2024 THOUGHT LEADERSHIP

BUILDING OUR WAY TO NET-ZERO: CARBON DIOXIDE PIPELINES IN THE UNITED STATES

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Acronyms

AEGLs	Acute Exposure Guideline Levels
AFOLU	Agriculture, Forestry, and Other Land Use
AIHA	American Industrial Hygiene Association
API	American Petroleum Institute
BECCS	Bioenergy with Carbon Capture and Storage
BiCRS	biomass carbon removal and storage
BLM	Bureau of Land Management
CATF	Clean Air Task Force
CBP	Community Benefits Plan
CCS	carbon capture and storage
CDR	carbon dioxide removal
CFCs	chlorofluorocarbons
CFR	Code of Federal Regulations
CH_4	methane
CO_2	carbon dioxide
COBRA	CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (US EPA)
COP 28	28th United Nations Framework Convention on Climate Change Conference of the Parties
COSHER	CO_2 safety, health, environment and risk
DAC	direct air capture
DNV	Det Norske Veritas
DOE	US Department of Energy
EDX	NETL Energy Data eXchange portal
E.O.	Executive Order
EOR	enhanced oil recovery
EPA	US Environmental Protection Agency
ERPGs	Emergency Response Planning Guidelines
ESG	Environmental, Social, and Governance
FECM	Office of Fossil Energy and Carbon Management (US DOE)
FOA	Funding Opportunity Announcement
GCS	Gulf Coast Sequestration
GHG	greenhouse gas
$GtCO_2$	gigatonnes of CO_2
GPI	Great Plains Institute
GWP	global warming potential
H_2O	water
HCA	High Consequence Area
ICS	incident command system
IDLH	immediately dangerous to life or health
IPCC	United Nations Intergovernmental Panel on Climate Change
IM	Integrity Management
LiDAR	Light Detection and Ranging
Mt	megatonnes
$MtCO_2$	megatonnes of CO_2
MLA	Mineral Leasing Act
MPa	megapascal
MWP	Mitigation Action and Implementation Work Programme
N_2O	nitrous oxide
NATCARB	National Carbon Sequestration Database and Geographic Information System
NETL	National Energy Technology Laboratory
NIMS	National Incident Management System
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
NPRM	notice of proposed rulemaking
NPV	net present value
OMB	Office of Management and Budget
OPS	Office of Pipeline Safety (an office within PHMSA)
OSHA	Occupational Safety and Health Administration (US Dept. of Labor)
PEL	permissible exposure limit
PHMSA	Pipeline and Hazardous Materials Safety Administration (US Dept. of Transportation)
PIPES	Protecting Our Infrastructure of Pipelines and Enhancing Safety Act of 2020
$PM_{2.5}$	particulate matter below 2.5 microns
ppm	parts per million
psig	pounds per square inch gauge
RP	Recommended Practice
RSPA	Research and Special Programs Administration (PHMSA's predecessor)
SO_2	sulfur dioxide
TWA	time-weighted average
UIC	Underground Injection Control Program (US EPA)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USDW	Underground Source of Drinking Water
USE IT	Utilizing Significant Emissions with Innovative Technologies Act of 2020

EXECUTIVE SUMMARY

The 28th United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP 28) concluded in Dubai with a significant consensus agreement to "Transition away from fossil fuels in energy systems" and to accelerate "zero- and low-emission technologies," including carbon capture, utilization, and storage (UNFCCC, 2023). Global ambition to address climate change by mitigating carbon emissions using carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies has never been higher.

CCS technology is a critical technological solution enabling a net-zero emissions world because 1) it is a technology proven to stop CO_2 emissions from reaching the atmosphere and 2) it is a versatile technology immediately deployable across a wide range of industries. Moreover, CCS remains the only viable near-term decarbonization solution for some industrial sectors. CCS can be applied to new facilities and retrofitted in chemical, steel, cement manufacturing, and power generation. CCS also enables the scale-up of technology-based carbon dioxide removal (CDR), providing a means to store CO_2 removed from the atmosphere.

Net-zero models indicate much of the CO_2 captured by new CCS and CDR projects will rely on transport via new CO_2 pipelines linking capture facilities to permanent storage sites (Larson et al., 2021; US DOE, 2023b). Although more than 5,000 miles of CO_2 pipelines exist in the United States, this pipeline network must substantially increase to achieve the country's net-zero goals. Estimates of the CO_2 pipeline infrastructure needed to accommodate future large-scale CCS projects in the United States (US) vary but range from 20,000 to 96,000 miles (Great Plains Institute, 2020; Larson et al., 2021; US DOE, 2023b; Wallace et al., 2015).

CO_2 pipelines in the US are well-established and regulated by federal and state authorities. Regulations and industry standards set forth in the US Code of Federal Regulations (CFR) and published by standards developing organizations such as the American Society of Mechanical Engineers (ASME) prescribe requirements for the design, materials, construction, assembly, inspection, testing, operation, and maintenance of pipeline systems. These regulations and standards mitigate risks associated with CO_2 pipelines and have resulted in a strong safety record, including zero fatalities in the CO_2 pipeline industry's 50-year history (NPC, 2019). Federal and state authorities, alongside industry associations such as ASME, are updating regulations and guidelines to enhance pipeline safety.

Studies indicate communities in the US are generally unfamiliar with CCS technology (Air Alliance Houston, 2023; Pianta et al., 2021). Therefore, robust community engagement – including addressing Environmental Justice – is required throughout the CO_2 pipeline project life cycle. Government agencies and industry trade associations alike have published, or are developing, recommended practices for engaging communities. Project developers' social license to operate is largely dependent on the success of their community engagement plan.

Although 2050 is more than 25 years away, CO_2 transportation infrastructure needs to be built now to scale up carbon management in line with net-zero targets in the US. Achieving net-zero must include CCS deployment across broad sectors of the economy. CCS is ready to deploy at scale today; however, deployment cannot occur without building new CO_2 pipelines connecting captured CO_2 to new CO_2 storage sites.

The US must build its way to net-zero.

KEY MESSAGES

CO_2 pipelines are vital infrastructure required to address climate change. Globally, a cumulative mass of 670 billion tonnes of CO_2 (gigatonnes, $GtCO_2$) will need to be captured through the combined application of CCS and technology-based carbon dioxide removal (CDR) by 2100 to limit global warming to 1.5°C (IPCC, 2022b). CCS and CDR projects can use CO_2 pipelines as an efficient method for transporting captured CO_2 to locations for permanent storage, while avoiding additional CO_2 emissions emitted by transportation alternatives (rail or truck). Recent studies estimate the current CO_2 pipeline transportation network in the US must increase by four- to 18-times its current size by 2050 to reach our climate goals (Great Plains Institute, 2020; Larson et al., 2021; US DOE, 2023b; Wallace et al., 2015).

To achieve net-zero goals and remain competitive in a growing global marketplace for low-carbon commodities and products, the US must address barriers to pipeline deployment, including permitting delays. The Global CCS Institute estimates a one-year delay in announced CCS projects and CCS projects in development could result in 91 Mt of unmitigated CO_2 emissions by 2030. In a positive step, the US Department of Energy and the White House Council on Environmental Quality recently announced permitting task forces focused on addressing permitting challenges and successes, improving the performance of the permitting process and regional coordination to promote the efficient, orderly, and responsible development of carbon capture, utilization, and sequestration projects and CO_2 pipelines. (US DOE, 2023c)

CO_2 transportation via pipeline is well-established and regulated in the US. The Pipeline and Hazardous Materials Safety Administration (PHMSA) within the US Department of Transportation regulates the construction, operation, and maintenance of CO_2 pipelines, including compliance, general inspection, repair, material inspection, transportation of pipe, welding, pipeline location, installation, valving, associated equipment (pumping), protection, and record keeping. CO_2 pipelines have a strong safety record since their introduction in 1972, with some of the lowest rates of incidents affecting people or the environment per mile of pipeline across the US; moreover, PHMSA is currently updating its CO_2 pipeline regulations and sponsoring continued research to enhance pipeline safety. Additionally, the US Department of Energy has launched new programs that will support regional pipeline development, including engineering and design studies to bolster the safe operation of the CO_2 pipeline network and loans and grants for infrastructure construction.

