in more detail later in this report.

As of June 2021, three hubs are in active consideration in the United States.

- **Navigator CO_2 Ventures LLC** is planning a 1,200-mile common carrier CO_2 pipeline crisscrossing the Midwestern states of Nebraska, Iowa, South Dakota, Minnesota, and Illinois.[46,47] Intended to be operational by 2024, the pipeline will have a capacity of 12 $MtCO_2$ per year and take CO_2 to multiple sites in Illinois where it will ultimately be stored. After a non-binding open-season process, Navigator found interest from a diverse set of potential customers and expanded the capacity of the pipeline by 50 percent.[48] The project is expected to cost $2 billion and is backed by Valero and Blackstone.[49]
- **Summit Carbon** is developing a CCUS hub that will be capable of transporting and storing up to 10 $MtCO_2$ per year at full scale and will be operational in 2024.[50] The project will cost about $4 billion and will collect emissions from 10 Iowa ethanol plants and 20 other companies across the region.[51] Biofuel producers that can benefit from California's Low Carbon Fuel Standard[g] have expressed interest in the hubs developed by Summit Carbon and Navigator.[52]
- **ExxonMobil** is considering a CO_2 hub that would gather emissions from the Houston Ship Channel and store CO_2 offshore in saline formations in the Gulf of Mexico.[53] The Houston Ship Channel is a 50-mile-long waterway connecting Houston to the Gulf of Mexico dotted with petrochemical facilities and several of the country's largest fuel refineries, among other industrial facilities. By 2040, ExxonMobil estimates that about 100 $MtCO_2$ could be captured from this industrial area and permanently stored.[54] ExxonMobil estimates the project could cost $100 billion to build and notes that a carbon market and supportive policy is needed to make the project viable.[55]

The proposed hubs in the United States benefit from the decades of investment in carbon capture and storage technologies developed by the Department of Energy (DOE). The storage site in Illinois, for example, builds on the groundwork of the Regional Carbon Sequestration Partnership program that surveyed the area, characterized the saline formation, and monitored CO_2 after injection.[56] Looking ahead, federal leadership in hub development, including funding and technical support, will continue to be essential for developing CO_2 hubs at the pace and scale needed to meet U.S. emission reduction targets.

[g] California's Low Carbon Fuel Standard provides nearly $200/ton for certain CCUS projects in California and for DAC projects anywhere in the world.

CHAPTER 3

Challenges to Gigaton-Scale CO_2 Infrastructure Development

A report by the International Energy Agency (IEA) calls for 7.6 Gt of CCUS per year by 2050 in order to reach net-zero emissions.[57] The United States accounted for about 15 percent of global fossil-based emissions in 2019. By reaching its gigaton-scale potential of CO_2 transport and storage infrastructure, the United States could make a significant contribution to meeting this global decarbonization target, while demonstrating U.S. leadership and supporting U.S. competitiveness in an emerging clean energy market.

As a relatively new and technically complex set of technologies, CO_2 capture, removal, transport, storage, and utilization pathways face a number of barriers to development in the United States. Building a gigaton-scale CO_2 infrastructure will be a large engineering endeavor that will require serious planning, logistics, workforce, and public-private partnerships. For example, when compressed to transport in a pipeline or store underground, one $GtCO_2$ has approximately the same volume as eight billion barrels of oil, which is about twice the volume of oil that the United States produced in 2020.[58,59] The challenges to deploying a gigaton-scale CO_2 system can be summarized into four main categories: inadequate federal policy guidance; a challenging permitting environment; insufficient revenues and uncertain costs; and lack of public awareness and varying support (Figure 5).

FIGURE 5

Key Challenges to Deploying CO_2 Infrastructure in the United States

Inadequate Federal Policy Guidance	Challenging Permitting Environment	Insufficient Revenues and Uncertain Costs	Lack of Public Awareness and Varying Support
Unclear Role in Achieving Climate Targets	Numerous Federal, State, and Local Jurisdictions Involved	Limitations of the Section 45Q Tax Credit	Low Public Awareness and Varied Opinions of CO_2 Infrastructure
Limited Existing Policy Designs	Uncertain Permitting Timelines	Challenge Aligning Players, Permitting, and Financing	Historic Inequities in Infrastructure Siting
New Policy Needed to Reach Gigaton-Scale	Variability in CO_2 Transport and Storage Regulation Among States	Lack of a Long-term Liability Framework	Concern of Continued Fossil Fuel Use

Inadequate Federal Policy Guidance for Gigaton-scale CO_2 Infrastructure

The Biden Administration released the U.S. Nationally Determined Contribution (NDC) to reduce 50 to 52 percent of emissions by 2030 relative to 2005 after re-joining the Paris Agreement in February 2021, and further committed to net-zero emissions by 2050.[60] While CO_2 capture, removal, transport, storage, and utilization pathways will play a role in meeting that target, it is unclear what the scale of that role is contemplated for meeting U.S. ambitions. The American Jobs Plan released by the White House in March 2021 includes funding for large-scale CCUS demonstration projects, especially in the industrial sector.[61] However, the American Jobs Plan does not set targets for CCUS, discuss the role of CCUS for decarbonizing the power sector, or include carbon removal technologies.

Research and development (R&D) and tax credits for carbon capture and removal have generated significant interest from project developers, but stronger policy support is needed to deploy technologies in hard-to-decarbonize sectors. Currently authorized tax credits have been extended only when their expiration dates are close and then are extended for only a few years at a time. These actions, while beneficial, do not provide the long-term certainty that investors and project developers need.

Existing federal statutes do not impose costs on companies emitting carbon, providing little incentive to decarbonize. Achieving gigaton-scale CO_2 infrastructure deployment could be rapidly accelerated by an electricity-sector clean energy standard (Box 2); this could create the predictability and market demand for captured or removed CO_2. In addition, financial incentives for certain types of CO_2 capture with larger capital and operating costs, such as for power plants, certain industrial facilities, and DAC, are needed to spur investment. Government support for non-capital project expenses, such as permitting and siting, are also lacking in the current environment.

BOX 2

The Role of Clean Energy Standards in Driving CO_2 Storage Deployment

The Biden Administration has set a goal to achieve 100 percent carbon-free power by 2035. In 2020, fossil fuel generation contributed 60 percent of utility-scale electricity generation in the United States, with the remainder split between nuclear and renewable resources. Achieving carbon-free power by 2035 will require dramatic changes to the electricity sector, which is anticipated to experience increased demand as end uses in transportation, buildings, and other sectors are electrified. With current technologies, CO_2 capture on fossil fuel power plants can reduce emissions by 90 percent or more and play a key role in grid reliability as more intermittent renewables and battery storage are deployed.

A clean energy standard (CES) is a policy approach under active discussion in Congress that could support the achievement of the administration's goals. A CES should allow the portion of greenhouse gas emissions that are captured and permanently stored from fossil generation to be eligible as a clean energy resource, in turn providing an incentive for generators to invest in CO_2 capture retrofits in the near term. The CES should also include guidance on how to abate the remaining 10 percent of emissions not possible to eliminate through CCUS, offsets, or other negative emissions technologies. The CLEAN Future Act of 2021 proposes a CES that would credit generators that capture and store emissions; facilities with a capture rate lower than 100 percent are eligible for a partial credit based on the emissions rate relative to a benchmark.[62]

Most of today's CO_2 capture industry depends on revenue from selling CO_2 to oil production companies for use in enhanced oil recovery (EOR). Relying on EOR revenues to fund CO_2 capture operations has led some projects to suspend operations during periods of low oil demand in which the costs of carbon capture exceed the revenues available from selling captured CO_2 to oil producers. In the absence of a carbon price, CO_2 capture projects with permanent geologic CO_2 storage are entirely dependent on incentives that are insufficient for the amount of CO_2 capture needed to achieve net-zero emissions.

Challenging Permitting Environment for CO_2 Infrastructure

The nascency of the CCUS and CDR industries coupled with the complexity of permitting CO_2 infrastructure at the local, state, and federal levels poses challenges for project development. Across the United States, the permitting landscape is variable, and numerous entities are involved in the permitting process. The exact location of each project determines the necessary permits and the local, state, regional, tribal and/or federal agencies involved.[63] Certain agencies of jurisdiction may not be familiar with CO_2 infrastructure, and project developers may not be aware of the myriad permits required for a given project.

Projects injecting CO_2 for EOR must obtain Underground Injection Control (UIC) Class II permits, while those seeking to inject CO_2 in deep geologic reservoirs must receive UIC Class VI permits. UIC permitting is done either by the Environmental Protection Agency (EPA) or a designated state agency if the state has qualified for UIC primacy[h] to oversee the UIC permitting process. The Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) has the authority to regulate the design, construction, operation and maintenance, and spill response planning of interstate CO_2 pipelines.[64] Projects seeking the 45Q tax credit must also meet Internal Revenue Service (IRS) requirements. There are many other potential permits that might be required for a given project. This complex permitting landscape poses a major challenge to development.

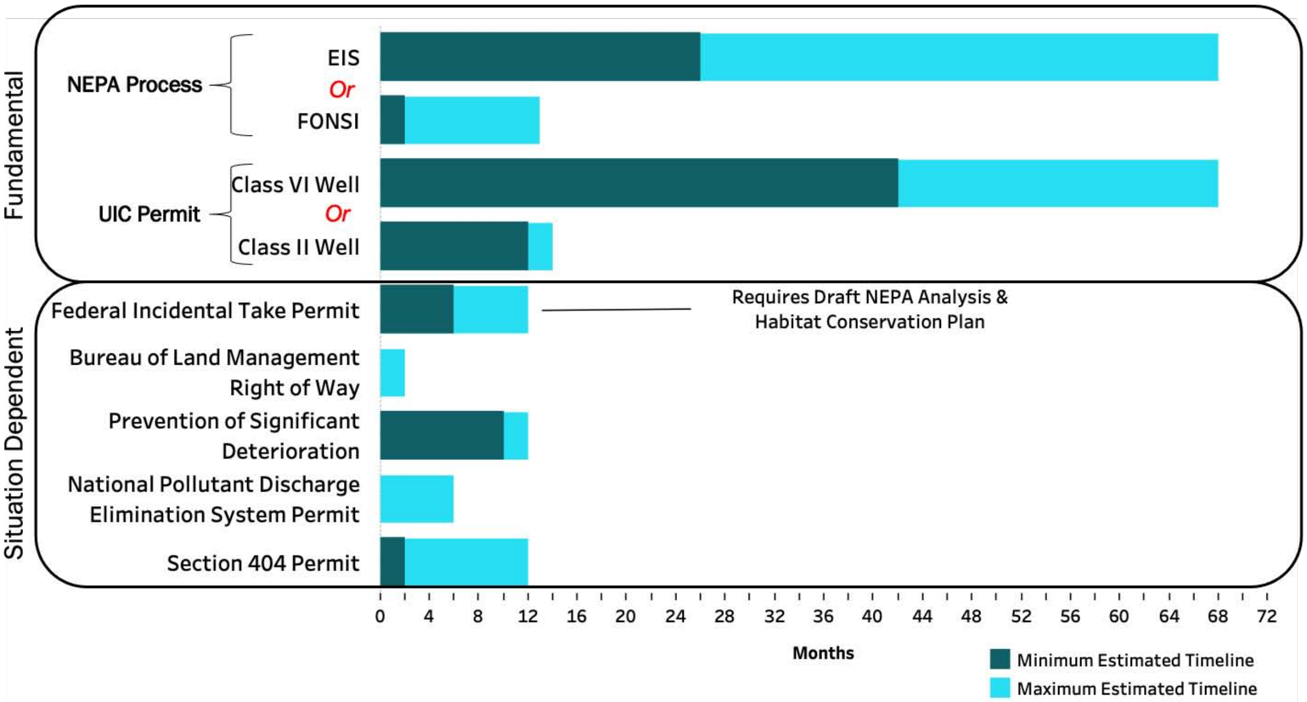
Another barrier to development is the highly uncertain and historically lengthy timeline for obtaining various permits (Figure 6). As of June 2021, only two operational Class VI wells—both part of the Archer Daniel Midland's CCUS project in Decatur, Illinois—had been permitted in the United States. It took nearly six years to receive its permit to inject.[65,66] While this timeline may shorten as more projects apply for Class VI permits, uncertainty remains a challenge. Some states with interest in developing CO_2 storage projects are seeking UIC Class VI primacy; however, the process of receiving state primacy itself can also take many years.[67] It took North Dakota, the first state to receive Class VI primacy, five years to do so, while the process took Wyoming, the second state to receive primacy, nearly three years.[68,69,70]

A key determinant of project permitting timelines is the duration of the National Environmental Protection Act (NEPA) process, which is required for "any federal action that may significantly affect the quality of the human environment."[71] This process has two main outcomes: if there are no significant environmental impacts associated with the project, an Environmental Assessment and Finding of No Significant Impact (EA/FONSI) is issued, and if environmental impacts are reasonably expected from the proposed project, an Environmental Impact Statement (EIS) is required. According to a 2020 Council for Environmental Quality (CEQ) report, the average time to complete an EIS from 2010-2017 was 4.5 years, but some projects can take significantly longer.[72] Additional challenges include litigation risk and specific procedures on top of CEQ regulations required by certain federal agencies.[73]

[h] Primacy refers to primary enforcement authority, which the EPA can give to states, territories, or tribal governments to implement UIC programs.

FIGURE 6

Estimated Range of Timelines for Some CO_2 Infrastructure Regulatory and Permitting Processes



Numerous regulatory processes and permits from local, state, and federal agencies are required to build CO_2 infrastructure, many of which have uncertain timelines. Blue bars that extend to the end of the figure may have indefinite timelines. The exact permits required and timelines to complete review vary dramatically depending on the exact location and type of project. Adapted from Energy Futures Initiative and Stanford University. "An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions." October 2020.

Property and ownership rights also factor into large-scale CO_2 storage development. For example, property law governing ownership of pore space varies drastically between states.[i] Legislatures in North Dakota, Wyoming, and Montana have clarified this issue by vesting ownership of the pore space with the surface owner.[74] However, in many states with suitable CO_2 storage sites, ownership remains ambiguous. Ownership and leasing of pore space on federal lands also remains uncertain; the mineral reservations granted on federal lands do not clearly extend to pore space, as the pore space itself is not "severable" from the subsurface, unlike oil and gas.[75]

Another property-related challenge for CO_2 infrastructure development is coordination among and negotiation between multiple property owners of the subsurface pore space. Unitization agreements, through which leaseholders or surface owners consolidate the mineral or leasehold interests over a common subsurface formation, are commonly used in the oil and gas industry and could be applied in the CO_2 storage space.[76] In most states where unitization rules exist, a certain percentage of landowners must agree in order to unitize the premises.[77] Table 5 shows approaches that different states have taken to clarify pore space ownership and establish unitization agreements.

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[i] Pore space refers to the fraction of rock volume in underground geologic formations that is not occupied by solid matter and which could be used for storing CO_2.

TABLE 5
Pore Space and Unitization Policies Comparison Table

	Texas	North Dakota	New Mexico	Wyoming	Montana	California
Pore Space Ownership	Ambiguous [78]	Surface owners[79]	Ambiguous[80]	Surface Owners[81]	Surface Owners[82]	Ambiguous[83]
Unitization Requirements	None[84]	60% approval by ownership[85]	None	80% approval by ownership; 75% approval permitted in some cases[86]	70% approval by parties paying costs[87]	None for pore space

Source: Adapted from Energy Futures Initiative and Stanford University. "An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions." October 2020.