Early and sustained community education and engagement are crucial for enabling pipeline development. Communities in the US are largely unaware of CCS technology, including its potential benefits and risks. Meaningful, proactive community engagement can deliver benefits to communities, contribute to project success, and prevent circulation of misinformation. Proactive engagement includes addressing Environmental Justice in communities where pipelines and projects will be developed. Addressing Environmental Justice is not simply a moral imperative but is also becoming an explicit requirement to qualify for some federal funding awarded by the US Department of Energy.

1.0 INTRODUCTION

1.1 Climate Change, and the Case for Carbon Capture and Storage (CCS)

June of 2023 made startling history – the planet experienced its highest average global surface temperature and the lowest global sea ice coverage for any June month on record (NOAA, 2023b). The heat persisted throughout 2023, with June through December each ranking as the warmest such months on record (NOAA NCEI, 2024). Observed increases in the frequency and intensity of climate and weather extremes, such as heat extremes on land and in the oceans, heavy precipitation, drought, and wildfires have resulted in pervasive impacts to ecosystems, populations – including increased heat-related human mortality – and infrastructure (IPCC, 2022a). These profound manifestations of climate change bolster growing public and private ambition to achieve a net-zero emissions world and prevent the worst climate outcomes.

Climate change is caused by global warming, which is driven by the sustained accumulation of carbon dioxide (CO_2) and several other "greenhouse gases" in the Earth's atmosphere since the Industrial Revolution of the early 19th century. Monthly measurements of CO_2 in the atmosphere began at NOAA's Mauna Loa Observatory in 1958 and show an unabated increase in the average monthly CO_2 concentration, climbing to 425.38 ppm CO_2 in March of 2024 (Figure 1). Prior to the Industrial Revolution, atmospheric concentrations averaged around 280 ppm CO_2 (IPCC, 1990).

GREENHOUSE GASES AND THE GREENHOUSE EFFECT

Sunlight penetrating Earth's atmosphere reflects off Earth's surface and returns to the atmosphere as infrared energy, where it is then absorbed by greenhouse gases, such as CO_2. This atmospheric energy absorption traps heat in the atmosphere, effectively insulating the planet, like the glass walls of a greenhouse. Hence, the terms "greenhouse gases" and "greenhouse effect" are used when describing global warming.

Other greenhouse gases (GHGs) include but are not limited to water (H_2O), nitrous oxide (N_2O), methane (CH4), and chlorofluorocarbons (CFCs) – all of which exist in the Earth's atmosphere. However, the impact of each of these gases on global warming is not equal. The potency of a GHG depends on its capacity to absorb infrared energy and the length of time each gas remains in the atmosphere. To provide a common scale to communicate a GHG's warming impact, the global warming potential (GWP) measurement was adopted as a standard metric in 1990 (UN IPCC, 1990). GWP accounts for these two GHG characteristics (absorption capacity and residence time) and evaluates their impact on warming over a given period – typically 20, 100, or 500 years. GWP values show that over a 100-year period, one tonne of emitted CH_4 would trap about 30 times more heat than one tonne of simultaneously emitted CO_2.

While this illustrates the potency of CH_4 as a greenhouse gas, CO_2 plays a more significant role in global warming because it is far more concentrated in the Earth's atmosphere than CH_4. In March of 2023, the average monthly methane concentration in the Earth's atmosphere was 1.921 ppm – 200 times less than the concentration of CO_2 (NOAA, 2023a)

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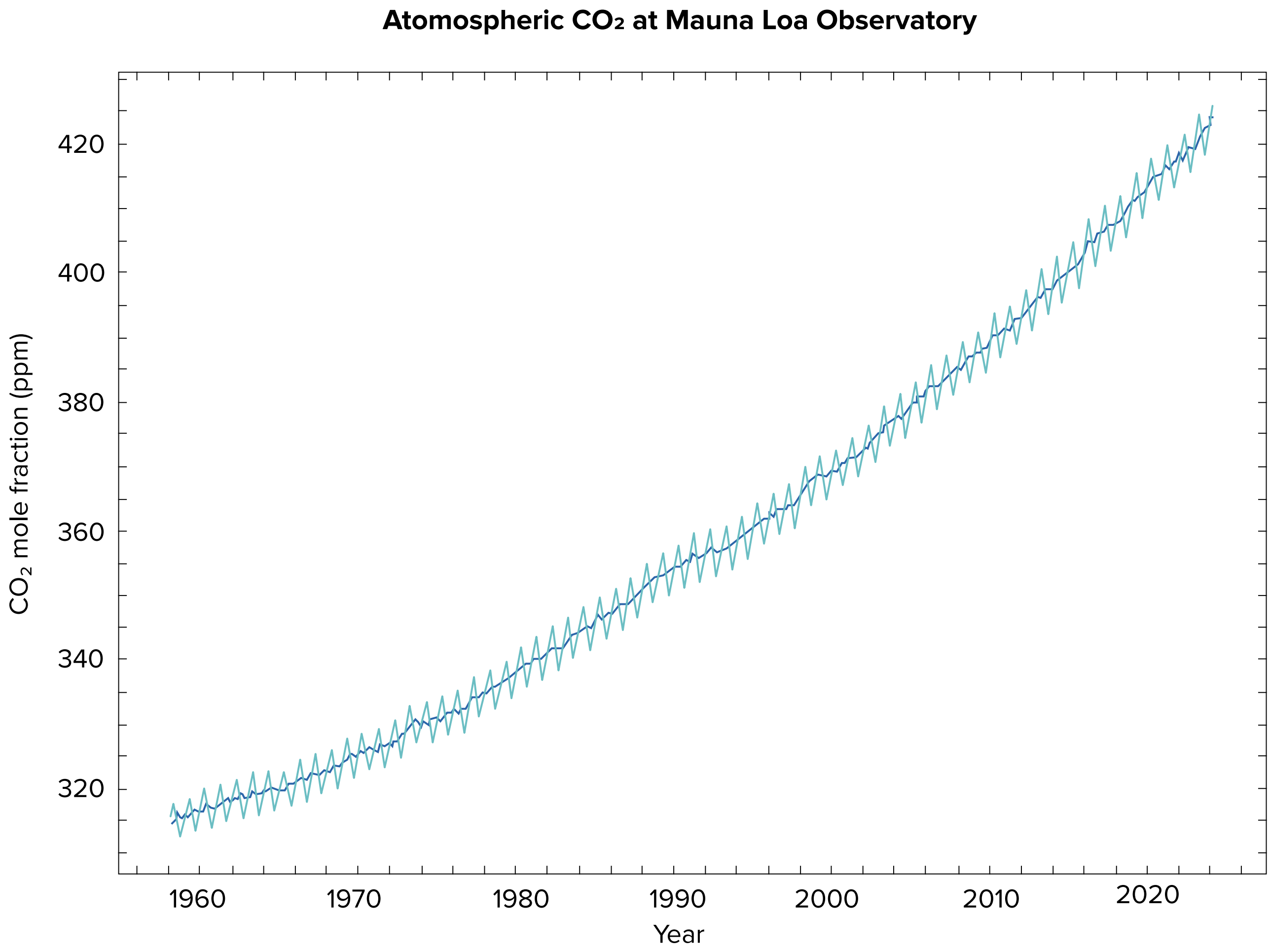