Finally, lack of a federal regulatory framework for siting interstate CO_2 pipelines could be a barrier to deployment. State regulation has played a leading role in siting, construction, and operation of CO_2 pipelines. Only a few states have a CO_2-specific pipeline siting rules, and in many other states, regulation of CO_2 pipelines falls within the statutes for other types of pipelines such as those for hazardous waste and oil and natural gas. To date, differences in state regulations have not significantly impeded on interstate CO_2 pipeline development because many interstate pipelines serve single sources and single end users and are in western states that tend to have more developed regulatory frameworks for CO_2 pipelines. However, as CO_2 pipeline networks become more extensive and complex, and more participants enter the market, a clearer regulatory framework will be needed. Developers of interstate CO_2 pipelines may increasingly encounter a range of regulatory obstacles due to inconsistent or unclear regulations of the states a pipeline passes through (Table 6). For example, many states allow natural gas pipelines to exercise eminent domain, but it is not clear whether this authority would extend to CO_2 pipelines.[88]

TABLE 6
Challenges of Siting Interstate CO_2 pipelines

	Authority	Challenges
Siting rules and processes	States	• In many states, the regulations for CO_2 pipelines are not clear because they fall within the statutes for other types of pipelines. • Builders of interstate pipelines face widely varying regulations of the multiple states that the pipelines pass through.
Rights-of-way/ eminent domain	Bureau of Land Management (federal lands) States (non-federal lands)	• The availability of eminent domain for CO_2 pipelines varies among states. • Unclear whether the eminent domain authority of natural gas pipelines would extend to CO_2 pipelines in many states.
Common carrier status requirements	Bureau of Land Management (federal lands) States (non-federal lands)	• Common carrier requirements vary among states.[j] • Unclear whether the entire pipeline is required to act as a common carrier when the pipeline passes both a state with common carrier requirement and a state without the requirement.

[j] Some states (e.g., Montana) grant eminent domain authority only to the CO_2 pipelines operating as common carriers. Private pipelines are permitted but are not allowed to use the power of eminent domain. On the other hand, North Dakota requires all CO_2 pipelines to operate as common carriers. Many other states do not have common carrier requirements to CO_2 pipelines.

Insufficient Revenues and Uncertain Costs for CO_2 Infrastructure

To achieve net-zero targets, geologic CO_2 storage in saline formations can unlock numerous decarbonization pathways. However, absent public policy support mechanisms, there is no financial incentive for the capture of CO_2 emitted from facilities and injection into geologic storage except for EOR, which provides a revenue stream. At the federal level, the 45Q tax credit is the key policy support mechanism for developing Class VI wells. California's Low Carbon Fuel Standard provides nearly $200/ton for certain CCUS projects in California and for DAC projects anywhere in the world.[89] These two policies are critical to developing projects but are insufficient to incentivize CCUS at gigaton scale.

Although the 45Q tax credit is a valuable incentive for CO_2 infrastructure development, some features of this incentive limit its effectiveness. Projects must commence construction by January 1, 2026, to claim the 45Q tax credit. The recent IRS guidance identified two methods for establishing commencement of construction: the Physical Work Test and Five Percent Safe Harbor. The former requires physical work "of a significant nature" be performed onsite or offsite, with no defined cost threshold. However, preliminary activities do not satisfy this Physical Work Test requirement. Therefore, all preliminary activities—from securing financing and exploring to obtaining permits and clearing a site—must occur before commencement of construction and therefore before the 45Q tax credit can be claimed.[90] As a result, project developers in 2021 have less than five years to undertake the numerous necessary preliminary activities, including the years-long permitting processes as shown in Figure 6, before the tax credit window closes in 2026.

For many sectors, 45Q tax credit levels are insufficient to facilitate cost recovery. Hard-to-abate industries, such as steel and cement, incur especially high capital costs to install CO_2 capture equipment, and facility retrofits can cause long and expensive delays in production. Additionally, the 12-year duration of the tax credit is shorter than the approximate 20-year lifespan of a typical CO_2 capture facility, further curtailing financial feasibility. Under the current 45Q tax credit requirements, federal financial incentives for any CCUS project would end by 2038, creating significant uncertainty as to whether CCUS would remain a viable alternative for meeting midcentury decarbonization goals. Extending to a 20-year window would shift the 45Q tax credit duration to 2045, making the contribution of CCUS to midcentury goals more viable.

As a tax credit, the 45Q requires the project proponent to have a large tax burden against which the credits become valuable or to partner with third party tax equity investors, who may seek a higher rate of return and prefer CCUS projects with the lowest costs. Lack of a direct pay option limits the market for 45Q tax credit beneficiaries, especially start-ups with a small tax liability, public utilities and cooperatives who do not pay federal taxes, and companies implementing a first-of-a-kind project.[91] A related challenge is the potential appetite of the tax equity market for CCUS project investments.[92] During the COVID-19 pandemic, the tax equity market was projected to shrink as much as $23 billion.[93] The tax equity market remains large, however, and is expected to grow, allaying some concerns.[94] Finally, there is recapture risk in which the tax equity investor would have to refund tax credits previously claimed in the event of a CO_2 leak. The updated 45Q tax credit IRS guidance includes a stipulation that, in the event of CO_2 leakage, a project developer's tax credits can be "recaptured" for up to three years after the last year the 45Q tax credit is claimed.[95]

Beyond the revenue challenges posed by the 45Q tax credit, there are some key cost challenges that further discourage investment. First, the industry faces a "chicken-and-egg" problem: CO_2 capture (whether from a point source or direct) has little value absent a CO_2 disposition pathway (either CO_2 utilization, geologic storage, or mineralization). Each segment of the value chain involves unique technologies and requires specific skills and expertise. CO_2 emitters may lack expertise in the downstream pipelines and storage components, while companies with expertise in subsurface drilling and pipeline development may not have the capability to capture CO_2. Disparate industrial stakeholders will need to be aligned to deploy gigaton-scale CO_2 infrastructure.

Next, there is an insufficient federal framework for financial liabilities and long-term stewardship of CO_2 injection sites and storage facilities, which presents another challenge. Current regulations for Class VI wells govern a limited scope of liability, focusing specifically on protecting groundwater. The regulations mandate a 50-year post-injection site care period after CO_2 injection wells have been capped.[96] Liability over this period is not well defined in the UIC program and the insurance industry is still learning how to properly underwrite projects and establish timelines and premiums for CO_2 storage. While the risk of CO_2 leakage is low and the risk of injury is even lower, uncertainty regarding the future of CO_2 regulation and the nature, duration, and structure of liability causes concern for potential investors and operators.

Lack of Public Awareness and Varying Support for CO_2 Infrastructure

The final category of challenges to gigaton-scale CO_2 infrastructure development is the lack of public awareness and varying levels of public support. Among those with some knowledge of CCUS, for example, perceptions are generally based on project-specific, local knowledge.[97] Public perceptions that contribute to negative opinions of CCUS include hesitancy about technology risks, limited track record, cost, and investment tradeoffs compared to other emissions abatement options.[98] Worries about the risk of geologic CO_2 leakage are also common.[99]

Energy and industrial infrastructure is disproportionately located in or near neighborhoods of lower-income households and with larger minority group populations.[100] The environmental impacts of these facilities have contributed to negative health outcomes and lowered property values in the adjacent communities.[101] These historic inequities necessitate open and honest engagement with environmental justice communities from the earliest stages of CO_2 infrastructure project development to allow local stakeholders to participate in an informed decision-making process.[102] It is essential for the federal government to engage in public outreach and education directly and through partnership with local governments, businesses, advocacy organizations, and other stakeholders to increase public awareness of geologic CO_2 storage for local communities.

A final public acceptance challenge is the concern that CCUS is an “end-of-pipe” solution that—despite its emissions reduction value—does not decrease the use of fossil fuels. Other concerns about CCUS include its perception as a “delaying tactic” that forestalls other climate change mitigation actions, such as improved energy efficiency or transition to non-fossil fuels.[103] There are also concerns that CCUS prolongs negative attributes of fossil fuels such as pollutants, environmental disruptions, and negative community impacts.[104] In all, public acceptance is a critical component of a just and equitable clean energy transition that must be overcome.

CHAPTER 4

Policy Blueprint to Build Gigaton-Scale CO_2 Infrastructure

Recent policy activity, including enactment of the Energy Act of 2020, placed greater emphasis on and support for carbon capture, utilization, and storage (CCUS) for decarbonizing the industrial and power sectors and contributing to U.S. climate policy goals. More must be done, however, to support the buildout of CO_2 infrastructure on the gigaton scale needed to reach the 2030 Nationally Determined Contribution (NDC) target of reducing emissions at least 50 percent and achieving net-zero emissions by midcentury.

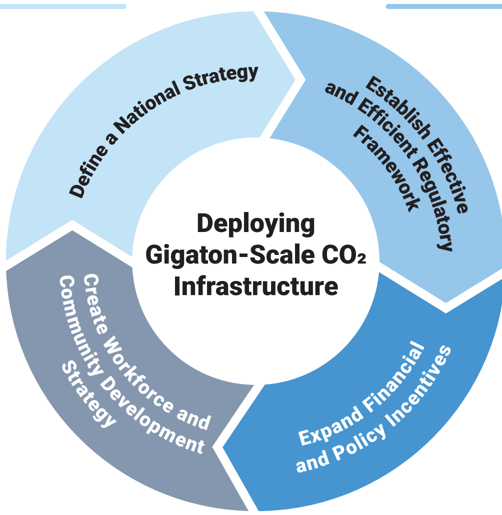
This section provides a policy blueprint with options to enable the full potential of CO_2 capture, removal, transport, storage, and utilization pathways. The blueprint emphasizes direct benefits and co-benefits of targeted policy action that could have the greatest impact on the high-level opportunities identified in Chapter 2: (1) rapidly reducing economywide emissions across multiple industries; (2) reducing emissions and preserving jobs in hard-to-decarbonize sectors that can provide clean domestic supply chains; and (3) creating new industries and additional jobs for U.S. workers.

Figure 7 summarizes the four main categories of recommendations: define a national strategy for gigaton-scale CO_2 infrastructure hubs; establish an effective and efficient regulatory framework; expand policy support and strengthen financial incentives; and create a workforce transition and community development strategy.

FIGURE 7

Policy Blueprint for Gigaton-Scale CO_2 Infrastructure Development

- Achieve gigaton scale CO_2 infrastructure by 2050
- Establish national target for carbon dioxide removal for 2030 and 2050
- Prioritize regional CO_2 hubs serving multiple users
- Enable scalable CO_2 storage business models



- Enhance federal capabilities to coordinate regulation and permitting of CO_2 infrastructure projects
- Strengthen implementation of UIC Class VI permitting process
- Establish an effective regulatory framework for siting interstate CO_2 pipelines

- Create opportunities to transition conventional fossil energy jobs to CO_2 management jobs
- Extend economic development funding to communities building CO_2 hubs
- Conduct public education and outreach to address environmental justice concerns of frontline communities

- Extend and expand provisions for tax credits for CO_2 capture and storage
- Expand federal funding for CO_2 storage and pipeline infrastructures
- Expand RFS eligibility for CCUS projects
- Establish a Federal scheme for managing long-term liability risk of stored CO_2

Many of the recommendations in this study build on policy proposals advanced by the Biden Administration and proposed legislation by the 117th U.S. Congress. While CCUS policies have advanced steadily for decades, the recent and rapid flurry of legislative activity suggests a watershed moment for advancing technologies that enable net-zero emissions, including carbon dioxide removal (CDR). The interest in CCUS is not limited to one party or one legislative chamber; key legislative proposals, such as the SCALE Act, ACCESS 45Q Act, and Clean Energy for America Act, have bipartisan support in both houses of Congress. Table 7 provides a non-exhuastive list of legislation and policy plans that would enact one or more of our recommendations, in part or in full.

TABLE 7

Proposed Legislation and Policy Plans Related to CO_2 Infrastructure

	Define National Strategy			Expand Policy Support							Improve Regulatory Environment		Create a Workforce Transition & Community Development Strategy			
	Target CCS Deployment in Transition Communities	Promote Clean U.S. Supply Chains	Set a CDR Target	45Q Extension	Increase 45Q Credit Value	Direct Pay for 45Q	Reinstate 48C	Expand 48A	Invest in Storage Technology	Invest in Large-Scale Pilot Projects	Increased Funding for Class VI Permitting	Repurpose Existing ROW	Fund Worker Transition Programs	Increase Funds to Transition Communities	Support Community Engagement Programs	Improve Decision Making Tools
Legislation																
CREATE Act of 2021			✓								✓					
CLEAN Future Act of 2021		✓								✓	✓					
SCALE Act									✓	✓	✓					
CCUS Tax Credit Amendments Act of 2021				✓		✓		✓								
ACCESS 45Q Act				✓		✓										
American Jobs in Energy Manufacturing Act of 2021	✓						✓									
The Clean Energy for America Act				✓		✓										
GREEN Act of 2021				✓		✓	✓									
The CATCH Act					✓											
H.R. 2633				✓	✓											
Carbon Capture Modernization Act								✓								
Blue Collar to Green Collar Jobs Development Act of 2021													✓			
RECLAIM Act of 2021														✓		
Environmental Justice for All Act															✓	
Climate Justice for All Act																✓
Policy Plans																
American Jobs Plan	✓	✓		✓		✓			✓	✓		✓*			✓	
Climate Crisis Committee Action Plan		✓		✓		✓	✓		✓	✓	✓	✓*		✓	✓	✓

** Recommendation is to use ROW for transmission projects, not carbon transportation*

Define a National Strategy for Gigaton-Scale CO_2 Infrastructure Hubs

Federal policy and regulatory action supporting CCUS and CDR pathways has increased substantially in the last few years. In addition to over $4 billion in new funding for CCUS authorized through the Energy Act of 2020,[105] the Bipartisan Budget Act of 2018 included the revised 45Q tax credit for CCUS projects. Under the American Jobs Plan, CCUS would receive further support through demonstration funding and modification of the 45Q tax credit to increase accessibility and incentives. While these measures are essential for moving the industry forward, a more comprehensive approach is needed to realize the decarbonization potential of large-scale CO_2 infrastructure.

Affirm Federal Support for Large-scale CO_2 Management Pathways

A federal strategy is needed to align the public and private sectors on the long-term role for CO_2 capture, removal, and storage in meeting the 2030 NDC target and net-zero by midcentury. Affirming support for such a strategy at the highest levels is essential.

> **"[Expanding 45Q tax credits] is only a small piece of the puzzle. What is needed is a rapid development and deployment of the infrastructure that will be needed to [move CO_2 and] deploy CCUS."**
>
> *—United Mine Workers of America*

The White House should issue an executive order to set a national target for implementing at least one Gt per year of CO_2 infrastructure capacity by 2050. The executive order should direct federal agencies to identify the infrastructure and labor force needed to meet the goal and the funding needed to support CO_2 infrastructure. This executive order would demonstrate that CO_2 management has a significant role in meeting President Biden's announced 2030 NDC target and reaching net-zero emissions by midcentury. This policy guidance should clarify that large-scale CO_2 transport and storage infrastructure is needed to support numerous CO_2 capture and removal pathways.

Policy guidance should also direct relevant federal agencies to align their respective regulatory activities with the high-level objectives described above. This guidance would provide greater certainty to project developers, state and local governments, and community representatives who will need to collaborate to ensure that future CO_2 infrastructure projects maximize climate mitigation benefits while reducing any associated risks.

> **"CCUS holds potential for energy, environmental and economic benefits. Deploying the technology at scale can protect and create high-paying jobs in energy production and other heavy industries while allowing us to meet our mid-century goals for mitigating carbon emissions across the economy."**
>
> *— Utility Workers Union of America*

The White House should work with Congress to target federal funding for CO_2 infrastructure to offer equitable transitions for workers and communities. The development and siting of all clean infrastructure should actively consider the positive and negative impact on local communities, including the ability to support workers in transition. Following Executive Order 12898, compliance with the National Environmental Policy Act (NEPA) requires projects to assess the possibility for a disproportionately high and adverse effect on low-income or minority populations.[106] However, this does not extend to communities that are burdened by the effects of climate change and the energy transition. While deploying CO_2 capture at existing industrial facilities may be the most cost-effective approach for rapid decarbonization,[107] it can also help to preserve thousands of jobs in foundational industries in regions that are most vulnerable to economic dislocation associated with the clean energy transition. This benefit has already been recognized by the Biden Administration: the American Jobs Plan promotes extending the benefits of clean infrastructure projects to communities that have been affected by the energy transition or are low-income communities and/or communities of color. CO_2 transport and storage infrastructure can be deployed in partnership with local stakeholders to minimize environmental stresses, while sharing economic benefits. The White House should work with Congress to articulate the criteria for targeting funds to a community, which would include presence of environmental justice and frontline communities.

The White House should issue an executive order that directs agencies to promote clean U.S. supply chains as a mechanism to encourage CCUS deployment. Agencies can promote decarbonization of U.S. supply chains by either supporting CO_2 infrastructure development or using their purchasing power to promote low-carbon products that rely on CO_2 infrastructure (Box 3). CO_2 capture is one commercial technology that can decarbonize multiple manufacturing industries that will enable the development of a clean economy. Cement and steelmaking, for example, could be decarbonized using CO_2 capture, leading to cleaner domestic supply chains for wind turbines, solar panels, electric vehicles, grid buildout needed for additional electrification and modernization, and other critical clean energy technologies. CO_2 capture can also help decarbonize petroleum refining, hydrogen production, natural gas processing, and other industries that produce the fuels that will remain in the energy mix in the near-term. One estimate found that, absent cleaner supply chains, $1.5 trillion of new infrastructure investments authorized through the Moving Forward Act could produce 200 $MtCO_2$.[108] As the federal government contemplates more than a trillion-dollar investment in infrastructure, now is the time to decarbonize industrial supply chains through CCUS.

BOX 3

Clean Procurement Standards Can Drive CCUS Deployment

Federal, state, and local governments have leveraged purchasing power to promote domestic supply chains and promote clean technology such as electric vehicles. Nearly 50 percent of all cement and 20 percent of steel is purchased with tax dollars, providing the public sector with an opportunity to create a market for low-carbon production in these sectors.[109] Cement is responsible for most of the greenhouse gas emissions in public construction, despite accounting for about one percent of the cost; adding CO_2 capture to a cement plant could increase project costs by as little as one percent overall.[110]

Strong markets for low-carbon products can be created through Buy Clean Standards, which are major facets of the CLEAN Future Act, introduced in the House of Representatives in January 2020. The Buy Clean Standard in this legislation covers aluminum, iron, steel, concrete, and cement. The Environmental Protection Agency (EPA) Administrator would also have the option to add flat glass, insulation, unit masonry (e.g., bricks), and wood products.[111]

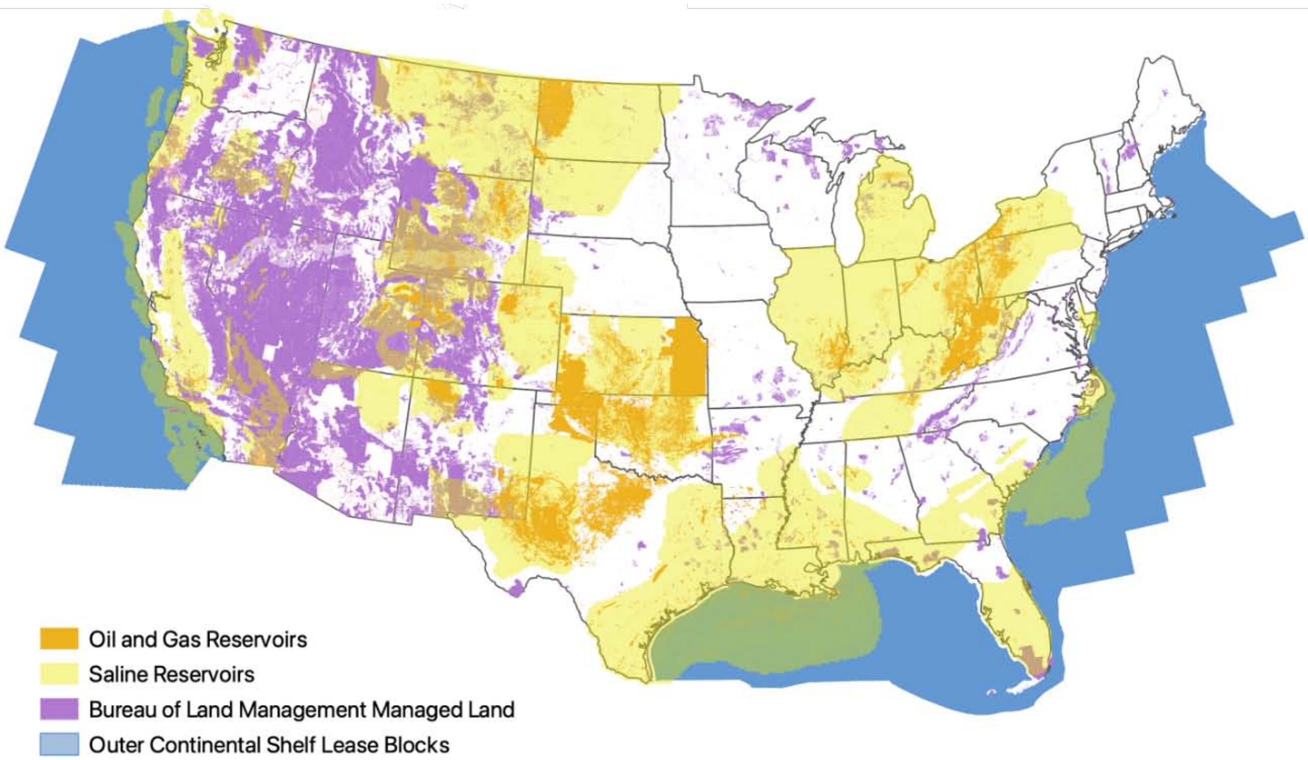
Adopting current best practices economywide through a Buy Clean Standard could achieve a 20 to 30 percent reduction in greenhouse gases, requiring further innovation to play a role in reducing emissions 50 percent by 2030 and 100 percent by 2050.[112] To encourage innovative technologies that dramatically reduce emissions from a variety of manufactured products, the CLEAN Future Act directs the EPA Administrator to establish the Climate Star Program. Climate Star would be a voluntary label for products with significantly lower embedded carbon emissions.[113]

Leverage Existing Federal Capabilities to Facilitate Gigaton-Scale CO_2 Infrastructure Development

While ensuring ongoing protection of highly sensitive ecosystems on federal lands, the U.S. government can facilitate the development of large-scale CO_2 infrastructure by offering leases for geologic storage of CO_2 on federal lands, designating corridors for CO_2 transport infrastructure, and establishing a CO_2 service provider to manage captured CO_2 for a fee.

FIGURE 8

Federal Lands, Waters, and Geologic Storage Reservoirs



This figure shows where the BLM-managed land overlaps with saline or oil and gas reservoirs, which BLM is authorized to lease for the purposes of permanent geologic CO_2 storage. It also shows ocean area managed by the Bureau of Ocean Energy Management (BOEM) known as the Outer Continental Shelf (OCS).[k] Often, defined leasing blocks within the OCS are leased to oil or gas companies interested in obtaining mineral rights to the subsurface.[114] BOEM also has authority to provide permits for CO_2 under the Outer Continental Shelf Lands Act.[115]

The Bureau of Land Management should offer long-term leases for geologic storage of CO_2 on federal lands. Federal lands account for approximately five percent of national CO_2 storage potential, most of which is in saline formations.[116] Long-term and renewable leases for CO_2 storage on federal lands at prices that reflect the national and societal benefit of storing CO_2 would allow project developers to coordinate with a single

[k] The OCS is defined as submerged lands, typically covering three nautical miles from the U.S. coastline to the edge of the Exclusive Economic Zone. The Texas, Louisiana, and Florida Gulf coasts measure the extent of the OCS differently than all other states. Texas and Florida extend nine nautical miles from state lands, while Louisiana extends three U.S. nautical miles (6082.2 ft) from land as opposed to international nautical miles (6076.1 ft) all other states adhere to.

entity for subsurface pore space and land access, saving on costs and reducing project timelines.[117] Rules and procedures to manage long-term CO_2 liabilities should accompany this policy to clarify the responsibilities of the project developers and the Bureau of Land Management (BLM) after leases expire.[l] The majority of federal land available for lease is controlled by BLM and the U.S. Forest Service (USFS), though BLM typically acts as the leasing agent for both agencies.[118] The Mineral Leasing Act gives BLM authority to lease federal lands for CO_2 storage (and the Federal Land Policy and Management Act gives BLM authority to regulate the siting and construction of CO_2 pipelines on federal land).[119,120] Figure 8 shows where BLM land overlaps with potential CO_2 storage reservoirs. These lands could also be used for federally funded pilot projects.

Congress should require federal agencies to designate CO_2 transport infrastructure corridors on federal lands. Section 368 of the Energy Policy Act of 2005 authorized federal agencies to designate "corridors for oil, gas, and hydrogen pipelines and electricity transmission and distribution facilities" on federal lands in the eleven contiguous Western States.[121,122] Under the Act, federal agencies including the BLM, Department of Energy (DOE), USFS, Department of Defense, and U.S. Fish and Wildlife Service identified potential corridors, evaluated the impacts of future projects within the designated corridors, explored measures to mitigate the impacts, and developed Interagency Operating Procedures for planning, constructing, operating, and decommissioning projects within the corridors through issuance of a Programmatic Environmental Impact Statement.[m]

The Interagency Operating Procedures are designed to expedite the permitting process by offering coordinated and consistent interagency management procedures to permit rights-of-ways (ROWs) within the corridors and clarifying the requirements of future projects.[123] The designated energy corridors incorporated more than 4,000 miles of existing ROWs including various highway and pipeline ROWs and were designed to accommodate multiple transmission and pipeline projects within a single corridor.[n] A similar approach can be adopted to designate CO_2 transport corridors.

The Bureau of Ocean Energy Management should provide a comprehensive regulatory framework for sub-seabed CO_2 storage in the Outer Continental Shelf. The Outer Continental Shelf (OCS) comprises 1.7 billion acres of ocean area, much of which offers suitable geologic storage (Figure 8).[124] The Outer Continental Shelf Land Act allows the Bureau of Ocean Energy Management (BOEM) to lease mineral resources to private and public entities, as well as the right to issue leases, easements, or rights-of-way for the purpose of sub-seabed CO_2 storage.[125] However, the procedures and requirements associated with sub-seabed CO_2 storage are undefined, creating a significant impediment to any offshore CO_2 storage leasing activity.[126] In other words, BOEM is unable to implement its authority without a guiding regulatory framework. For example, there are no established monitoring requirements applicable to the injection process. Similarly, there are no existing inspection requirements for wellheads, platforms, or pipelines in the context of CO_2 storage. Technical requirements regarding the characteristics of pipelines, for example, should be in place to ensure the integrity of the pipes. Safety standards for CO_2 handling equipment on offshore platforms may also need to be delineated.[127] Finally, procedures and requirements for sealing wells and addressing possible leaks also are needed.[128]

The White House should work with Congress to develop scalable business models for CO_2 storage. CO_2 management can be considered an essential public service, like water supply, sewage, electricity, and telecommunications. These services may be managed by different structures with some form of government involvement and regulation. New business models are needed that can manage the difficulty and uncertainty

[l] Policy options to manage long-term CO_2 liabilities are discussed separately in the latter part of this report.

[m] A proposed energy project within the corridor is still required a site-specific environmental review because accurate evaluation of impacts can be made only with an actual proposed project.

[n] According to the final Programmatic Environmental Impact Statement of the Section 368 Corridor, the designated energy corridors could be made available for "other energy-related transport systems besides those identified in Section 368," which include CO_2 pipelines. There was an application submitted to the BLM for a CO_2 pipeline to use the Section 368 Corridor in 2014, but it was withdrawn later.

of developing and operating CO_2 infrastructure projects and can increase operations to reach gigaton-scale CO_2 removal. These projects can involve multiple project segments—including direct air and point source capture facilities, CO_2 pipelines, and geologic storage—operated by different firms and integrated across different sectors. Aligning all project segments creates significant complexity for project financing, deterring scalability. For example, capture facilities are eligible to receive the 45Q tax credit, though they cannot receive the credit until after CO_2 has been permanently stored or adequately managed under IRS guidance. New business models need to also manage the uncertainty of the timescales required to site, permit, and build that vary significantly across each project segment.

There are several options for how the federal government might support and create scalable business models for CO_2 infrastructure. Options to consider include the ownership and operational structure, sources of financing, management of liability, and project permitting and siting. Table 8 describes four possible ownership and management structures that highlight some of these design options.

TABLE 8

Possible Ownership and Management Structures for CO_2 Storage Business Models

Ownership	Operation	Financing	Liability	Permitting	Siting	Analogs
Private Sector Model						
Private	Private	Private with government subsidy	Private	Works with Governments	Works with Governments	Current CCUS Projects (e.g., ADM*, Petra Nova)
Utility Model						
Government chartered, Private	Private	Private with government subsidy, Government regulated	Private, Government insurance model, Obligation to serve	Works with governments	Works with governments	Investor-owned interstate utilities in electricity, gas, telecoms, etc.
Public Authority Model						
State/local government, Interstate compact	Private, Government	Government, Private partners	Government, Obligation to serve	Eminent domain authority, Works with governments	Eminent domain authority, Works with governments	Public utilities for electricity, etc.; interstate or intermunicipal agencies (e.g., DC WASA*, Port Authority); federal quasi-corporations (e.g., Amtrak, USPS)
Quasi-Federal Government Model						
Federal Government	Government, Contractors	Government, Private partners	Government, Regional or national jurisdiction	Eminent domain authority, Works with governments	Eminent domain authority, Works with governments	TVA, Power Marketing Administrations (e.g., BPA, WAPA, SWPA*)

*ADM=Archer Daniels Midland; DC WASA = District of Columbia Water and Sewer Authority; TVA = Tennessee Valley Authority; BPA = Bonneville Power Administration; WAPA = Western Area Power Administration; SWPA = Southwestern Power Administration

BOX 4

What a Quasi-Federal Government Model Could Look Like

A CO_2 management entity could adopt an ownership, operation, and financing model like other quasi-federal government entities, such as the Power Marketing Administrations (PMAs). The entity could be established by Congress, similar to the formation of the Bonneville Power Administration (BPA) through the Bonneville Power Act of 1937 to "provide preference and priority in sales of federally generated power to Pacific Northwest public bodies and cooperatives."[129] Alternatively, the CO_2 management entity could be developed as a new agency under an existing federal department, similar to the Western Area Power Administration (WAPA) established concurrently with the formation of the DOE. PMAs are federally owned and operated, have access to government financing, and have eminent domain authority for permitting and siting new infrastructure. As federal government entities, they also are included under federal liability protection. PMAs also work closely with the private sector and state and local governments to deliver wholesale electricity to customers.

PMAs operate using a tiered customer model. Tier 1 customers are other federal entities that receive first preference and pay wholesale prices. Surplus generation after servicing Tier 1 customers is sold to preference customers, such as state, municipal and cooperatively owned electric power distributors, under long-term contracts to receive electricity at cost. After preference customer commitments are met, PMAs may sell surplus generation into competitive markets. Revenues from the sale of power by PMAs are deposited in the Treasury Department. The PMAs have access to certain funds, such as those for purchase power and wheeling, without the requirement for appropriations. Bonneville and WAPA have authority to borrow funds from the Treasury Department for certain capital investment costs; other capital investment and operating funds are subject to annual appropriations.