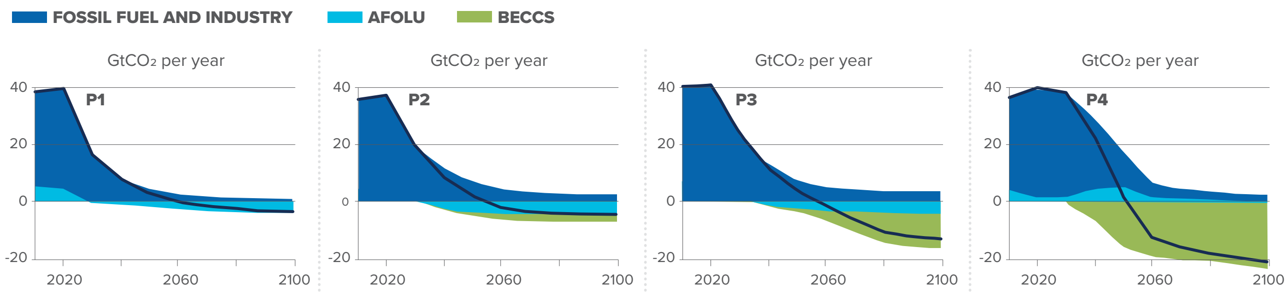
Figure 1. Monthly mean atmospheric CO_2 concentrations measured at Mauna Loa Observatory, Hawaii. The light blue curve is the monthly mean value, and the dark blue curve is the same data corrected for the average seasonal cycle. These data represent the longest record of direct measurements of CO_2 in the atmosphere, started by C. David Keeling of the Scripps Institution of Oceanography in 1958. (Source: NOAA, 2023a)

Messaging from the global scientific community and the United Nations (UN) is consistent. Decarbonization of global economies must occur with unprecedented speed and employ a broad portfolio of emissions mitigation technologies to stop and reverse this CO_2 accumulation trend.

Unabated CO_2 emissions from the continued burning of fossil fuels in energy production, transportation, and industrial processes across the globe are driving the overwhelming concentration of CO_2 in the Earth's atmosphere. As global economies work to integrate renewable energy sources and transition away from fossil fuels, CCS is a pivotal emissions mitigation technology that can prevent additional CO_2 emissions from these critical economic sectors. Additionally, through direct air capture (DAC) and biomass carbon removal and storage (BiCRS), CCS enables the removal of legacy CO_2 emissions already in the atmosphere.

In 2018, the UN's Intergovernmental Panel on Climate Change (IPCC) showed that CCS technology must be applied across large segments of global economies to limit global warming to 1.5 °C by 2050 (IPCC, 2018). At that time, the IPCC estimated between 350 and 1,200 gigatonnes of CO_2 ($GtCO_2$) would need to be captured through the combined application of CCS and carbon dioxide removal (CDR) and stored this century to achieve this goal (Figure 2).

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patents, low carbon technology innovation, and well managed land testers with limited social capability for BECCS.

P3: A middle-of-the-road scenario in which society aware as technological development allows historical patterns. Emissions reductions are rarely achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Figure 2. Four potential pathways to limiting global warming to 1.5 °C by 2050. Pathway 1 requires drastic societal changes, including ending the use of fossil fuels. All other pathways require varying contributions from CCS and significant adoption of CDR to achieve the climate goal (AFOLU = Agriculture, Forestry and Other Land Use; BECCS = Bioenergy with Carbon Capture and Storage; After UN IPCC, 2018).

In 2022, the IPCC updated its analysis. Results from 97 modelled pathways show that to limit global warming to 1.5 °C in this century with limited or no overshoot (i.e., not exceeding 1.5 °C by more than 0.1 °C), a cumulative mass of 670 $GtCO_2$ will need to be captured using CCS by 2100 (IPCC, 2022b).

Additionally, the global climate community is coalescing around CCS. The UN's 28th Conference of the Parties (COP28), held in Dubai in November 2023, brought together more than 150 heads of state and thousands of representatives from government, civil society, intergovernmental, and non-governmental organizations to hold negotiations and discussions focused on climate change. CCS was highlighted in multiple ways, including, reaffirmation of the need to scale carbon management technologies to keep the goal of limiting warming to 1.5 °C alive, featuring CCS in the Paris Agreement's first Global Stocktake, and CCS forming a central theme of the Mitigation Action and Implementation Work Programme (MWP)[1] (Al Amer, 2023).

CCS is a proven technology capable of gigatonne-scale abatement of CO_2; moreover, CCS is underpinned by technologies that have been available since the 1970s coupled with decades of global research, development, and intergovernmental collaboration (Loria & Bright, 2021). CCS captures CO_2 emissions from point sources, such as fossil fuel power plants, cement plants, gas processing facilities, etc., or directly from the atmosphere (direct air capture, or DAC). While DAC facilities can be constructed directly above suitable geologic storage sites, point source facilities may be miles away from such sites. In these cases, the captured CO_2 must be transported to sites where it can be utilized or injected deep underground for permanent storage.

While CO_2 can be economically transported in small quantities over short distances by truck or rail, the preferred method for transporting large volumes of CO_2 over long distances from capture facilities to storage sites is often by pipeline. Globally, 41 projects in operation or under construction use pipelines for CO_2 transportation, and 195 of the 325 CCS projects in development also plan to transport CO_2 by pipeline (Figure 3; Global CCS Institute, 2023). More than 5,000 miles (8,000 km) of CO_2 pipelines in the US already exist, transporting more than 66 million tonnes of CO_2 per year (NPC, 2019; PHMSA, 2023b). While most CO_2 pipelines currently transport CO_2 produced from natural subsurface accumulations for enhanced oil recovery operations, the current CO_2 pipeline network in the US is inadequate for the growing CO_2 transportation demand emerging from the CCS industry. CO_2 pipelines will provide the critical link between CO_2 emissions point sources and dedicated geologic storage sites.

[1] The MWP is a report summarizing global dialogues held in 2023 focusing on accelerating the just energy transition. Other CCS highlights include the launch of the Global Decarbonization Accelerator (recognizing the need for CCS in various industries), the new Cement and Concrete Breakthrough will need CCS for planned emissions reductions, and the emergence of new avenues for youth engagement through a series of energy-related events featuring CCS at COP28.