A new CO_2 management entity could be created, managed, and operated under a PMA-like model. The CO_2 management entity would be responsible for the CO_2 after it is received from customers and could work with private sector partners to design and build the CO_2 storage facilities, and to estimate the near- and long-term sequestration capacity. This entity could work with DOE, the U.S. Geological Service, the U.S. Department of Agriculture, and other offices within the Department of the Interior to identify federal lands and waters with robust geologic storage resources (Figure 8). The availability and use of federal lands will vary by region, as federal lands comprise about 50 percent of western states and less than five percent of most eastern states. Like PMAs, CO_2 storage services could be provided first to other federal entities, and then to other customers classes including state and local government projects and private sector CCUS projects.

Certain federal agencies could be "first movers" in CO_2 management in this model and can leverage CO_2 removal opportunities to reduce the federal government's own emissions footprint. Federal facilities emitted 37 $MtCO_2e$ from Scope 1 and 2 emissions in FY2019; at the same time, multiple policy proposals, including the American Jobs Plan,[130] the 100 percent Clean Economy Act of 2019,[131] and the House Select Committee on the Climate Crisis' "Solving the Climate Crisis Plan" call for the federal government to reach net-zero emissions.

Reaching gigaton-scale CO_2 infrastructure will likely require increased federal support, especially in managing project permitting and siting. An expanded federal role can help in three separate (or combined) ways: supporting the upfront costs for developing the necessary infrastructure; offering CO_2 takeaway and/or storage services to a large cross-section of potential CO_2 capture facilities; and playing a role in managing long-term liability of stored CO_2.

An expanded federal role in project development, such as through the creation of a dedicated entity for planning, siting, constructing, and operating CO_2 infrastructure at scale, would address some of the thorniest issues for CCUS projects. The singular focus and a guarantee of adequate financing means projects could be built sooner and with more foresight for future needs than an at-risk project developer might be equipped to do.

Alternatively, a CO_2 management entity with government charter or ownership could assume all or some liability for the captured CO_2 at a designated point of ownership transfer, allowing the capture site to lower its risk profile. This could greatly reduce the regulatory, permitting, and liability challenges associated with growing this nascent industry.

Finally, the federal government could support long-term management of subsurface CO_2. Management of subsurface geology is complex and cumbersome; securing property rights, obtaining permits, and maximizing the total available injection capacity requires region-wide and patient project planning, a task that has proved challenging for individual emitters. The need for monitoring and management can also extend beyond the life of the business that generated emissions. Transferring long-term subsurface management to a federal entity would provide the best assurance for fidelity and public safety. Box 4 details one possible design of a scalable CO_2 capture business model.

Partner with the Private Sector to Create CO_2 Management Jobs and Industries

Building out large-scale CO_2 infrastructure will require close collaboration with the private sector, especially in the development of a robust, trained workforce to construct, operate, and maintain that infrastructure.

The federal government should encourage the formation of regional hubs to achieve high-capacity CO_2 infrastructure. While 45Q tax credits provide financial incentives to capture and store CO_2, companies that transport CO_2 do not have federal financial support mechanisms. The federal government has unique capability to convene major emitters, midstream companies, geologists, economists, and regulators to facilitate commercial activity and public-private sector collaboration. One approach is to focus efforts where there is geographic clustering of CO_2 sources and the potential to create economies of scale through a CO_2 infrastructure hub. Hub formation has been a successful tool internationally to encourage the private sector to engage in CO_2 capture from a variety of emissions sources (see Table 2). Public-private partnerships can enable hub formation where a single entity could develop the CO_2 infrastructure for use by emitting entities. One key challenge is sizing the CO_2 transport and storage infrastructure for future, large-scale capacity before commitments are made from all the CO_2 sources. A new financing program could provide flexible, low-interest loans to CO_2 transportation project developers for initial excess capacity on new infrastructure to facilitate future growth. The SCALE Act would create such a program called the CO_2 Infrastructure Finance and Innovation Act program and allocate $2.1 billion over five years to the program.[132]

DOE should work with other federal agencies to identify priority regions for CO_2 transport and storage development to expedite private investments. Proactive planning and siting of CO_2 transport and storage can borrow the best practices of stakeholder engagement from siting renewable energy projects. For example, federal and state programs reduced barriers by designating energy infrastructure areas, such as BOEM's Wind Energy Areas (WEA), California's Development Focus Areas, and Texas's Competitive Renewable Energy Zone (CREZ) (Box 5). Priority regions for CO_2 hubs can be explored using a process similar to those used to identify priority WEAs. To identify a WEA, BOEM works across federal, state, local, and tribal governments to identify suitable areas of development in the Atlantic OCS with the least environmental impacts and conflicts between stakeholders. Proposed projects within a WEA can expedite permitting processes.[133]

BOX 5

Designating Energy Areas at the State Level: Examples

California's Desert Renewable Energy Conservation Plan identified Development Focus Areas for utility-scale development of wind, solar, and geothermal energy projects in the desert regions of seven California counties. The plan aimed to provide a more efficient and easy-to-understand permitting process for developers of renewable energy projects in these areas as well as to conserve desert ecosystems.[134] In 2016, BLM approved the land use plan, covering the 10 million acres of BLM-managed lands in the Development Focus Areas.

Texas developed a similar process, designating a CREZ that allowed developers to proactively site transmission to connect wind resources to the grid.[135] Financing of renewable energy needs certainty of transmission access; at the same time, transmission lines require demonstrated need and load to be built. The CREZ process can address the chicken-and-egg problem by planning transmission—which typically takes five to 10 years to develop—in anticipation of siting future renewable energy projects—which typically take one to three years to develop. The CREZ process has six steps: (1) design a process compatible with local laws; (2) assess resource potential; (3) select candidate zones; (4) develop transmission options; (5) designate a final transmission plan; and (6) upgrade the transmission system.

DOE should assist in the planning and development of hydrogen infrastructure in conjunction with CO_2 infrastructure. Federally supported CO_2 hubs should identify opportunities to build infrastructure for transporting and storing hydrogen that can be produced with CO_2 capture via steam methane reforming, called "blue hydrogen," or used in industrial processes that produce CO_2. Some industrial plants such as cement, for example, can both use clean hydrogen for process heat and adopt CO_2 capture technology for process emissions unrelated to heating—those produced by the chemical conversion of calcium carbonate to lime in the case of cement. Coordinated regulatory structures could be valuable for capturing emissions, preserving and creating jobs, enabling a range of new technologies (e.g., DAC) and industries, maintaining existing industrial activity, and creating a pathway and infrastructure needed for longer-term green hydrogen[o] options.

Establish Federal Carbon Dioxide Removal Strategy

Numerous global assessments highlight the critical role of technological CDR in achieving U.S. and global net-zero emissions targets. As noted, multiple CDR pathways, including DAC with CO_2 storage (DACCS), direct ocean capture with CO_2 storage, enhanced carbon mineralization, and bioenergy with carbon capture and storage (BECCS), need CO_2 transport and storage infrastructure. CDR pathways are also complementary to CCUS in terms of expertise and workforce requirements. Setting a midcentury target for CDR could spur innovation and investment in CDR technologies and associated CO_2 infrastructure.

The White House should set a national CDR target that is separate and distinct from carbon abatement goals in meeting the NDC. The climate benefits from direct CO_2 abatement are indistinguishable from

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[o] "Green" hydrogen is produced from electrolysis using zero emissions electricity resources.

removing the same amount of CO_2 from the atmosphere, and both options would benefit from CO_2 infrastructure. In practice, however, CO_2 abatement and CO_2 removal have significant differences in cost, technology readiness, and verification. Creating explicit targets for CO_2 abatement (such as retrofitting an industrial facility with carbon capture) and CO_2 removal (such as DAC) creates more certainty for developers of both options and supports the emergence of improved regulatory and market frameworks that address permanence, additionality, and market design challenges for carbon removal.[136]

In the Energy Act of 2020, Congress directed the Secretary of Energy to assemble a CDR task force that will advise the Secretary on CDR, identify barriers to the technology, and identify tools to advance CDR.[137] Developing a national CDR strategy or target, however, is not within the task force's mandate. The CREATE Act of 2020 would establish a Committee on Large-Scale Carbon Management in the National Science and Technology Council to develop a national strategic carbon management plan.[138] This Committee could inform a national CDR target as part of the NDC, based on an all-of-government review of CDR technologies and relevant agency programs.

Establish an Effective and Efficient Regulatory Framework

CCUS and CDR project developers must navigate a complex regulatory environment involving multiple jurisdictional authorities spanning federal, state, and local levels. Uncertain and lengthy permitting timelines combined with the relatively tight timeframe to claim the 45Q tax credit can be particularly discouraging for CO_2 storage project developers. Certain states have frameworks for improved siting and permitting or have analogous frameworks for the oil and gas sector that could be applied to CO_2 infrastructure. Improving the effectiveness, transparency, and efficiency of the regulatory environment, however, would significantly reduce uncertainty surrounding CO_2 infrastructure projects and encourage expanded development of CCUS and CDR technologies.

Enhance Federal Capabilities to Regulate CO_2 Infrastructure

Permitting of CO_2 storage sites is often a lengthy process that introduces significant uncertainty into project outcomes, making the CO_2 transport and storage industry unattractive to potential investors and limiting deployment of CO_2 infrastructure.[139]

DOE should create a Clean Energy Permitting Facilitation Office (CEPFO) to assist with timely and efficient CO_2 infrastructure permitting. CCUS, DACCS, BECCS, and other CO_2 capture and storage projects are subject to numerous permitting processes. As the industry grows, the number and scope of regulatory bodies at the local, state, regional, and federal levels with jurisdiction over certain parts of the value chain will likely pose additional—and discouraging—complexities to the permitting process when rapid action is needed to address the urgency of climate change. A dedicated office at DOE could provide three critical functions to help guide project developers. The CEPFO could provide technical resources, such as a permitting guidebook and targeted access to technical information that is in the public domain but otherwise difficult to find, to help project developers understand the permitting landscape. Additionally, the CEPFO could provide technical assistance to assist in major projects of national significance via demonstrations, case studies, or other technical support, potentially through collaboration with government contractors. Finally, the office could monitor permitting activities among the various local, state, and federal agencies involved in permitting a particular project to flag issues that might otherwise cause significant project delays and thus ensure timely completion.

DOE should convene an Interagency Working Group to develop an action plan for deploying CO_2 hubs. DOE should form an Interagency Working Group for Decarbonization Hub Deployment to develop an action plan with implementation steps and clear timelines. The action plan should be based on an inventory of existing policy blueprints and analyses as well as consultation with agencies, project developers, and interested parties. The action plan should identify priority implementation measures and timelines. After the report, the Working Group could publicize relevant changes in policy, funding, and regulations to project developers and incorporate the reviews and guidance requested from the Council on Environmental Quality (CEQ) and EPA through Section 102 of the Consolidated Appropriations Act of 2021. The guidance must (1) facilitate reviews associated with deployment of CCUS projects and infrastructure and (2) support "efficient, orderly, and responsible" development of CCUS projects and infrastructure. In addition to sharing information, the Working Group could establish best practices for hub formation, including aligning project partners, communicating with stakeholders, and navigating regulatory processes.

Improve UIC Class VI Permitting Process

Gigaton-scale CO_2 capture and removal hinges on the ability of the EPA to permit Class VI wells for permanent geologic CO_2 storage and to potentially review Class VI primary applications as more states seek to develop CO_2 storage.

EPA should work with Congress to increase funding for permitting Class VI storage wells, including hiring designated staff with geologic expertise to oversee the review of Class VI permits. One of the key determinants of a project's timeline is the Underground Injection Control (UIC) Class VI well permit. Additional staff with the requisite skills could help EPA shorten the review timeline for UIC Class VI well permits and state primacy applications. Increased funding to EPA for Class VI permitting programs has already been recommended in a number of draft laws and plans including the Storing CO_2 and Lowering Emissions (SCALE) Act, the CLEAN Future Act, and the Congressional Action Plan for a Clean Energy Economy and a Healthy, Resilient, and Just America.[140] Only two operational projects have received Class VI permits since EPA developed the UIC Class VI program in 2010; the latter of which took six years.[141] This timeframe is an obstacle to CO_2 infrastructure project developers, especially given the commencement of construction deadline of January 1, 2026 to receive the 45Q tax credit.

"Passage of the SCALE Act is very important because that will begin the process of developing the infrastructure to get carbon to the places where it will be injected in the ground."

—United Mine Workers of America

EPA should engage technical experts to inform its Class VI injection permitting review process. EPA's Drinking Water Protection Division should request that the UIC National Technical Workgroup (NTW) engage technical experts to help develop internal program guidance for permitting Class VI wells. The NTW could also develop a report with practical management tools like diagnostics, databases, and screening criteria to help federal and state UIC regulators address potential issues related to Class VI permitting. In 2015, the NTW worked with experts across several state offices to address potential injection-induced seismicity.[142] The NTW should further consult with academic and industry professionals with expertise on topics such as plume migration, permanence, leakage risks, and monitoring practices. Any follow-on report should be informed by an extensive review of available technical literature on supercritical CO_2 storage, input from non-government experts, and data from demonstration projects in the United States and abroad. This process should be time limited to inform the range of federal activities on CCUS.

Provide Regulatory Clarity for Siting Interstate CO_2 Pipelines

Creating connected CO_2 infrastructure hubs will require the buildout of CO_2 pipelines; however, to date, states have played a leading role in siting, constructing, and operating CO_2 pipelines, posing a range of regulatory obstacles to interstate CO_2 pipeline development. A federal regulatory framework for siting interstate CO_2 pipelines could facilitate widespread infrastructure deployment.

CEQ should lead the implementation of a government-wide assessment and solicit improvements for CO_2 infrastructure regulations. The Utilizing Significant Emissions with Innovative Technologies (USE IT) Act, signed into law as part of the Consolidated Appropriations Act of 2020, authorized the chair of CEQ to conduct a review and assessment of federal permitting for CCUS and develop permitting guidance, in consultation with EPA, DOE, Department of the Interior (DOI), and the Federal Permitting Improvement Council (Box 6). The USE IT Act also establishes at least two task forces to solicit input from affected stakeholders and will identify challenges to and improve the performance of the permitting process and regional coordination.[143]

BOX 6

CEQ and the USE IT Act

The Utilizing Significant Emissions with Innovative Technologies (USE IT) Act directs CEQ to issue a report and guidance and to assemble at least two task forces. The USE IT Act gives CEQ 180 days to convene various federal agencies and issue a report, making the deadline for the report June 25, 2021. In the report, CEQ is directed to (1) compile existing information on federal permitting, reviews, and resources for applicants, agencies, and other stakeholders; (2) inventory current or emerging activities that promote commercial use of CO_2; (3) inventory existing studies and reports that analyze or identify priority CO_2 pipelines; (4) identify gaps in federal regulations; and (5) identify federal financing mechanisms.

Following the publication of the report, CEQ is directed to issue guidance consistent with the report's findings. The USE IT Act gives CEQ one year to issue the guidance, making the deadline December 20, 2021. The guidance, developed in consultation with DOE, EPA, DOI, and the Energy Program for Innovation Clusters, must (1) facilitate reviews associated with deployment of CCUS projects and infrastructure and (2) support "efficient, orderly, and responsible" development of CCUS projects and infrastructure. The guidance will address the reviews related to the NEPA, Federal Water Pollution Control Act, Clean Air Act, Safe Drinking Water Act, Endangered Species Act, National Historic Preservation Act, Migratory Bird Treaty Act, Bald and Golden Eagle Protection Act, and any other review deemed necessary.

As part of the guidance mandated by the USE IT Act, CEQ should provide a clear regulatory framework for federal agencies that could help address obstacles to siting of interstate CO_2 pipelines through the assessment of current regulations and review of the options for a federal role in developing CO_2 infrastructure. The following are the most widely discussed options for a CO_2 pipeline regulatory framework:

- **Natural Gas Pipeline Model**: Under this model, the Federal Energy Regulatory Commission (FERC) has the authority to approve construction and operation of interstate pipelines and to set transport fees for pipelines. FERC also grants federal eminent domain authority to pipeline developers. To apply this model to CO_2 pipelines, Congress would need to grant FERC or another federal agency federal eminent domain authority and the authority to permit and set rates for pipelines.[p] This model offers a clear and consistent regulatory framework but adds new costs and regulatory barriers.[144] For instance, under this model, an interstate CO_2 pipeline operator crossing private land would be subject to federal environmental review that could extend the permitting process and increase project costs, which would not be the case under the current regulatory framework. Because this model does not require pipelines to operate as common carriers, the operators of pipelines have greater ability to structure transactions compared to the oil pipeline model. This model is compatible with the various business models discussed above because it provides regulatory certainty and allows the ability to structure transactions for the operators.

[p] If an agency is granted the federal eminent domain authority, the agency can delegate the power to exercise eminent domain to private companies.

- **Oil Pipeline Model**: If an oil pipeline model is applied, states still have siting or eminent domain authority, while FERC or another federal agency has authority over rates and access.[q] Congress would need to authorize FERC or another federal agency to establish federal common carrier requirements and regulations on tariffs and rates. Under federal supervision, interstate CO_2 pipelines would be required to operate as common carriers and provide their services at non-discriminatory rates. As a common carrier, the operator could not refuse space to any shipper that meets the conditions of service.[145] A limited exception for contract carriers could be made in the new regulatory framework for efficient operation of CO_2 pipelines.

- **Federal Backstop Authority**: Under this model, states would maintain primary responsibility over siting CO_2 pipelines, but FERC or another federal agency could issue a permit for the facilities within pre-designated national corridors if states delay or fail to issue the permit. This approach could be modeled after DOE's electricity transmission backstop siting.[146] The Energy Policy Act of 2005 added section 216(h) to the Federal Power Act granting the Secretary of Energy the authority to designate national interest electric transmission corridors in areas experiencing electric energy transmission capacity constraints or congestion. Within these corridors, the Secretary is authorized to issue a permit if a state fails to issue a permit in a timely manner.[r]

- **Interstate Compacts:** Interstate compacts are contracts negotiated among states on a particular policy issue.[s] Under this model, states could create commissions focusing on coordinating regulatory processes or could create regulatory agencies whose regulations are binding on participating states.[147] This approach could simplify the permitting process for interstate CO_2 pipelines while states maintain their own siting authority for intrastate pipelines.

  There are many examples of such compacts; some of them require congressional consent, though this consent could be quite broad (e.g., general authority for states to form such compacts).[t] Also, many interstate compacts have been formed to support environmental protections and issues that span multiple states, similar to those that might be needed for CCUS hubs. The Ohio River Valley Water Sanitation Compact, for example, "establishes a commission for the purpose of maintaining waters in the river basin in a satisfactory condition, available for use as public and industrial water supply after reasonable treatment, suitable for recreational use, and capable of maintaining healthy aquatic communities with the guiding principle being that pollution from one state shall not injuriously affect the various uses of the interstate waters." Another relevant example is the New Hampshire-Vermont Interstate Sewage and Waste Disposal Facilities Compact, which "authorizes local governments and sewage districts in New Hampshire and Vermont to engage in programs for abatement of pollution through joint facilities for the disposal of sewage and other waste products."[148]

DOE should explore and support the use of existing rights-of-way to enable CO_2 infrastructure deployment. Using existing ROW provides opportunities to quickly scale up CO_2 transport infrastructure. Co-locating CO_2

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[q] Under the Interstate Commerce Act, an oil pipeline is a common carrier under federal supervision, but there is a very limited exception: An oil pipeline that transports production from its own wells to its own refinery for its own use is a private pipeline that is not under FERC jurisdiction.

[r] The DOE designated two National Corridor in 2007 based on the study of transmission congestion, but the corridors were vacated by a court decision in 2011. A collection of organizations concerning the corridors' potential harm on local species filed petitions, and the court faulted DOE for not meeting its statutory obligations. Since then, DOE has not designated any transmission corridor.

[s] The Interstate Oil Compact to Conserve Gas and Oil is one of example of an interstate compact. In 1935, six states endorsed the compact and Congress ratified it to resolve unregulated petroleum overproduction and the resulting waste. It resulted in the creation of a multi-state government agency, the Interstate Oil and Gas Compact Commission (IOGCC), which has been a forum for state officials through a range of programs to share information, technologies, and regulatory methods.

[t] The U.S. Constitution contains a requirement for the consent of Congress for compacts between states, but the U.S. Supreme Court has held that some compacts between states do not require such congressional consent. The court stated that congressional consent is required only if a compact increases political power in the states, which may interfere with the just supremacy of the United States in 1893.

pipelines on existing ROWs would enable developers to avoid construction on undisturbed land, negotiate with fewer property owners, and reduce permitting complexity.

DOE could lead a study of the potential use of existing ROWs for CO_2. Many successful energy infrastructure projects have used existing highway or railway ROWs. Opportunities to use existing ROWs for CO_2 pipelines, however, are not well explored compared to other infrastructure such as renewable energy or transmission lines. DOE could explore the opportunities for potential use of existing ROWs in collaboration with DOI and the Department of Transportation (DOT).

Building on the study of existing ROWs, DOE could support state efforts to co-locate CO_2 pipelines using existing ROWs or existing infrastructure. The Federal Highway Administration's (FHWA) support for installing renewable energy facilities in highway ROWs offers an example. As the number of proposals to use the highway ROW for renewable energy facilities grows, the FHWA has supported the State Departments of Transportation (SDOT) in the installation of renewable energy in highway ROWs by providing resources such as guidance, research reports, and example agreements as well as promoting peer exchanges among SDOTs.[149]

DOE should explore and support the use of existing infrastructure for CO_2 pipelines. Repurposing the expansive U.S. network of existing oil and gas pipelines presents a ripe opportunity to lower costs for CO_2 transport. Many of more than 45,000 miles of oil and gas pipelines lying on the seafloor are no longer needed due to the declining demand since the 1980s; decarbonizing the energy system could further reduce use of this existing pipeline network.[150] These pipelines could be reused for CO_2 transport. Natural gas pipelines have been successfully converted to CO_2 pipelines in northern Mississippi, saving project developers more than $35 million from avoided ROW purchases, materials, and labor expenses.[151]

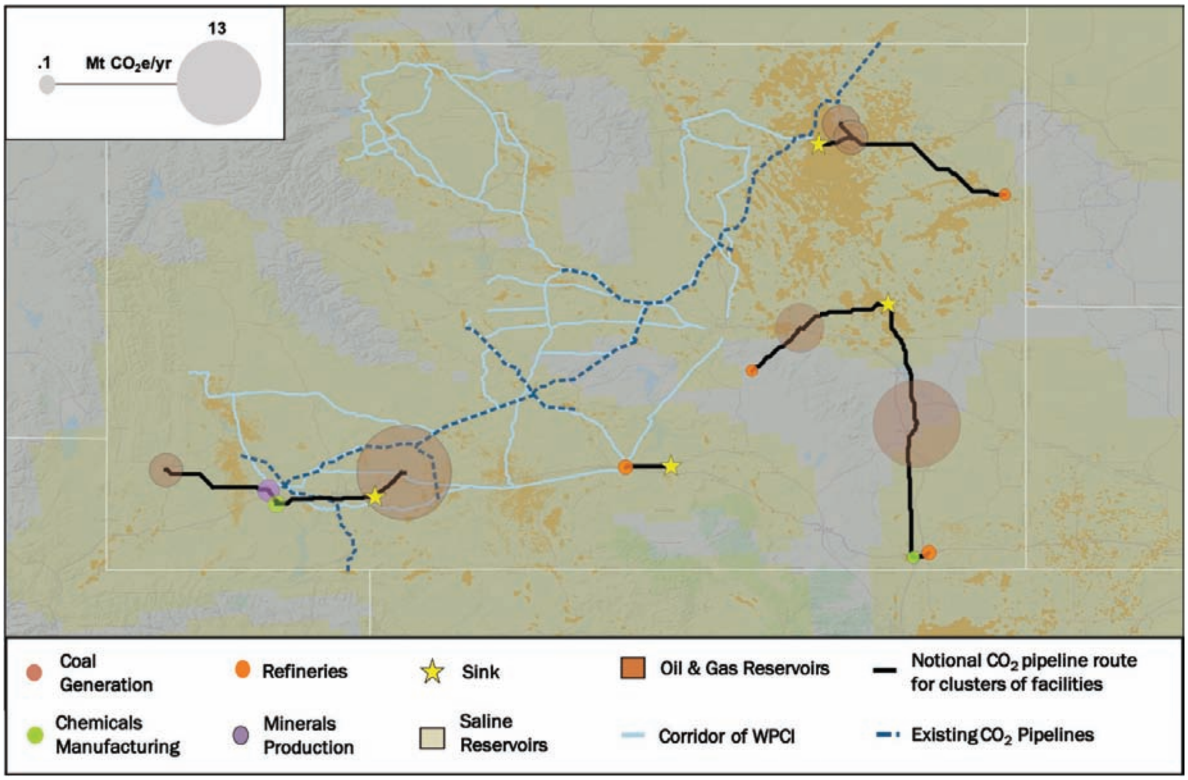
DOE could lead a feasibility analysis on the potential reuse of existing oil and gas pipelines for CO_2 transport to inform states and private entities of key considerations and efficient and safe options for expanding CO_2 infrastructure. For example, pressure and corrosion are two key considerations when assessing repurposing natural gas pipelines for CO_2 transportation. While the required pressure rating for CO_2 pipelines is typically higher than natural gas pipelines, shorter pipelines (<100 miles) and those with lower flow rates are often more compatible.[152] Transporting CO_2 as a gas (rather than in a supercritical state) can also mitigate pressure rating issues.[153] A DOE analysis could bring these factors to the attention of developers and other parties. The DOE National Renewable Energy Laboratory is spearheading similar efforts to understand the potential of repurposing natural gas pipelines for transporting hydrogen.[154]

The idea of repurposing offshore oil and gas infrastructure to reverse flow CO_2 is also gaining traction in other parts of the world. The Korea National Oil Corporation presently transports natural gas from an offshore platform in the Donghae gas fields to the South Korean port of Ulsan via pipeline. The company is investigating the feasibility of injecting 400 ktCO_2 per year into the nearly exhausted gas field that is set to close in 2022 using the same natural gas pipeline and offshore platform. The project would begin operation in 2025 and operate for 30 years, making it one of the largest of its kind. In total, South Korea plans to deploy offshore storage capacity of 4 MtCO_2 per year by 2023. Repurposing existing infrastructure can help reduce the cost and increase project feasibility.[155]

Modeling a CO_2 Infrastructure Hub in Wyoming

FIGURE 9

Wyoming CCUS Project Development Possibilities



This figure shows CO_2 emitting facilities and notional CO_2 pipeline routes and sinks in Wyoming modeled by SimCCS, as well as the Wyoming Pipeline Corridor Initiative (WPCI) routes. Also shown are existing CO_2 pipelines in the state, many miles of which run along the WPCI.

The state of Wyoming has been transporting and storing CO_2 for enhanced oil recovery (EOR) operations for years. In 2019, the state produced approximately eight million barrels of oil retrieved using 679 EOR wells.[157] The significance of EOR in Wyoming is amplified by the presence of the Enhanced Oil Recovery Institute, borne out of the legislature to help increase oil production and subsequent tax revenue for the state. There is deep workforce experience of transporting CO_2 and injecting it into the ground and several hundred miles of pipelines are already dedicated for CO_2 transportation in the state, an outcome of collective experience working with EOR.[158] Existing pipeline infrastructure could also be used in service of permanent storage in saline formations.

To understand opportunities for CO_2 transport and storage infrastructure development, 17 45Q-eligible facilties emitting nearly 43 MtCO_2e each year (roughly a third of waste emissions in the United States) were modeled in SimCSS to identify potential transport routes to CO_2 storage sinks

(Figure 9).[u] This analysis found 413 miles of pipeline that connect the 17 emitters to four CO_2 sinks. The sinks correspond with National Energy Technology Laboratory (NETL)'s NATCARB database of existing saline and oil and gas reservoirs throughout North America.[159] In northeast Wyoming, emitters were connected to a sink located on top of expansive oil reservoirs, where EOR could provide a viable economic opportunity for sequestration. As shown in Figure 9, there are already many miles of existing CO_2 pipeline that could transport CO_2 to the northeast Wyoming sink location from other parts of the state. Emitters in southeast Wyoming are also drawn to a sink on top of oil reservoirs, though the pipeline segments connecting those emitters is 234 miles long (over half the modeled pipeline in the state) to account for mountainous terrain. In the southwest, there is overlap between the SimCCS notional pipeline routing and the Wyoming Pipeline Corridor Initiative (WPCI), discussed further below. Among the emissions sources analyzed, power generation is responsible for most of the CO_2 (91 percent) that could be feasibly stored.

Wyoming has worked proactively to create a welcoming policy and regulatory environment for large-scale CO_2 transport and storage infrastructure. On October 9, 2020, the state became the second in the United States for EPA's delegation of permitting authority for UIC Class VI wells.[160] Primacy allows requirements to be adapted to the local geology, industry, and regulatory expertise and gives the state control of the permitting process. Wyoming is also one of only three states to specify in legislation that pore space ownership lies with the surface owner; this has greatly simplified the task of securing subsurface pore space needed to permanently store CO_2.[161]

The WPCI, a state entity created to identify corridors on federal, state, and federal lands for future CO_2 pipeline development, identified nearly 2,000 miles of suitable existing pipeline ROWs. In January 2021, after more than eight years of vetting land in the central and western parts of the state, BLM authorized 1,111 miles of corridor on federal lands.[162] These corridors will reduce the complexity, uncertainty, and timelines associated with future CO_2 pipeline development. Over 300 miles of existing CO_2 pipeline already align with the corridors, further minimizing costs of the infrastructure buildout.

Federal lands in the state may also be candidates for storage sites. BLM oversees more than 18 million acres in the state, approximately eight percent of all BLM-managed land in the country. They also oversee 43 million acres of federal mineral estate, 69 percent of the entire land area of Wyoming.[163]

[u] To be eligible for the 45Q tax credit, industrial emitters must produce at least 100,000 metric tons of CO_2 each year, while power generators must produce 500,000 metric tons of CO_2 each year.

Enhance Policy Support and Strengthen Financial Incentives

Existing federal support for CO_2 capture, removal, utilization, and storage is currently insufficient to overcome the myriad uncertainties facing project developers. Indefinite project timelines due to siting, permitting, and financing challenges contribute to uncertainty around how much developers can expect from the 45Q tax credit (if it can be applied at all). Further, few insurance mechanisms for geologic CO_2 storage have been established, making potential company liability uncertain. Federal assistance including research grants, financial incentives, and liability-reduction program management can play an important role in increasing the long-term predictability of the CO_2 storage market and driving market formation.

Create Long-term, Predictable Financial Incentives for CO_2 Infrastructure

Current financial incentives are insufficient to spur widescale deployment of CO_2 transport and storage infrastructure. As described above, in the absence of carbon pricing, the 45Q tax credit is currently the main revenue stream for CO_2 storage projects. Figure 10 demonstrates the levels of the tax credit available for various sources and uses of CO_2. Projects must commence construction by January 1, 2026 to qualify for the credit. As a result, the 45Q tax credit does not provide project developers and financiers with sufficient long-term certainty, which is necessary given the long timeframes for project scoping, permitting, construction, and ultimately operation.

FIGURE 10

45Q Tax Credit Value Available for Differing Sources and Uses of CO_2

Minimum Capture Requirement ($ktCO_2$/yr)				Value of Tax Credit[3] ($USD/$tCO_2$)									
Type of CO_2 Storage/Use	Power Plant	Other Industrial Facility	Direct Air Capture	2018	2019	2020	2021	2022	2023	2024	2025	2026	Beyond 2026
Dedicated Geological Storage	500	100	100	26	29	32	35	38	41	44	47	50	Indexed to Inflation
Storage via EOR	500	100	100	15	18	20	23	25	28	30	33	35	Indexed to Inflation
Other Utilization Processes[1]	25	25	25	15	18	20	23	25	28	30	33	35	Indexed to Inflation

[1] Each CO_2 source cannot be greater than than 500 $ktCO_2$/yr.