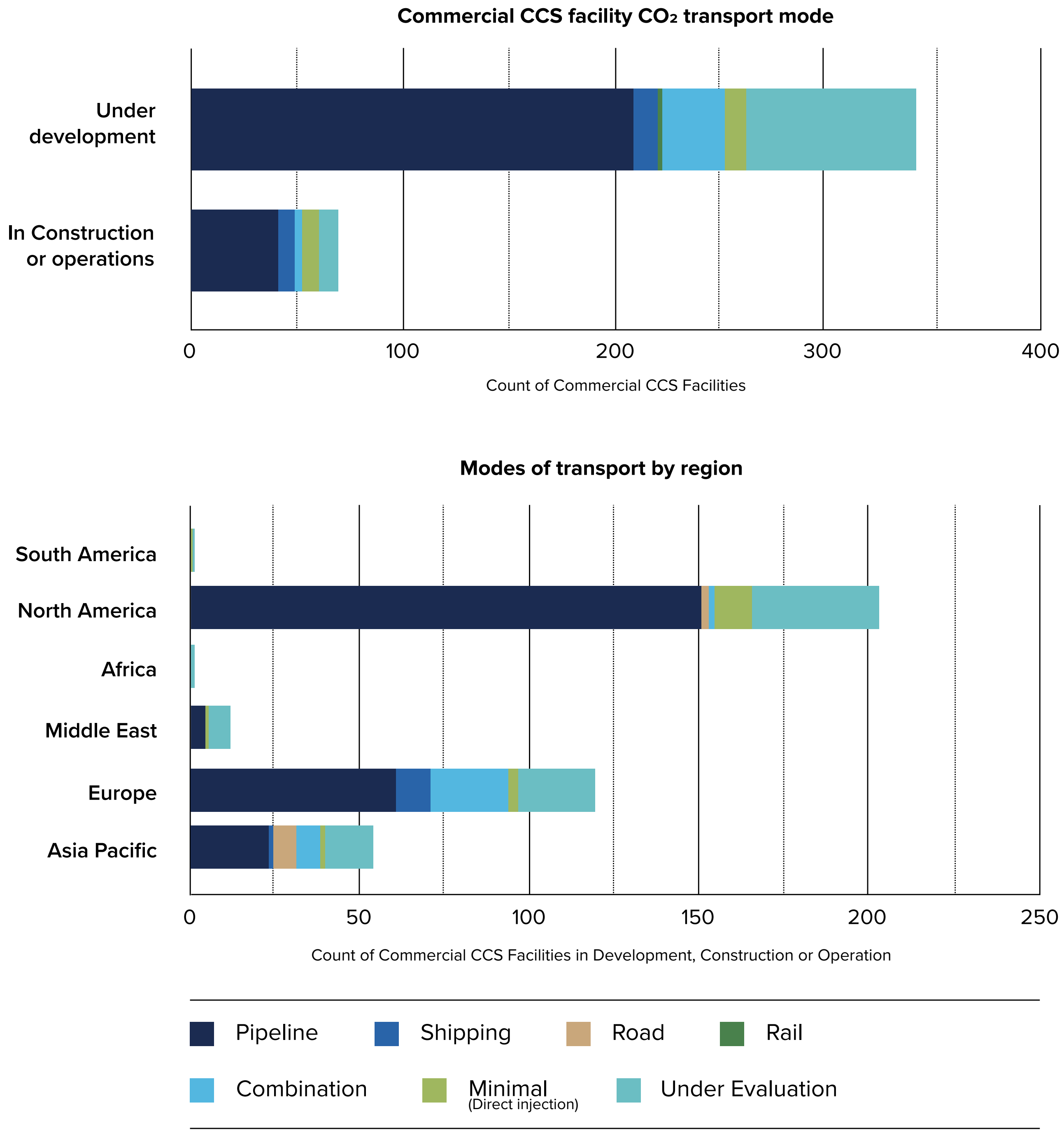


Figure 3. Selected modes of CO_2 transportation for global CCS projects in operation, construction, or under development (Source: Global CCS Institute, 2023).

Estimates indicate that CO_2 pipeline infrastructure in the US must grow dramatically to support CCS and enable the country to meet its decarbonization goals. Four to 18 times the current mileage of CO_2 pipelines (20,000 miles / 32,000 km to 96,000 miles / 155,000 km) will be needed by 2050 to transport captured CO_2 to secure geologic storage sites (Great Plains Institute, 2020; Larson et al., 2021; US DOE, 2023b; Wallace et al., 2015).

How the country builds this infrastructure, however, is equally important as the infrastructure itself. Recently, high-profile CO_2 pipeline projects have been cancelled or delayed due to community opposition and permitting challenges (Navigator CO_2, 2023; Ranevska, 2023). Some of this opposition has been driven by property owners expressing concerns about issues ranging from environmental and safety considerations to fair compensation and property values. Some opposition is due to a lack of agreement about why CCS is needed. These issues will need to be addressed by project developers through robust community engagement (see Section 4).

2.0 LEGAL AND REGULATORY STATE OF PLAY OF CO_2 PIPELINES IN THE US

The CO_2 pipeline network in the US exceeds 5,000 miles but is far surpassed by the country's nearly 260,000 mile hazardous liquid pipeline network and nearly 3-million-mile natural gas pipeline network (PHMSA, 2023b; US EIA, 2022). It is also discontinuous across five geographic zones. As shown in Figure 4, these five zones are in the West/Southwest, the northern Midwest, central US, the Gulf Coast, and northern Michigan (US DOE et al., 2017).

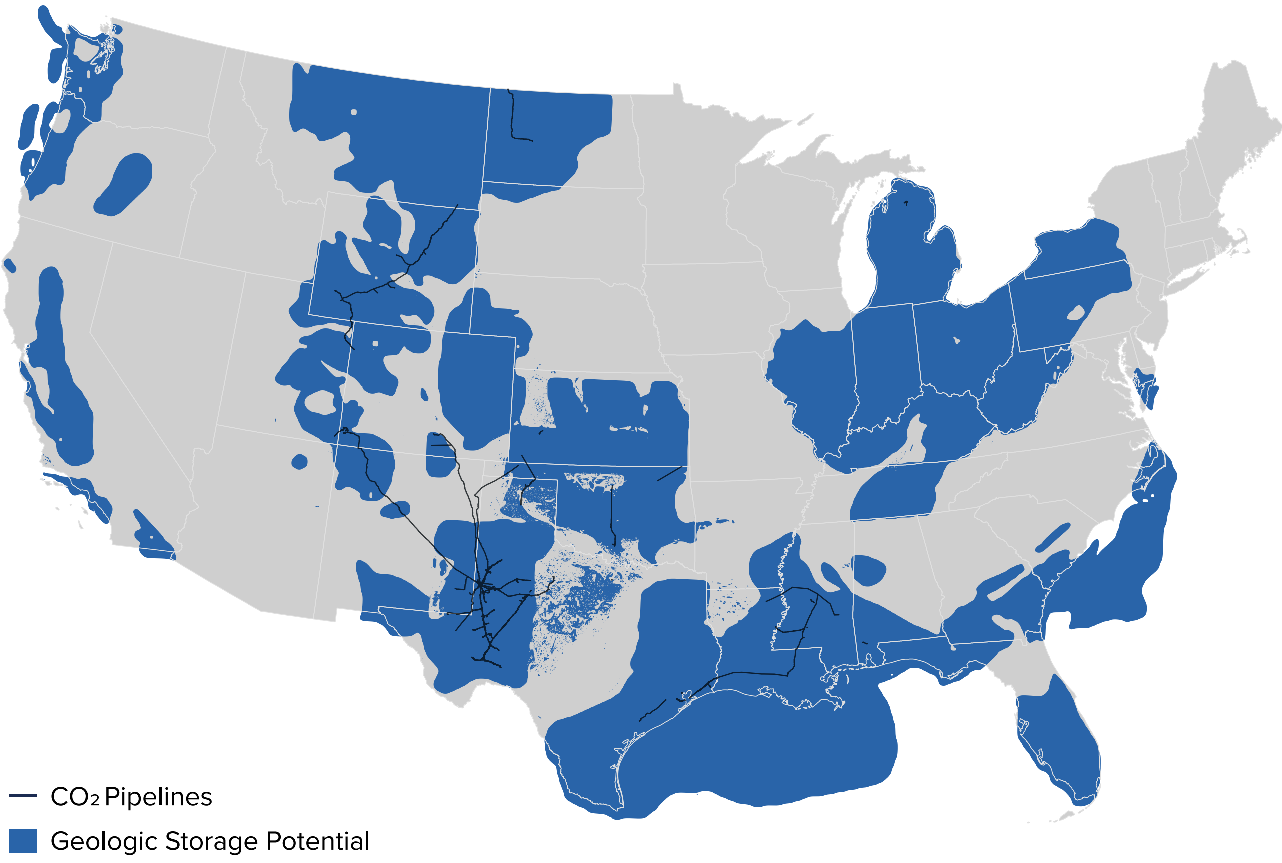


Figure 4. CO_2 pipelines and geologic storage potential in the US. (Storage regions from the National Carbon Sequestration Database and Geographic Information System, NATCARB. Figure courtesy of the Great Plains Institute.)

Beginning in 1972 and continuing through to the present, CO_2 pipeline development has been driven primarily by the energy industry for use in enhanced oil recovery (EOR) projects. A 2015 report indicated that nearly 80% of the CO_2 pipeline network connects naturally occurring sources of CO_2, like the Jackson Dome in Mississippi, to EOR projects (Wallace et al., 2015). New CO_2 pipelines, however, are needed to transport CO_2 captured for the purposes of carbon management from emissions sources or direct air capture facilities to permanent geologic storage sites due to technical and capacity constraints of existing CO_2 pipelines.

Demand for CO_2 pipelines routed to dedicated geologic storage sites will grow as new CCS projects are developed. Analysis by the Global CCS Institute shows that 78% of the total capacity of current and future CCS facilities (i.e., in operation, construction, or development) use dedicated geological storage sites rather than EOR sites to store CO_2 (Figure 5).