[2] Any credit will only apply to the portion of the converted CO_2 that can be shown to reduce overall emissions.

[3] Credit values as stated in the January 2021 IRS guidance.

Source: Energy Futures Initiative, 2021. Adapted from Simon Bennett and Tristan Stanley, 2018.

Congress should modify the 45Q tax credit. The 45Q tax credit is widely considered a vital tool for the financial feasibility of CO_2 storage projects. Adjustments to the 45Q tax credit would provide long-term stability and reduce uncertainty for developers of CO_2 storage projects. Several pieces of proposed legislation seek to modify the 45Q tax credit, often through extending the tax credit period or changing the credit payment method. These bills include: (1) the CCUS Tax Credit Amendment Act of 2021; [164] (2) the Growing Renewable Energy and Efficiency Now (GREEN) Act of 2021;[165] (3) The Clean Energy for America Act;[166] (4) the Coordinated Action to Capture Harmful (CATCH) Emissions Act;[167] and (5) the Accelerating Carbon Capture and Extending Secure Storage (ACCESS) through 45Q Act.[168]

- **Extend the commencement of construction deadline for CCUS projects to qualify for the 45Q tax credit.** Extending the commencement of construction deadline would provide long-term stability and reduce uncertainty for project developers since projects can take as long as six years to develop (driven largely by long permitting timelines for Class VI wells and other key permits, described above).[169] The current January 1, 2026 deadline allows little flexibility for project delays from permitting or unforeseen circumstances, such as the COVID-19 pandemic. Recognizing the uncertainty of project development timelines for such a new industry, several pieces of proposed legislation, including the CCUS Tax Credit Amendment Act,[170] the GREEN Act,[171,] the Clean Energy for America Act,[172] and the ACCESS 45Q Act,[173] seek to extend the 45Q tax credit commencement of construction deadline to varying degrees.[174] Extending this deadline to January 1, 2036, as proposed in the ACCESS 45Q Act,[175] would significantly reduce the risk for developers interested in starting new CO_2 storage projects. The Clean Energy for America Act, reported by the Senate Finance Committee, would extend the period of eligibility for the 45Q tax credit indefinitely, with a phase out once CO_2 emissions from the electricity sector are reduced by 75 percent or more from current (2021) levels. The 45Q tax credit for carbon storage from DAC would be permanent.

- **Increase the credit value to make projects pursuing geologic storage economically attractive.** Increasing the dollar value of the 45Q tax credit will accelerate development of CO_2 infrastructure and lead to significant increases in capture capacity, particularly in the hydrogen, cement, iron and steel, and refining industries.[176] Two pieces of proposed legislation—the CATCH Act and H.R. 2633—increase the tax credit value to $85 per metric ton of CO_2 stored in secure, geologic formations.[177,178]

- **Extend the 45Q tax credit period to be commensurate with period of capital cost recovery.** Although CO_2 capture projects typically have a 20- to 30-year financing lifespan, the 45Q tax credits are only available for 12 years under the current rule.[179] An extension of this credit period, as suggested in the proposed legislation H.R. 2633, would increase the long-term financial predictability of CCUS projects.[180]

- **Provide a direct pay option for projects pursuing permanent geologic storage.** Because clean energy project developers typically have minimal tax liability, they often cannot directly claim their 45Q tax credits and must work with tax equity partners—at notable expense—to receive the benefit.[181] A 45Q direct pay option, rather than a tax credit, would reduce the financial burden on developers and their dependence on tax equity markets, which became more challenging to access during the COVID-19 pandemic.[182] A direct pay option for 45Q has been widely recommended[183,184,185] and is also included in several proposed pieces of legislation (e.g., the Clean Energy for America Act, the CCUS Tax Credit Amendment Act, the GREEN Act, and the ACCESS 45Q Act).[186,187,188,189]

EPA should incorporate CCUS as a lifecycle GHG emission reduction technology pathway in the Renewable Fuel Standard (RFS). By offering CCUS as an emission reduction technology pathway, renewable fuels industries would be eligible to receive more valuable credits through the RFS program, thus incentivizing deployment of CO_2 infrastructure. Biofuel facilities are natural candidates for CO_2 capture because they produce relatively concentrated streams of CO_2 emissions.[190] In particular, widespread adoption of CCUS by the ethanol industry could lead to expansive growth of CCUS markets due to the market size and global dominance of U.S. ethanol production. Notably, capturing CO_2 from the ethanol fermentation process alone would reduce the carbon intensity by 40 percent.[191] Such a change to the RFS would not only spur development of CO_2 infrastructure and enhance the flexibility of the RFS program but could also significantly reduce the carbon intensity of renewable fuels.

Congress should reinstate and expand the Section 48C Advanced Manufacturing tax credit. The former Section 48C Advanced Manufacturing Tax Credit program, which expired in 2013, provided $2.3 billion for production of clean energy technologies, including CCUS equipment.[192] Reinstating the 48C tax credit, as is proposed in both the American Jobs in Energy Manufacturing Act of 2021 and the GREEN Act, and increasing its total funding could spur investment in clean energy technology manufacturing and equipment for both new and retrofit CCUS projects.[193,194,195] Further, the 48C tax credit previously included only equipment to capture or store CO_2 but could be expanded to include CO_2 transport infrastructure, as proposed in the American Jobs in Energy Manufacturing Act of 2021.[196,197] This Act further proposes that the Secretary of Energy consider a project's potential for job creation in low-income communities or communities with displaced manufacturing, coal plant, or coal mine workers when certifying the credit—an enhancement that would amplify the social and economic benefits of the 48C tax credit.

"The Boilermakers are encouraged by the interest and support that many U.S. lawmakers have shown in this critical technology, including the expansion of tax incentives for CCUS projects. We hope to see that momentum continue with additional CCUS-focused legislation and increased funding for the Department of Energy's CCUS research and development."

—International Brotherhood of Boilermakers

Congress should update the Section 48A Advanced Coal tax credit. The Section 48A Advanced Coal tax credit was originally designed to support efficiency improvements in coal plants. While the current language of Section 48A does allow for the credit to be applied to coal plants with CO_2 capture, technical restrictions (i.e., rigid efficiency requirements) prevent CCUS projects from accessing this tax credit.[198] Updating 48A with unique requirements for CCUS projects, as is recommended in the 2021 Carbon Capture Modernization Act and the CCUS Tax Credit Amendment Act, would better incentivize new and retrofit CO_2 capture projects for coal plants.[199,200] In addition to Section 48A, which only applies to coal plants, Congress could introduce legislation granting a similar tax credit for CCUS equipment on natural gas plants.

Establish a Federal Framework and Structure for Addressing Long-term Liability for CO_2 Storage

Currently there is no federal framework for addressing the financial liabilities associated with CO_2 leakage over the longer term from CO_2 injection sites and storage facilities. A federal liability framework could greatly facilitate private investments in CO_2 storage projects by reducing financial uncertainty associated with the possibility of future leakage from geologic storage.[v] The potential for leakage is greatest during operation, prior to well closure. Two decades of operational CO_2 storage projects show, however, that this risk can effectively managed.[201] As with other infrastructure projects, risks related to security and operations should also be considered.

The Treasury Department and DOE should develop a federal liability framework for CO_2 storage. No approach to manage long-term liability has been tested because no commercial CO_2 storage operation has been in the post-injection site care phase in the United States.[202] A time-limited White House directive to Treasury and DOE to convene an interagency process, with input from industry and a range of other stakeholders, should examine options to address long-term liability associated with CO_2 leakage from geologic storage facilities. A range of suggested instruments to address liability concerns could be considered:

- **Transfer long-term liability to the government:** Under this approach, long-term liability would be transferred to the government after a certain period. The operator could be required to pay a fee to a trust or stewardship fund during operation or at the time of transfer of liability to cover the government's expenses.[203] Four states—Texas, Illinois, Louisiana, and North Dakota—have adopted a similar approach.[204] For example, the property rights of CO_2 were transferred to the state from the operator of the FutureGen project and the project was exempted from tort liability in Texas.
- **Layered approach*:*** Under this approach, the federal government shares risk with the operators of the projects and the industry through cooperative agreements.[205] In the event of an incident, the operator incurs the first layer of responsibility up to a per-incident dollar limit. If the costs exceed the limit, the second layer cost is shared by the industry participants in the agreements. The third layer is a stop gap by the federal government, which is also be capped at a limited amount. Any remaining damage falls back on the operator. This approach limits overall liability while leaving operators with some potential liability that is prescribed and bounded; this encourages the operators' responsible behaviors.[206]
- **Establish a new entity to manage CO_2 liabilities:** A newly created entity could take CO_2 liabilities from the project operators. The 2016 Parliamentary Advisory Group in the UK recommended the establishment of the "CCUS Delivery Company," which could take on the long-term CO_2 liabilities that private entities could not take.[207] The entity could be government-chartered or owned by the federal government.

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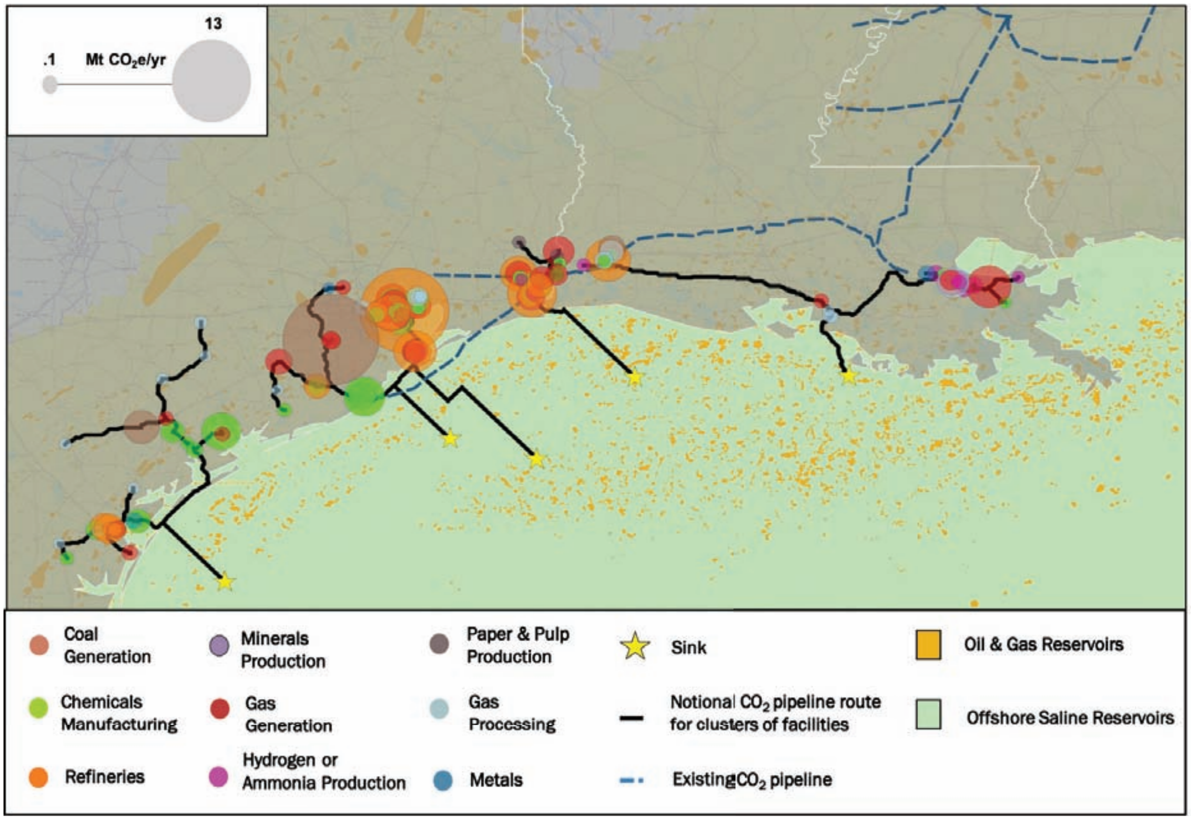
[v] According to the Global CCS Institute, three forms of liability are applicable to CCUS operations: civil liabilities, administrative liabilities, and greenhouse gas emissions/climate change liabilities. Civil liabilities are associated with another party's seeking compensation for damages caused by CCUS operations. Administrative liabilities are associated with the requirements by a regulator to the CCUS operator. Greenhouse gas emissions/climate change liabilities are associated with leakage requiring the operator to account for any credits obtained for CO_2 storage. The greenhouse gas emissions/climate change liabilities are unique and require special attention. The other two forms of liability are not unlike liabilities associated with other industrial processes, for which there are well-established liability management strategies.

Modeling a CO_2 Infrastructure Hub in the Texas and Louisiana Gulf Coast

FIGURE 11

The Texas and Louisiana Gulf Coast CCUS Project Development Possibilities



This figure shows CO_2 emitting facilities and notional CO_2 pipeline routes and sinks on the Texas and Louisiana Gulf Coast modeled by SimCCS, as well as the existing CO_2 pipelines in the region. Storage is also available on land, but ample storage potential offshore offers compelling opportunities worth exploration.

The Gulf of Mexico along east Texas and Louisiana is a prime location for large-scale CO_2 infrastructure. Dozens of industrial facilities—some already equipped with CO_2 capture—are located along existing CO_2 pipelines near ideal subsurface geology onshore and offshore, and states have experienced regulatory agencies and a mature policy environment. Several CCUS projects are already located in the region: the Petra Nova power plant, the Lake Charles Methanol plant, and Air Products' Steam Methane Reformer.[208] Exxon also recently announced a $100 billion plan for large-scale CO_2 removal infrastructure in the Houston area.[209]

Along the coastline, there are more than 150 facilities in close proximity, each emitting 100,000 or more metric tons of CO_2 annually. Combined, their annual emissions are nearly 190 $MtCO_2e$ (Figure 11).[210] SimCCS used five notional CO_2 storage sites near different depleted oil and gas reservoirs throughout BOEM-managed waters, connected by over 1,400 miles of notional CO_2 pipeline. In the modeling, approximately 170 $MtCO_2$ of emissions were captured.

While offshore geologic storage tends to be more costly than onshore, the region has compelling geography for both storage options.[211] NETL has funded or is currently funding six storage feasibility projects in the Gulf of Mexico alone.[212] Preliminary results show that the Gulf of Mexico offers the greatest potential for storage in the country. Depleted oil and gas reservoirs in the Gulf's federal waters have the capacity to hold nearly five $GtCO_2$, enough to store 26 years' worth of emissions from the sources evaluated in the modeling.[213] Saline formations in the Gulf of Mexico bordering Texas and Louisiana offer significantly more storage than oil and gas reservoirs–one study estimates 559 $GtCO_2$ of storage potential.[214]

There may be no state with a better experience with geologic CO_2 storage than Texas. EOR operations in the state have positioned Texas as a leader in subsurface engineering, and local regulatory agencies are well-versed in permitting Class II wells. The state also has a very large workforce of engineers, geologists, and other experts in subsurface geology. Louisiana and Texas are two of five states to clarify that post-injection liability for stored CO_2 transfers to state agencies, greatly reducing long-term developer risks.[215,216] Both states have primacy over Class II wells.[217]

The area also has a vast network of underwater pipelines. There are more than 45,000 miles of pipelines supporting oil and gas production on the seafloor; many are no longer needed due to reduced oil and gas demand.[218] Above this extensive network of pipelines, there are over 1,800 platforms for oil and gas production operations.[219] Repurposing existing infrastructure for Class VI sequestration operations, as opposed to laying new pipelines, could greatly reduce project costs.[220]

Provide Funding for CO_2 Infrastructure

Other than the 45Q tax credit, federal funding for carbon capture and geologic storage has largely focused on discrete pilot projects and smaller-scale projects. More support is needed for regional development of CO_2 transport and storage infrastructure. Box 8 discusses opportunities for leveraging the DOE Loan's Program Office.