Pipelines, pipeline safety, and the transportation of hazardous materials are regulated through the Pipeline and Hazardous Materials Safety Administration (PHMSA, part of the US Department of Transportation). CO_2 transportation through pipelines falls under PHMSA's regulations for hazardous liquid pipelines (49 CFR Part 195, 2023a). Federal pipeline safety standards are applicable to both interstate and intrastate pipelines. In the case of intrastate pipelines, a state would have jurisdiction to inspect and enforce regulations if it has the necessary PHMSA certification in place (see Section 2.3). CO_2 is transported in a liquid-like dense state, referred to as supercritical (see Section 3.3.1) (US DOE et al., 2017).

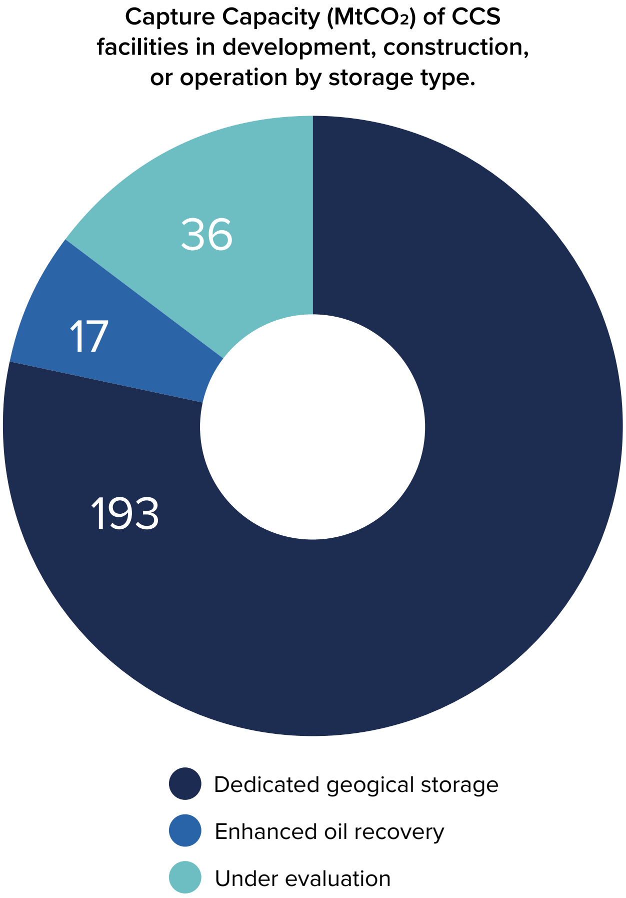


Figure 5. Total capacity of current and future CCS facilities (i.e., in operation, construction, or development) by storage type. The vast majority of current and future projects – 78% – will store CO_2 in dedicated geological storage sites (Source: Global CCS Institute, 2023).

2.1 Federal Legislation

In the US, several federal statutes govern the regulation of pipelines, especially pipeline safety. Pipeline regulation began with the Natural Gas Pipeline Safety Act of 1968, whose jurisdiction applied to natural gas (Natural Gas Pipeline Safety Act, 1968). Regulation of hazardous liquids began with the Hazardous Liquids Pipeline Safety Act of 1979, which defined a hazardous liquid as "petroleum or any petroleum product" (Hazardous Liquids Pipeline Safety Act, 1979). On July 12, 1991, CO_2 was added to the regulations governing the transportation of hazardous liquids (see Section 2.2; 49 CFR Part 195, 2023b).

The federal government possesses statutory jurisdiction for siting CO_2 pipelines when they cross federal lands (Bliss Esq. et al., 2010; US DOE et al., 2017). If any pipeline needs to traverse federal lands, federal statutes apply. The US Department of the Interior, Bureau of Land Management (BLM), for example, possesses the authority to grant rights-of-way for federal lands it administers under the Mineral Leasing Act (MLA) of 1920 or the Federal Land Policy and Management Act of 1976 (US DOE et al., 2017). Other federal lands (forests, for example) are regulated by other agencies, such as the US Department of Agriculture Forest Service. Pipelines granted a right-of-way by BLM under the MLA will also carry a common carrier transportation status (not private or proprietary). Common carrier status is afforded to those pipelines that offer services to third parties subject to contractual agreements. Montana and North Dakota provide useful definitions (Montana Code Annotated 2021, 2021; North Dakota Century Code, 2023).

The federal government does have jurisdiction to regulate the safety of CO_2 pipelines[2]. These are discussed in more detail in Section 2.2. Among the statutes forming the legal basis for PHMSA to regulate pipeline safety (US Department of Transportation, 2022) are:

1. Natural Gas Pipeline Safety Act of 1968.
2. Hazardous Liquid Pipeline Safety Act of 1979.
3. Pipeline Inspection, Protection, Enforcement and Safety Act of 2006.
4. Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011.
5. Protecting our Infrastructure of Pipelines Enhancing Safety (PIPES) Act of 2016.
6. Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2020, Public Law No. 116-260, Division R December 27, 2020.

PHMSA Reauthorization

PHMSA receives funding and authorization for its pipeline safety program from the US Congress. The last congressional authorization, the Protecting Our Infrastructure of Pipelines and Enhancing Safety (PIPES) Act of 2020, was signed on December 27, 2020, and expired on December 31, 2023. Bills aimed at reauthorizing PHMSA's pipeline safety program are currently moving through the US Congress.

[2] Offshore pipelines are regulated either by the Department of Transportation (DOT) PHMSA Office of Pipeline Safety or by the Department of Interior Bureau of Safety and Environmental Enforcement (BSEE). DOI offshore pipelines that are defined separately from DOT pipelines are regulated by the BSEE through 30 CFR 250 Subpart J. BSEE is authorized by the Secretary of the DOI through the OCS Lands Act (page 64491).

2.2 Federal Safety Regulation

Regulations that govern pipeline safety, like other federal regulations, are listed in the relevant and applicable Code of Federal Regulations (CFR). For CO_2 pipelines, 49 CFR Part 195 applies. The scope of this CFR "…prescribes safety standards and reporting requirements for pipeline facilities used in the transportation of hazardous liquids or carbon dioxide." While this CFR in its original form did not include CO_2 transportation by pipeline, the American Petroleum Institute (API) in 1989 recommended that the Office of Pipeline Safety (OPS, now within PHMSA) amend this regulation to include CO_2, which ultimately resulted in the Research and Special Programs Administration (RSPA, PHMSA's predecessor) amending the CFR accordingly (49 CFR Part 195, 2023b; IEAGHG, 2013).

The regulation is broad in scope, covering compliance, general inspection, repair, material inspection, pipe transportation, welding, installation, valving, associated equipment (pumping), protection, and record keeping.

In May 2022, PHMSA announced new measures to enhance CO_2 pipeline safety following the 2020 leak in Satartia, MS (PHMSA, 2022b). The pipeline safety measures include the following:

- Conducting solicitations and funding research to strengthen CO_2 pipeline safety
- Conducting a failure investigation and completing the 2020 CO_2 pipeline failure report
- Issuing Notice of Probable Violation, Proposed Civil Penalty, and Proposed Compliance Order to the pipeline operator
- Initiated new rulemaking to update CO_2 pipeline standards to include emergency preparedness and response requirements
- An advisory bulletin issued to all pipeline operators nationwide that stressed the need to plan for and mitigate the risks of geohazards and land movements that could pose risks to the integrity of pipelines.

PHMSA Rulemaking Update to CO_2 Pipeline Safety Standards

In response to the expected expansion of CO_2 pipeline networks in the US and to the CO_2 pipeline failure in Satartia, MS, PHMSA is currently evaluating existing rules governing CO_2 pipelines and plans on issuing a proposed rule in 2024. On 18 January, 2024, Tristan Brown, PHMSA Deputy Administrator, testified to the US House of Representatives Committee on Energy and Commerce that "…the anticipated expansion of pipeline infrastructure to transport CO_2 has made PHMSA's update of current CO_2 pipeline regulations a top priority for the agency. PHMSA anticipates issuing a Carbon Dioxide and Hazardous Liquid Pipeline Safety NPRM [notice of proposed rulemaking] early this year [2024]."