DOE should work with Congress to increase funding to the Carbon Storage Program to develop sites for commercial-scale geologic storage. The NETL Carbon Storage Program funds a portfolio of applied research projects spanning advanced storage R&D, storage infrastructure, and risk and integration tools.[221] The Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative is part of the Carbon Storage Program and aims to develop several storage sites with 50 $MtCO_2$ or greater storage potential for deployment in the 2025-2030 timeframe.[222] Additional funding could accelerate the 19 projects currently in Phases I, II, and III (pre-feasibility, storage complex feasibility, and site characterization, respectively) and expand the number of projects studying proposed sites for CO_2 storage. DOE has not funded any projects to begin Phase IV, where funding can bring these sites to

"Policymakers will need to ensure that our nation builds out the infrastructure and incentives to reduce the costs and ensure widespread deployment of carbon capture technology."

—United Steel Workers

commercial readiness. Increased funding could establish large-scale demonstration projects with potential to evolve into regional CO_2 transport and storage hubs and provide critical data on deployment of large-scale geologic storage projects to reduce uncertainty for future project developers. Special attention should be paid to the regions described in the callouts on p. 45, 51, and 56 that identify 17 potential storage sites based on potential clustering of emission sources.

BOX 8

Federal Funds Available for CO_2 Infrastructure

The DOE Loan's Program Office (LPO) has almost $40 billion in loans and loans guarantees available for large energy projects.[223] LPO provides tailored debt financing for commercial deployments and acts as a partner to potential applicants by providing no-cost consultations early in the application process. Title 17 of the Energy Policy Act of 2005 established the Innovative Energy Loan Guarantee Program that bridges the financing gap between pilot demonstrations and full commercial deployment. Within the Innovative Energy Program, $8.5 billion is available specifically for innovative fossil energy technologies that reduce, avoid, or sequester greenhouse gas emissions.[224] As of May 2021, the LPO had received applications for more than $12 billion in funding from CCUS project developers, demonstrating clear interest on the part of CCUS project developers in leveraging the program.[225]

Congress appropriated $126 million for carbon capture programs and $79 million for carbon storage programs for fiscal year 2021.[226] Within the funding for fiscal year 2021, $8 million was designated for research and optimization at industrial capture facilities, $10 million was designated for natural gas power systems, and $15 million was designated for FEED studies (with at least two studies for industrial applications such as steel or cement). [227] Congress also appropriated $32.5 million across three offices in DOE for DACCS R&D.

The omnibus further appropriated $30 million for CarbonSAFE, which funds FEED analyses, and $20 million for the Regional Carbon Sequestration Partnership.[228] FEED analyses have been a crucial part of planning and coordination for other hubs across the world.[229] A FEED analysis can be used to determine the best technology for carbon capture, and the most suitable method of CO2 transportation, interim storage, and storage.

The federal government currently spends about $850 million per year on manufacturing and industrial innovation through the DOE's Advanced Manufacturing Office and programs at NIST.[230] The Advanced Manufacturing Office was appropriated nearly $400 million for fiscal year 2021.[231] New production pathways bolstered by demonstration grants will increase the use-case for a robust CO_2 transport and storage system.

Recent funding under the Advanced Storage R&D technology platform provided nearly $4 million to enhance the safety of CO_2 storage by reducing the risk of seismic disruptions.[232] Additional funding opportunities would accelerate development of CO_2 storage infrastructure. Box 7 discusses some additional R&D needs for CO_2 capture to lower costs and space requirements that could help ensure that, at some point in the future after the clean energy transition becomes the clean energy future, tax incentives and other financial support will no longer be needed. After CarbonSAFE brings a project up to the point of commercial investment, other financial incentives and mechanisms—such as the 45Q tax credit—should provide the support needed for commercialization.

BOX 7

R&D Needs for Carbon Capture Technologies

Carbon capture technology has been demonstrated and is in initial commercial deployment stage. Further improvements in the cost and performance of carbon capture technology can provide additional inducements for expanding deployment and strengthening the business case for CO_2 hub formation. The current commercial carbon capture technologies and processes entail significant costs and energy penalties: operating costs, including thermal energy requirements, electricity requirements for compression, materials consumption; maintenance costs; and capital costs, including equipment and related materials and integration for retrofits.

The DOE Carbon Capture Program is supporting R&D activities to reduce both the cost and energy requirements of current carbon capture technologies. The 2nd Generation Technologies R&D program contains a portfolio of engineering-scale projects with innovation pathways in materials, processes, and/or equipment.[233] The goal of this program is to develop these technologies to be ready for deployment by 2030. Further, the DOE's Transformational Technologies research initiative pursues emerging technologies in early stages of development for target deployment in 2035.[234] These technologies target key pathways to reduce costs and energy consumption, including improving thermodynamics, kinetics, durability, and scalability and reducing capital costs.

DOE should work with Congress to secure appropriations of $4 billion over the next five years to fully fund the CCUS projects authorized in the Energy Act of 2020. The Energy Act of 2020 (Division Z of the Consolidated Appropriations Act, 2021) authorized $4.4 billion[w] over the next five years for CO_2 capture and storage programs, including $1 billion for large-scale pilot projects, $2.6 billion for commercial-scale demonstration projects, $200 million for front-end engineering and design (FEED) studies, $800 million for CO_2 storage testing and validation, and over $400 million for DACCS. DOE should seek appropriations from Congress for the full amount authorized in the Act—especially for commercial-scale demonstration projects in the industrial and power sectors.[235]

> **"[Policymakers should] increase funding for the development of the technology as well as to increase the funding for the demonstration projects that were included in the Energy Act that was passed last year—that bill called for six demonstration projects, two industrial, two gas, and two coal, but no money was appropriated for these projects."**
>
> *—United Mine Workers of America*

DOE should consider the local benefits when evaluating grants for regional demonstration projects. CO_2 capture can provide local air quality benefits for communities living near industrial facilities, such as cement plants or refineries, that currently emit high levels of criteria air pollutants. Each CCUS project is unique in design and circumstance, and as a result the local community benefits and impacts will vary by project and location. DOE Funding Opportunity Announcements should include regional economic and social benefits as a criterion for selection for funding. As DOE reviews funding applications, it should carefully consider the local impacts, including environmental, economic, and social impacts of each project. DOE should also prioritize funding to regions that will benefit from the cost-sharing and economies of scale offered by shared CO_2 transport and storage infrastructure.

[w] The funding authorization included $1 billion over the next five years on commercial-scale CCUS demonstration projects, $2.6 billion for the construction and operation of six demonstration facilities, and $800 million for a large-scale carbon sequestration demonstration program and an integrated storage program.

Create a Workforce Transition and Community Development Strategy

Potential direct job creation from CO_2 infrastructure is primarily rooted in growing the domestic supply chain for carbon capture technologies, construction and fabrication jobs to build or retrofit facilities, and construction of a CO_2 pipeline and storage network to connect industrial emitters. The operation of CO_2 capture and storage facilities only creates a small share of the jobs in the long term.

Additionally, jobs in high-skilled industries that are threatened by the energy transition can transfer skills to build and maintain gigaton-scale CO_2 infrastructure. Transitioning jobs with CCUS and CDR can produce a more resilient workforce. Energy jobs offer competitive pay and are less impacted by macro-economic cycles. During the COVID-19 pandemic, for example, the energy sector lost fewer jobs, on average, than other sectors.[236]

Support the Transition of Conventional Fossil Energy Jobs to CO_2 Management Jobs

A large-scale CO_2 management economy can leverage the expertise of the existing energy workforce. There are a number of transferrable skills across the value chain of CO_2 capture, removal, transport, utilization, and storage (Box 9). CCUS provides a unique opportunity to support workers who might otherwise be displaced during the clean energy transition, given overlapping knowledge, technology, and operations experience.

The Department of Labor (DOL) should expand apprenticeship and pre-apprenticeship programs that train skills relevant to CO_2 transport and storage. Apprenticeship and pre-apprenticeship programs are a vital way to train the workforce and develop a pipeline of talent for evolving needs in the economy. DOL's State Apprenticeship Expansion, Equity and Innovation Grants and Registered Apprenticeship Technical Assistance Centers of Excellence programs can support and expand existing apprenticeship programs that provide skills relevant to carbon transport and storage.[237] The National Apprenticeship Act of 2021, which passed the House, would invest $3.5 billion in the apprenticeship system, create one million new apprenticeship opportunities, and permanently authorize the Office of Apprenticeship and the National Advisory Committee on Apprenticeships.[238] Both the Office of Apprenticeship and the National Advisory Committee on Apprenticeships coordinate with labor unions to promote and improve apprenticeship programs. Labor unions have a long and successful history of developing Registered Apprenticeships programs in partnership with employers and have benefitted from federal support for program development.[239] Programs should be designed closely with labor representatives to ensure training programs match the needs of the evolving market and deliver the skills employers are actively seeking.

> **"As a craft that constructs and repairs electric power plants, refineries, pulp and paper mills, and steel mills, we see enormous opportunities for our members with widespread adoption of CCUS."**
>
> *—International Brotherhood of Boilermakers*

BOX 9

Skill Translation from Traditional Energy Sectors to the CO_2 Management Sector

The skills developed over decades in traditional fuel industries can translate directly to each segment of the CCUS value chain. In some cases, fossil fuel companies are already leveraging expertise to support CO_2 capture, transport, and storage projects.

CO_2 Capture Jobs. Capturing CO_2 leverages the same skills of chemical engineers, process technicians, and other well-paid specializations. Leading CO_2 capture technology has been developed by traditional oil and gas companies and engineering firms specializing in oil and gas industries. For example, Shell, UOP (a division of Honeywell), and General Electric all develop liquid solvent technologies that have been used in CO_2 capture projects such as Petra Nova's coal-fired power plant and ExxonMobil's gas processing plant at Shute Creek, Wyoming.[240] Other CO2 capture technologies, including solid adsorbents and membranes, have been developed by Air Products, Air Liquide, and UOP and have been implemented at carbon capture sites including Air Product's steam methane reformer at Port Arthur, Texas, and Southern Company's Plant Barry in Alabama. [241]

CO2 Transport Jobs. The United States already has a base of knowledge in CO_2 transport that can be scaled up: over 5,000 miles of CO_2 pipelines transport 68 $MtCO_2$ each year.[242,243] While few full-time employees are required to operate CO_2 pipelines, they will be critical to growing the industry.

CO2 Storage Jobs. The skills required to characterize reservoirs, drill wells, design compression and injection facilities, and operate said facilities translate directly from oil and gas exploration and extraction.[244] The main difference for carbon storage is the direction of flow, though even today thousands of enhanced oil recovery wells have injected CO_2 underground. Exploration and production skillsets have enabled carbon storage projects in the United States already. Schlumberger Carbon Management worked with Archer Daniels Midland to develop the carbon storage project at Archer Daniels Midland's ethanol refinery in Illinois.[245] Schlumberger has 80 years of experience in the exploration and production business, and it is currently involved in over 60 CCUS projects worldwide[246] Schlumberger advertises services in storage identification and feasibility, site appraisal, development, and injection, monitoring and verification, and post-injection site care.[247]

Converting jobs in the fossil fuel industry to the CCUS industry is more challenging for small- and medium-sized independent producers who rely on steady cash flows.[248] When oil prices fall, these firms are the first to implement hiring freezes, end training programs, and lay off workers. Government assistance for retraining programs will have the most substantial effect when offered during periods of low oil prices and reduced hiring.

Congress should sustain funding for the Dislocated Worker Grant program and prioritize grants that translate existing skills to new, low-carbon sectors. In 2009, the American Recovery and Reinvestment Act provided a temporary increase in funding to the Workforce Investment Act's Dislocated Worker Program, but funding was quickly expended, and workers had less support as job creation remained slow throughout the 2010s.[249] While recent stimulus measures have revitalized the program, Congress should apply lessons from the last recession and sustain funding for Dislocated Worker Grants should be sustained over several years as the economy recovers.

Congress should also look for opportunities to support retraining for established or ongoing projects that are developing CO_2 infrastructure. Community colleges and universities can be strong partners for education and training programs. In Decatur, Illinois, the location of a commercial-scale CCUS project, Richland Community College offers Associate degree programs that help students develop skills transferable to working with CCUS technologies.[250] The Blue Collar to Green Collar Jobs Development Act of 2021 would establish an energy workforce grant program that pays wages and stipends for employees being trained to work at a company that is implementing a clean technology such as CCUS.[251] Such programs can develop the workforce, are key components of a clean energy transition, and are important to avoiding stranded communities.

Modeling a CO_2 Infrastructure Hub in the Ohio River Valley

The region along the Ohio River and into the Cleveland and Pittsburgh metropolitan areas has some of the nation's largest coal-fired power plants and the most steel plants per square mile in the country, both sources of good-paying jobs in one of the poorest U.S. regions. Targeted deployment of CO_2 infrastructure could support large emissions reduction and preserve or create thousands of jobs.

The Ohio River Valley is home to more than 50 facilities each emitting at least 123 $MtCO_2e$ per year, the equivalent of roughly 27 million passenger vehicles. Coal-fired power plants contribute 90 percent of that total. The region has plentiful CO_2 storage capacity in saline reservoirs. Geospatial analysis using SimCCS found that as few as eight CO_2 injection wells and 855 miles of CO_2 pipeline could permanently dispose of emissions from all the facilities analyzed in this study (Figure 12).

Building large-scale CO_2 removal infrastructure in the region could be a boon to the local economy. Of the 54 counties in this regional snapshot, 42 have poverty rates that exceed the national average. Individuals on disability make up large shares of these community populations, in some cases comprising nearly a quarter of a given county's population.[252]

Seven counties in the region ranked in the 90th percentile in the country for particulate matter pollution. Nine counties are in the 95th percentile for cancer risks.[253] Allegheny County, Pennsylvania, home to one of the coal plants included in this analysis, ranks in the top two percent of all counties for cancer risk.[254] The emissions-reduction benefits of CO_2 capture at these point sources could improve

> **"In regions such as the High Plains and the Ohio River Valley in particular, we see great potential for the use of this technology in preserving legacy industries in an environmentally responsible manner suited to the 21st Century. By preserving some of the highest quality and most skilled jobs in the economy, we can ensure that these regions are not left behind by the clean energy revolution.**
>
> — *Utility Workers Union of America*

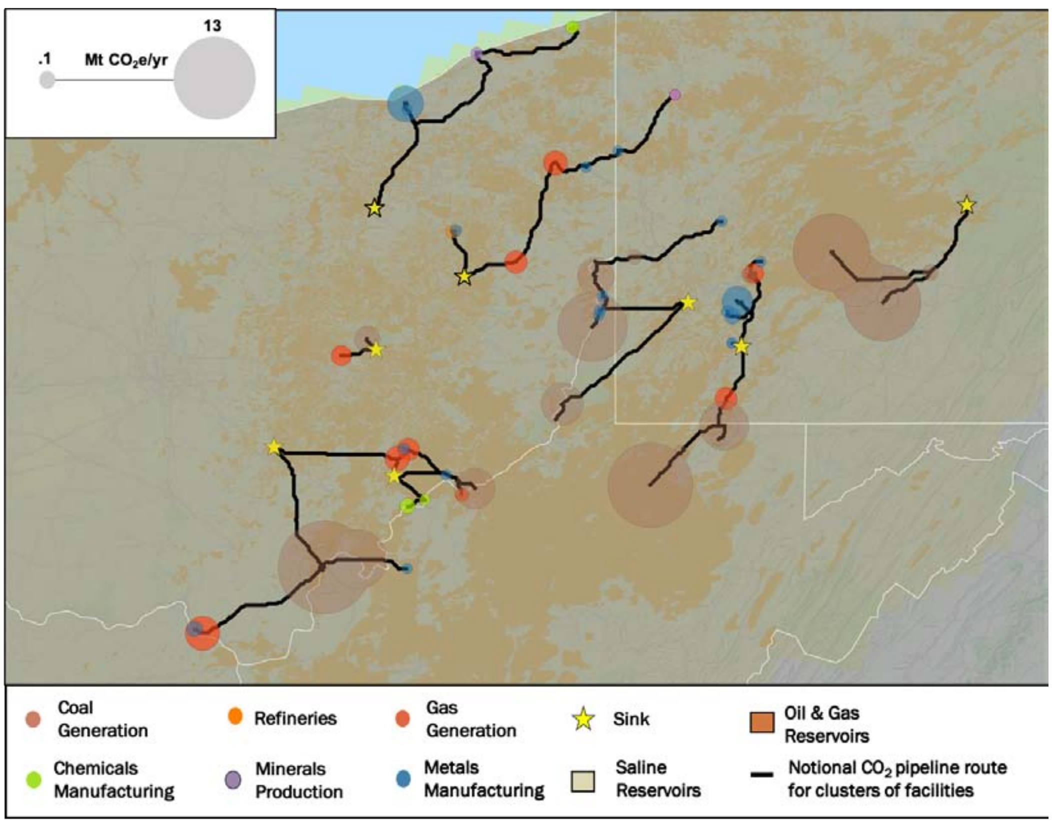
the health of the region's residents by reducing particulate matter and other hazardous air pollutants.[255]

The region is vulnerable to job losses—five of the coal plants analyzed have partially retired or will retire by 2050 and ten other coal plants not modeled in this study will completely or partially retire by 2050 as well.[256]

As a part of President Biden's Executive Order "Tackling the Climate Crisis at Home and Abroad," the newly-formed Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization, identified communities of priority across the country that are expected to struggle in the near future due to the decline of coal. Eleven communities identified by the Interagency Working Group[x] are included in this study's analysis of the Ohio River Valley region, which assesses 54 counties containing or in proximity to major emitters. The Working Group has emphasized the need to put federal resources into these communities, which could take the form of infrastructure investments that enable the creation of CCUS hubs. Critically, such investments can help create jobs in the region, while simultaneously improving the health of these communities.[257]

FIGURE 12

The Ohio River Valley CCUS Project Development Possibilities



This figure is a compilation of major emitting facilities and notional CO_2 pipeline routes and sinks in the Ohio River Valley, modeled using SimCCS. The black lines show notional pipelines that run in seven separate locations on the map.

[x] The regional assessment was constrained to three states: Ohio, Pennsylvania, and West Virginia.

Ensure Good Jobs are Accessible to Displaced and Disadvantaged Workers

Extending employment opportunities to displaced energy workers and those that come from disadvantaged communities should be a priority. Existing programs and funding can provide immediate support to build the CCUS industry while elevating vulnerable populations.

Federal agencies should expand engagement to communities with displaced energy workers to improve access to available funding. Existing federal programs have $38 billion immediately available for programs—such as DOE's Loan Program Office (see Box 8), DOT's Rebuilding American Infrastructure with Sustainability and Equity, and U.S. Department of Agriculture's Rural Innovation Hubs—that can support investments in communities with high rates of displaced coal workers.[258] The available funding could be used to invest in local infrastructure such as roads, bridges, and local transportation; deploy low carbon technologies; finance remediation of abandoned mines, gas wells, and brownfield sites; support community organizations (e.g., small businesses, community financing, nonprofits) and economic innovation hubs; and develop the regional workforce.[259] Some of these funding instruments could directly support CO_2 infrastructure and others could provide transition assistance through mine reclamation and brownfield redevelopment.

The Department of Commerce and DOI should extend economic development funding to communities that are developing CO_2 transport and storage hubs. The Economic Development Administration Assistance to Coal Communities program could be used to fund infrastructure projects, brownfields redevelopment, and technical assistance and financing for non-infrastructure projects with an "economic development focus."[260] The Economic Development Administration was allocated $3 billion under the American Rescue Plan and could provide both material and logistical support to communities. The Economic Development Administration should prioritize Assistance to Coal Communities program funds to locations that are developing transport and storage hubs so that the skills in the region can be leveraged in the new carbon management industry. The FY 2022 Budget Request doubles the Assistance to Coal Communities program ($80.5 million requested, an increase of $47 million from FY 2021).[261] Another potential funding instrument for communities transitioning from fossil fuels is DOI's Abandoned Mine Reclamation Fund, which currently has a narrow authorization of projects that it can support. The bipartisan RECLAIM Act of 2021 increases assistance to coal communities by relaxing restrictions on the Abandoned Mine Reclamation Fund. DOI should work with Congress to expand the authorization to develop CO_2 infrastructure along with other community development projects.

Congress should require projects that receive all forms of federal financial support to pay prevailing wages consistent with the Davis-Bacon and Related Acts. The Davis-Bacon and Related Acts mandate contractors and subcontractors who receive federal funds to pay laborers a wage that matches the wages for a given area.[262] Davis-Bacon prevents a race to the bottom for wages in an area and promotes safer- and higher-quality construction. A number of analyses have found that Davis-Bacon does not raise costs for taxpayer-funded construction.[263,264] Extending Davis-Bacon to projects receiving tax credits and other forms of federal financial support will extend labor protections and higher wages to more workers.

Conduct Robust Public Education, Prioritizing Outreach to Environmental Justice Communities

As noted, public awareness of CO_2 capture, removal, transportation, utilization, and storage technologies is generally low in the United States. Among those with some knowledge of the technologies, opinions are highly variable. To ensure the clean energy transition is equitable, there must be transparent conversations with local communities and stakeholders about the risks and challenges alongside discussions of the significant climate and local economic benefits possible through deployment of these technologies. Fortunately, the risks related to CO_2 transport and storage are not greater than ongoing activities related to natural gas storage, EOR, and other operations, according to a review by the Intergovernmental Panel on Climate Change (IPCC)—assuming proper site characterization, monitoring, and regulation.[265]

EPA and DOE should direct project developers—including recipients of loan guarantees—to allocate a portion of federal funds for community engagement processes. The most important predictor for acceptance of CCUS is the perception of its benefits, followed by perception of risks.[266] Public acceptance of CO_2 removal and storage projects is also influenced by trust in the stakeholders involved, including project developers, energy companies, government agencies, and non-governmental organizations. Analysis suggests that trust in decision-making processes increased if decision-makers sought input from diverse stakeholder groups and communicated fully and factually.[267,268,269] Projects should engage communities where they are working; allocating a portion of project funds for engagement will promote broader public education and acceptance. Funding for community engagement should include accommodations such as childcare services, transportation reimbursements, and language services. EPA and DOE should set guidelines for the proportion of project funds that should be dedicated to community engagement for all grant and loan guarantee recipients.

DOE and EPA should expand and standardize local outreach programs to engage communities about CO_2 transport and storage. While the Regional Carbon Sequestration Partnership (RCSP) has successfully completed 19 projects around the United States,[270] many local communities may not be aware of a project near them. A review of public engagement under RCSP found that common issues included limited understanding of how CO_2 storage works, lack of familiarity with natural carbon cycles, and difficulty communicating technical material.[271] Best practices that have been established for RCSP engagement include developing a background of knowledge on the community and key stakeholders, creating outreach plans that match the knowledge and concerns of the community, and being adaptable in the process.[272] DOE should hold regular meetings for ongoing RCSP projects to ensure that communities are engaged and informed regarding carbon sequestration development. Meetings should allow for co-design with local stakeholders and ensure that marginalized groups are represented and provided equitable accommodations. Community engagement through RCSP was also recommended in the House Select Committee for the Climate Crisis' Action Plan; by directing DOE to hold more regional meetings, including through RCSP, communities can better understand CO_2 storage.[273]

The UIC program is required to hold public notice and participation for all new permit applications.[274] EPA has developed best practices for public engagement for Class VI wells, which include creating a communication plan, identifying stakeholders, selecting appropriate communication methods, and testing the effectiveness of the communication plan.[275] However, public engagement requirements end after final permitting decisions. After permitting, EPA should hold regular meetings under the UIC program for Class VI wells and provide transparent communication regarding potential risks, long-term monitoring and verification plans, and precautionary measures in place.

EPA should work with Congress to increase funding requests for existing environmental justice engagement programs. Communities that are burdened by pollutants and systemic injustices may need extra assistance in engaging in stakeholder processes and developing solutions. Existing programs have reduced the barriers for engagement and developed collaborative solutions. These programs should be scaled up in keeping with increased spending on infrastructure and clean technology. The Environmental Justice (EJ) Small Grants Program, for example, provides funding opportunities to groups working on solutions to local environmental and public health issues.[276] Funding the EJ Small Grants program at $10 million would allow for EPA to increase the maximum level per grant from $75,000 to $100,000 for about 100 recipients. Other programs that should receive funding include Collaborative Problem-Solving Cooperative Agreement Program, Environmental Education Program, and the Community Action for a Renewed Environment Grant Program.[277] The Environmental Justice for All Act creates several grant programs that would build the capacity to address environmental justice for (1) community organizations, (2) state governments, and (3) tribal governments.

[278] Additional programs such as these can build local capacity to make stakeholder processes more equitable.

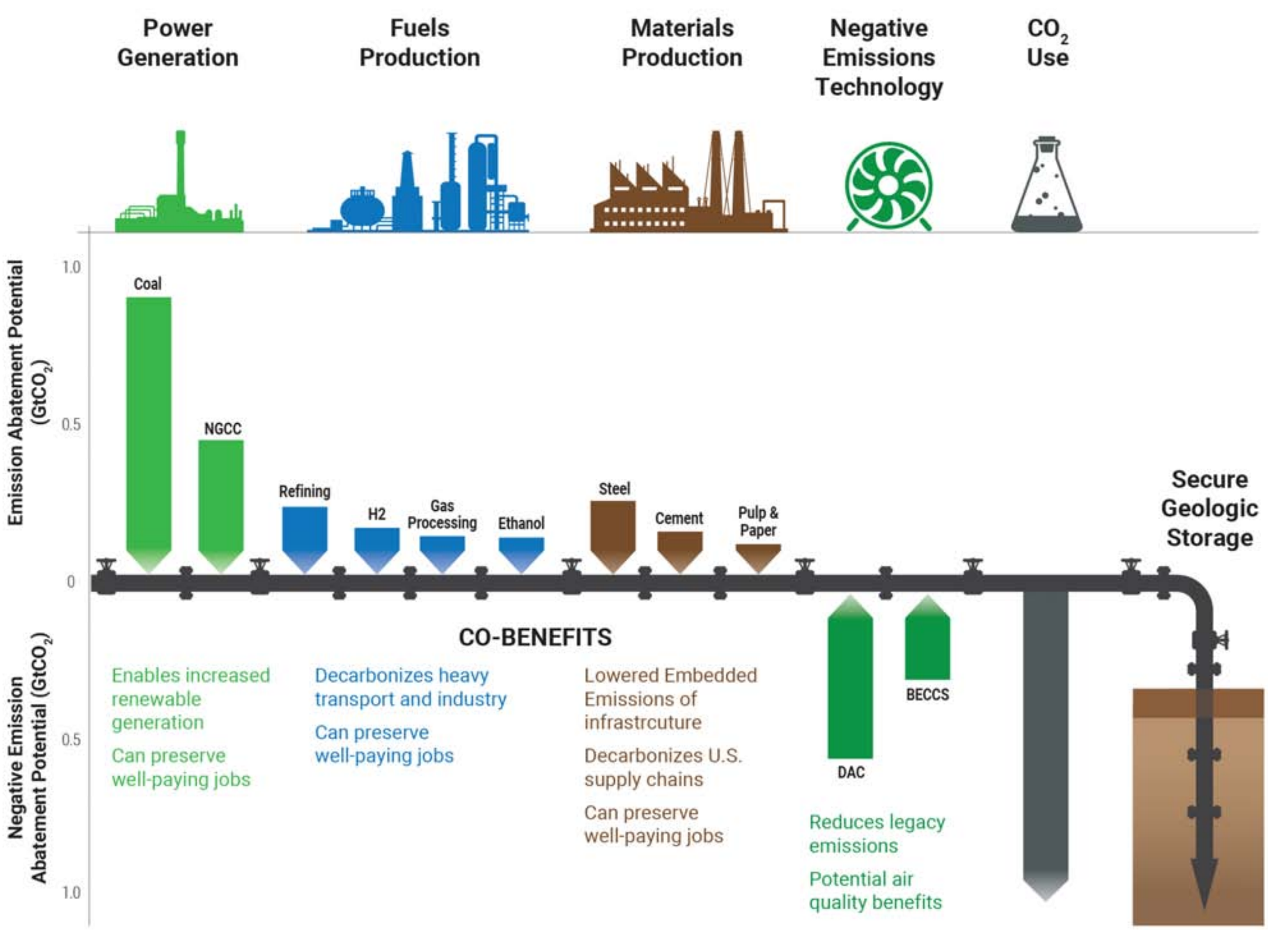
EPA should improve the EJScreen tool to better consider equity in decision-making. EJScreen, a mapping tool developed by EPA, consolidates and standardizes data for environmental indicators, demographics, and environmental justice indicators.[y,279] EJScreen can be used to prioritize areas for funding by identifying which communities have high rates of environmental stressors, inadequate health outcomes, and high concentrations of low-income households. Updates to the EJScreen tool should include risk factors related to climate change, data related to worker dislocation, and more granular data regarding pollutants and demographics. The tool should also have easily accessible mapping and reporting capabilities. The Climate Justice for All Act of 2021 would expand EJScreen to include factors such as the exposure to risks of climate change and any experience of economic transition, deindustrialization, or chronic underinvestment.[280] The legislation then directs all federal agencies and White House offices to identify climate-burdened communities using EJScreen.

[y] EJScreen currently has data for 11 environmental indicators (cancer risk, respiratory hazard, diesel particulate matter, particulate matter, ozone, traffic proximity and noise, lead paint indicator, proximity to Risk Management Plan sites, proximity to National Priority Lists sites, and water discharge indicator), 6 demographic indicators (Percent Low-Income, Percent People of Color, Percent people less than high school education, Linguistic isolation, Individuals under age 5, and Individuals over age 64:), and 11 EJ indexes that combine demographic indicators with a single environmental indicator.

Appendix

Methodology for Figure 4

Sector emissions for natural gas combined cycle (NGCC) and coal were obtained from EIA,[281] and abatement potentials were computed based on capture rates of 85 percent and 90 percent respectively as found in the literature.[282] Sector emissions for refining,[283] pulp and paper,[284] cement,[285] and gas processing[286] industries were obtained from EPA's Greenhouse Gas Reporting Program (GHGRP). Sector emissions for steel were computed for a 2019 production figure of 88 Mt,[287] and a direct emission rate of 2.17 tCO_2 per metric ton of steel.[288] Abatement potentials for these industries were calculated based on capture rates found in Leeson et al.:[289] 65 percent for refining, 75 percent for pulp and paper, 86 percent for steel, and 99 percent for gas processing. Abatement potential for cement was computed based on an 88 percent capture rate – an average of estimates from Bjerge and Brevik[290] and IPCC.[291] Ethanol emissions were from EIA's 2019 reported production 1,336 TBtu[292] and a production emission rate of 31.4 gCO_2e/MJ from Scully et al.[293] The abatement potential was calculated based on a capture rate of 60 percent found in Sanchez et al.[294] Sector emissions for hydrogen production were based on DOE's 2019 production figure of 10 Mt,[295] an estimate of 95 percent of production from steam methane reforming (without capture), and an assumption of no emissions from the remaining 5 percent of production.[296] The abatement potential was 90 percent according to Collodi et al.[297] Negative emissions potentials were obtained from The National Academies Press for BECCS[298] and CO_2 utilization (CO_2u)[299] and from Fasihi et al. for DACCS.[300]



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