PHMSA submitted its NPRM to the Office of Management and Budget (OMB) for review on 1 February, 2024. The proposed rule aims to cover operational and maintenance safety issues relevant to all phases of CO_2 (e.g., supercritical, gaseous, etc.) transportation via pipeline. The NPRM submission announcement states the proposed rulemaking "would amend PHMSA's Pipeline Safety Regulations (49 CFR parts 190-199) to adopt revisions that would enhance the safe transportation of carbon dioxide by pipelines," including requirements related to emergency preparedness and response.

Details of the proposed rulemaking are not made public until the OMB review is complete. Following OMB review, the NPRM will be published in the Federal Register and a defined public comment period will begin.

After the public comment period, comments are reviewed and PHMSA's Pipeline Advisory Committees review the technical feasibility, reasonableness, cost-effectiveness and practicability of the proposed rule before the rule is finalized.

2.3 State Legislation

State agencies may enter into agreements with PHMSA for pipeline inspections that help ascertain compliance with the safety regulations specified at the federal level. In the case of intrastate pipelines, the state will handle both inspection and enforcement if it has the necessary PHMSA certification in place. Some states also have interstate agency certification, allowing them to help inspect interstate pipelines located in their state. Any actual or probable violations are reported to PHMSA for regulation enforcement in states without intrastate certifications. States have jurisdiction over assigning the right of way to developers, and if common use/carrier developers need to exercise eminent domain laws, they can do so through the appropriate authorities in the relevant state. Several states have legislation in place with jurisdiction covering pipelines.

Appendix 1 lists pipeline legislation in US states.

2.4 State Safety Regulation

In most states, the Office of Pipeline Safety (OPS) (an Office within PHMSA at the Department of Transportation) certifies state-level agencies to inspect and enforce pipeline safety regulations for intrastate pipelines. State-level agencies have adopted safety regulations defined in 49 CFR Part 195 (which has requirements for CO_2) into their regulations and rules, and thus, these regulations apply to CO_2 pipeline operators as well.

Appendix 2 lists state-level pipeline regulations and the corresponding state-level agency that has jurisdiction over pipelines in the relevant state.

Some examples of regulations in force from states that have CO_2 pipelines are shown in Table 1.

STATE	REGULATION	AGENCY
Texas	Texas Pipeline Safety Rules (Texas Administrative Code, Title 16, See Chapters 8 & 18)	Pipeline Safety Department of the Texas Railroad Commission
New Mexico	New Mexico Administrative Code Title 18, Chapter 60 Part 3	Pipeline Safety Bureau in the Transportation Division of the New Mexico Public Regulation Commission
Colorado	See the Commission's 49 USC. § 60105(a) certified pipeline safety program	Colorado Public Utilities Commission
North Dakota	49 CFR Part 195 in effect for Pipeline Safety	North Dakota Public Service Commission
Montana	Rule 17.80.204	Montana Public Service Commission
Wyoming	Public Service Commission Rules Chapter 3	Wyoming Public Service Commission
Kansas	Certifications and Agreements with PHMSA under 49 USC. § 60106	Pipeline Safety Section of the Kansas Corporation Commission
Oklahoma	Certifications and Agreements with PHMSA under 49 USC. § 60105	Pipeline Safety Department of the Oklahoma Corporation Commission
Mississippi	See MS Code Section 11-27-47	Mississippi Public Service Commission
Louisiana	Certifications and Agreements with PHMSA under 49 USC. § 60105	Office of Conservation, Louisiana Department of Natural Resources
Michigan	Certifications and Agreements with PHMSA under 49 USC. § 60105	Michigan Public Service Commission

Table 1. States with CO_2 pipelines and associated regulations.

2.5 CO_2 Pipeline Permitting

Many CCS projects in operation or development rely on, or will rely on, CO_2 pipelines for CO_2 transportation. As described above, federal and state pipeline permitting is complex and projects may be subject to a wide range of requirements that could slow down CO_2 pipeline development (Lockman, 2023). Project development and permitting can include multiple steps such as obtaining rights of way, conducting environmental assessments, providing public notice, and undertaking community engagement. It can involve various federal, state, and local agencies, as well as public interest groups and citizens. Table 2 below describes some of the authorizations and types of permits that may be required (CEQ, 2021).

Delays in CO_2 pipeline development caused by the permitting process will also impact the CCS project to which those pipelines are linked. **The Global CCS Institute estimates a one-year delay in announced CCS projects and CCS projects in development could result in 91 Mt of unmitigated CO_2 emissions by 2030**.

Project delays also have tangible economic and social consequences on communities, some of which are discussed in Section 4. To remain competitive in a growing global marketplace for low-carbon commodities and products, the US must address barriers to project development, including permitting delays.

Portion of the CCUS efforts*	Authorization	Authorities that may require permits/permissions	Type of Agency
	Land use	Local government, Federal Government (public lands)	City Council, Federal Land Manager (USFS, BLM, etc.)
	Discharges to surface water	State and/or Federal Government	State Department of Environmental Quality, U.S. Environment Protection Agency
	Discharge of dredge or fill materials to waters of the U.S.	State and/or Federal Government	U.S. Army Corps of Engineers and or relevant State office (Florida, Michigan and New Jersey)
	Endangered species	State and/or Federal Government	State Environmental or Natural Resources Department, U.S. Fish and Wildlife Service, NOAA Fisheries
	Greenhouse gas reporting	State and/or Federal Government	State Environmental Department, U.S. Environment Protection Agency
	Air permits	State and/or Federal Government	State Environmental Department, U.S. Environment Protection Agency
	CO_2 pipeline safety	State and/or Federal Government	State and Federal Departments of Transportation
	Siting CO_2 pipelines	Local, State, and Federal Government	State Transportation Department or Utility Commission; Federal Land management agencies
	Pore space ownership and mineral rights	Local, State, and Federal Government (if Federal lands)	Determined by State-specific law, Federal agency managing Federal Lands to be used
	CO_2 injection (and sequestration) permitting	State and/or Federal Government (some states have primary for Class VI permitting)	State Environmental Department, U.S. Environment Protection Agency

Denotes Utilization, **Denotes capture,**

Denotes transportation, and **Denotes geologic sequestration**

**Federal responsibility is listed together with exemplary state and local governments (which vary depending on local context). For Tribal lands/sovereign nations, the Tribal government will have oversight.

Table 2. Overview of types of permits and permissions needed for CCUS projects. Source: https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf Appendix A of the same report provides an inventory of federal permits and reviews potentially relevant to pipelines.

3.0 PIPELINE SAFETY, RISKS, AND BEST PRACTICES

Pipelines are the most economic means to transport significant volumes of fluids over long distances onshore. Statistically, they have some of the lowest rates of incidents affecting people or the environment per mile of pipeline across the US. Pipelines in the US move a wide range of liquids and gases, including water, hydrocarbons, chemicals, and CO_2.

Pipeline infrastructure in the US is supported by a well-established industry with the technical expertise and tools needed to ensure they are designed, constructed, operated, and maintained correctly. Federal laws and regulations ensure that pipelines safely transport water, hydrocarbons, and other fluids to where society requires them.

3.1 CO_2 Hazards: Cooling, Corrosion, Pooling

The most significant hazard CO_2 presents to society is its contribution to climate change, the implications of which have far-reaching consequences for humanity (see Introduction). However, under certain conditions, CO_2 can be harmful to humans. In this section, we will examine how and when CO_2 is hazardous.

Ordinarily, CO_2 is in the air surrounding us. At low or trace concentrations, CO_2 is not directly harmful to humans. We all produce CO_2 when breathing, and we ingest it when drinking carbonated beverages. However, in very high concentrations and volumes, CO_2 must be handled appropriately.

CO_2 can, in certain conditions, be very cold – this can create risks of cold burns and have implications for the properties of materials used to carry it. For example, if high-pressure CO_2 experiences a significant pressure drop, the CO_2 will expand and cool rapidly as a result of the thermodynamic behavior of gases (i.e., Joule-Thomson effect cooling). To address such risks, pipelines and ancillary equipment are designed to minimize the risk of skin contact, and careful consideration is given to the thermal properties of CO_2 and the materials utilized in pipeline construction.

In the presence of water, CO_2 can form corrosive carbonic acid, presenting potential integrity risks to steel pipelines. Care is taken to ensure CO_2 is dehydrated prior to entry into steel pipelines. Specifications are defined to ensure that fluids entering a CO_2 pipeline contain very low levels of water. Equally, procedures are implemented to monitor corrosion in pipelines and manage their integrity.

CO_2 is denser than air. If accidentally released, it can collect in open low-lying areas and confined spaces, presenting a toxic hazard and an asphyxiation risk. To address this risk, air dispersion analysis is performed to understand where CO_2 will migrate in the highly unlikely event of a CO_2 release.

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3.2 Exposure Limits

Studies by the National Institute for Occupational Safety and Health (NIOSH) in 1976 corrected a previous assumption that carbon dioxide is only an asphyxiant gas (NIOSH, 1976). In examining the biological effects of CO_2 exposure, the studies determined CO_2 can also be toxic in very high concentrations. Exposure to lower-level CO_2 concentrations may cause headaches, lethargy and impact the cardiovascular system.

When breathing, as the concentration of carbon dioxide in the ambient air increases, lower quantities of carbon dioxide leave the bloodstream. Therefore, there is less room for oxygen, affecting its intake. This effect is called CO_2 Intoxication. The health effects of CO_2 exposure at differing levels are summarized in Table 3 below.

5,000 ppm (0.5%)	OSHA Permissible Exposure Limit (PEL) and American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) for 8-hour exposure
10,000 ppm (1.0%)	Typically no effects, possible drowsiness
15,000 ppm (1.5%)	Mild respiratory stimulation for some people
30,000 ppm (3.0%)	Moderate respiratory stimulation, increased heart rate and blood pressure, ACGIH TLV-Short Term
40,000 ppm (4.0%)	Immediately Dangerous to Life or Health (IDLH)
50,000 ppm (5.0%)	Strong respiratory stimulation, dizziness, confusion, headache, shortness of breath
80,000 ppm (8.0%)	Dimmed sight, sweating, tremor, unconsciousness, and possible death

Table 3. Health effects of CO_2 exposure showing the impact of differing concentrations and duration.
Source: https://www.fsis.usda.gov/sites/default/files/media_file/2020-08/Carbon-Dioxide.pdf

CO_2 concentration and exposure time have important implications for health effects. Today, background levels of CO_2 in atmospheric air average around 418 ppm (.04%). OSHA has established a Permissible Exposure Limit (PEL) for CO_2 of 5,000 ppm (0.5% CO_2 in air) averaged over an 8-hour workday (time-weighted average, or TWA). An exposure time of 1 hour to a 3% concentration of CO_2 results in mild headache, sweating, and dyspnea (difficult or labored breathing) at rest. At concentrations of 4 to 5% CO_2, the onset of headache, dizziness, increased blood pressure, and uncomfortable dyspnea occurs "within a few minutes."

During an unintended release of CO_2, high concentrations of CO_2 may be encountered. Concentration levels will decrease as the CO_2 disperses. Emergency thresholds will vary significantly from occupational thresholds. NIOSH has not developed any emergency exposure levels for CO_2. There are no Acute Exposure Guideline Levels (AEGLs) for CO_2 defined by the US EPA and no Emergency Response Planning Guidelines (ERPGs) for CO_2 defined by the American Industrial Hygiene Association (AIHA). Pipeline operators work with stakeholders to establish emergency response and action thresholds as part of their emergency response planning in the highly unlikely event of a CO_2 release.

3.3 Industry Best Practices and Risks

Although there are similarities between CO_2 and conventional hydrocarbon pipelines, there are differences in the design, construction, and operation of CO_2 pipelines, primarily due to the specific characteristics of CO_2. The subsections below detail the unique aspects of CO_2 pipelines and how they are addressed through industry best practices.

3.3.1 CO_2 Phase Behavior

Factors such as temperature, pressure, and CO_2 stream composition (which varies with the CO_2 source) influence CO_2 phase behavior. CO_2 exists in a solid, liquid, or a gas phase depending on the pressure and temperature conditions (Figure 6). When pressures exceed 1070 psi (or 7.38 MPa / 72.8 atm), CO_2 enters what is referred to as its **dense phase**, which includes both supercritical[3] and dense phase liquid CO_2 (Figure 6). Dense phase CO_2 exhibits liquid-like density and gas-like viscosity. Because of its higher density and lower pressure losses compared to gas phase CO_2, dense phase CO_2 is generally the preferred phase for CO_2 pipeline transport.

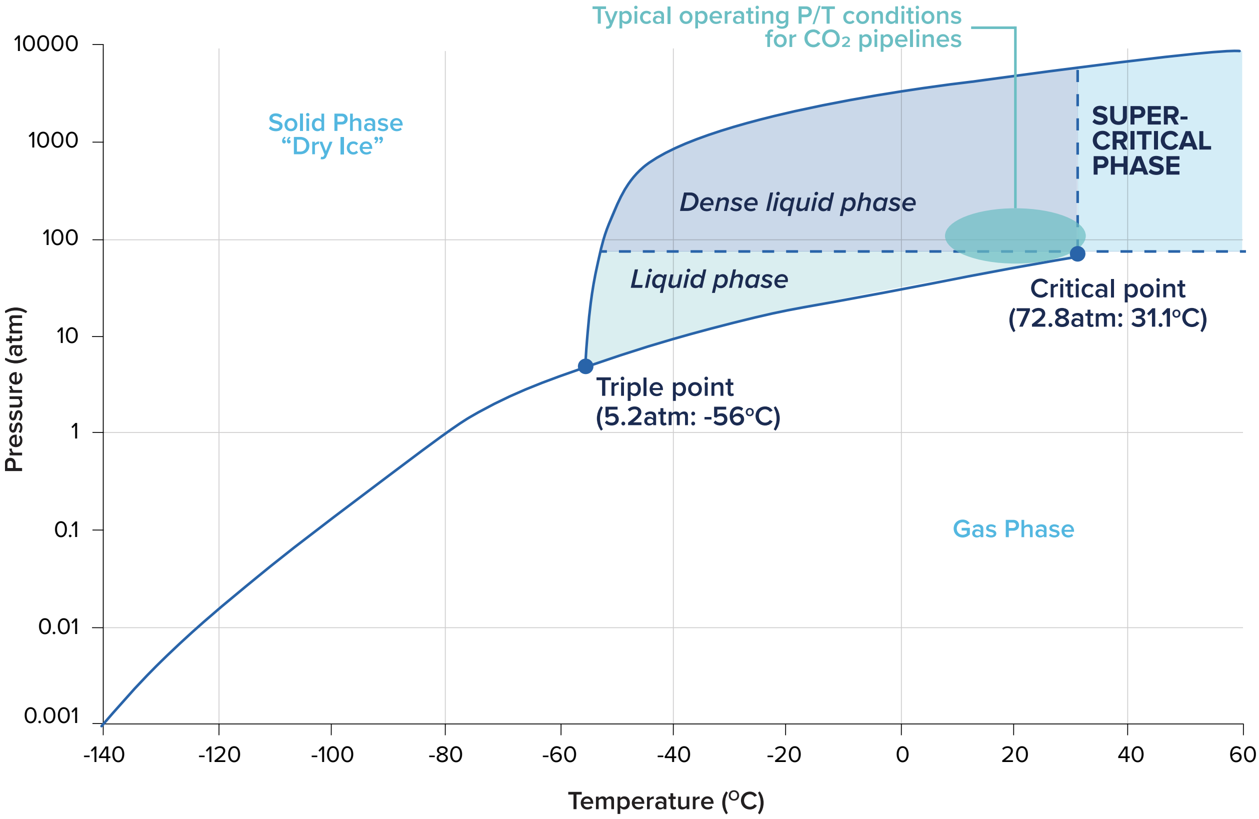


Figure 6. Carbon dioxide phase diagram (after Mazzoldi et al., 2008). Dense phase CO_2 includes both dense liquid phase CO_2 and supercritical CO_2. CO_2 is typically transported in its dense liquid phase (circled region in the figure).

Conventional industrial carbon capture systems use a variety of methods to separate CO_2 from flue gases and deliver CO_2 at atmospheric pressure. Capture systems may use chemical solvents, such as amines, chemical sorbents, physical membranes, or other technologies to isolate and capture carbon dioxide. A conditioning plant is used to ensure that the stream of CO_2 is dry (contains very little water) and meets the necessary pipeline entry specifications.

Dense phase CO_2 pipelines typically operate at pressures between 73 atm and about 207 atm (1,075 psig to 3,045 psig). A compressor is used to increase the pressure of the CO_2 to its dense liquid phase (72.8 atm, referred to as the critical pressure) and pumps are used to further boost pressures to those required for transport in a pipeline. Currently, PHMSA only regulates CO_2 transported in supercritical phase. However, PHMSA does have safety authority over gas and liquid phases as well.

[3] Supercritical CO_2 refers to a fluid state of CO_2 occurring when pressures exceed the critical pressure of 7.38 MPa or 1,070 psi (72.8 atm) and temperatures exceed the critical temperature of 31.1°C or 88°F. The distinction between dense liquid phase CO_2 and supercritical CO_2 exists because CO_2 no longer exists in distinct gaseous and liquid phases in the region above the critical pressure and critical temperature (Wang et al., 2019).

3.3.2 CO_2 Streams and the Impact of Impurities on CO_2 Pipelines

In the context of carbon capture, CO_2 may come from various sources and be captured by different techniques, leading to variations in product composition. Within the industry, **typical specifications require a minimum of 95% CO_2 in the stream composition**, where the remaining 5% typically comprises hydrocarbons, nitrogen, and other non-condensable fluids, with possible traces of sulfur, oxygen, glycols, and water. **However, some CCS projects require a more conservative composition close to 99% CO_2, driven by limitations on acceptable impurities across the value chain.**

Pipeline operators determine the required specifications for the composition of CO_2 entering a pipeline. Generally, CO_2 composition is monitored to ensure that it meets the required specifications. If, for example, the water content exceeds a specified limit, an alarm would be triggered, alerting the operator to respond accordingly.

3.3.3 Materials and Fracture Control

A key consideration for the design of CO_2 pipelines is a well-known metallurgical phenomenon called running ductile fracture. Running ductile fractures are possible in natural gas pipelines, but they are a particular concern for CO_2 pipelines, due to the thermo-physical properties of CO_2 (Di Biagio et al., 2017). A running ductile fracture may occur when a failure leads to a pipeline rupture and CO_2 release. As the CO_2 escapes, its pressure drops, and it transitions from dense phase to gaseous phase, undergoing rapid expansion and volume increase.

For example, at ambient temperatures, 1 lb of pure CO_2 at dense phase pipeline pressure (100 bar) would have a volume of around 0.017 ft^3, whereas at atmospheric pressure (1 bar) that same quantity of gas would have a volume of around 9 ft^3 – a more than 500-fold increase. Rapid expansion as a consequence of a pressure drop and CO_2 phase change can cause a rupture to propagate along a pipeline.

To date, we are unaware of any cases of running ductile fractures occurring in operational CO_2 pipelines. Such failures are avoided by the implementation of robust integrity management systems and CO_2 pipeline design in accordance with industry standards. Proper design includes selecting materials with sufficient toughness, ductility and suitable wall thickness, and/or by installing mechanical devices called crack arrestors at appropriate intervals (see DNV-RP-F104).

3.3.4 Safety Design

In the US, federal regulations govern CO_2 transportation safety. The US Department of Transportation provides general oversight for onshore CO_2 pipelines at the federal level. PHMSA is responsible for administering pipeline safety regulations. These regulations apply to all dense phase CO_2 pipelines, with some exemptions. For instance, the Department of Interior's BLM can regulate CO_2 pipelines crossing federal lands. Tribal entities will oversee pipelines through tribal lands. Additionally, some state agencies have authority to regulate pipeline safety, as long as their standards meet or exceed the federal rules contained in 49 CFR part 191-199 and they have an active certification and agreement with PHMSA under 49 U.S.C. § 60105- 60106. PHMSA also has regulatory and safety authority for offshore pipelines, including CO_2. Offshore CO_2 pipelines are also regulated by the Department of the Interior, Bureau of Safety and Environmental Enforcement (BSEE), under 30 CFR Part 250 Subpart J.

Industry standards and recommended practices provide operators with requirements and specifications that can be used consistently to ensure safe pipeline design. This includes the materials, products, processes, and services used in pipeline construction. Further, they provide guidance for safe pipeline infrastructure management – both for new design and re-use. Ultimately, they reflect industry experience and often result from joint industry projects, establishing trust and confidence between stakeholders, authorities, and society. For pipeline transport of CO_2, existing design codes provide design criteria and guidance specifically for CO_2 transport, such as ASME B31.4, DNV-RP-F104, and ISO 27913. Such documents often supplement existing standards for hydrocarbon pipelines.

Generally, one or more of the following standards are used in the design process in North America. The pipeline operator must justify any deviations from such standards and will be subject to inspection by the regulator.

The most commonly used standards in North America are detailed in CFR 49 part 195 and ASME B31.4 in the US and CSA Z662 in Canada. These are the same rigorous hazardous liquid pipeline standards that govern the transportation of crude oil, petroleum products, and highly volatile liquids such as propane, butane, and ammonia. In other parts of the world, commonly referenced standards include the Recommended Practice DNV-RP-F104 "Design and operation of CO_2 pipelines," or ISO 27913 'Carbon dioxide capture, transportation, and geological storage: Pipeline transportation systems.'

Such standards specify CO_2 pipeline engineering and design parameters with which operators typically must comply. Some standards are under review to update guidelines and enhance safety and system performance. Pipeline standards typically address:

- Specific properties of CO_2
- Safety aspects of transportation of CO_2 in pipelines relevant in the context of CCS
- Emergency response
- Concept development and design premises
- Materials and pipeline design
- Pipeline construction
- Operation and integrity management
- Public awareness

3.3.5 Safety History

PHMSA collects and publishes data on the safety and performance of pipelines that transport CO_2. These datasets include the mileage, incidents, causes, and consequences of pipeline failures, as well as the trends and inventories of pipeline infrastructure. PHMSA uses these datasets to monitor and improve pipeline transportation safety and inform the public and stakeholders about the risks and benefits of pipelines.

3.3.6 Safe Operations and Integrity Management

Pipeline integrity management (IM) is a system or program that aims to ensure the safety, reliability, and compliance of pipelines throughout their life cycle. It involves engineering analyses, inspections, maintenance, and repairs of pipelines to prevent or address issues that might compromise their integrity and lifespan. In the US, CO_2 pipelines are regulated under the same statute as hazardous materials, which requires stringent inspection requirements.

Pipeline IM programs are structured to monitor and prevent pipeline safety risks using various inspection techniques and to mitigate any identified safety issues with remedial actions. In most jurisdictions, regular safety inspections are a regulatory requirement. In the US, pipeline operators are required to follow PHMSA regulations found in 49 CFR Part 195.

A wide variety of inspection techniques enable pipeline operators to monitor pipeline conditions. Visual inspection involves examining the pipeline using human visual senses or optical devices to assess the external surface and accessible internal components for visible defects, anomalies, or signs of damage. Pipeline inspectors use this technique to identify any visible issues requiring further attention.

While visual inspection is valuable, it does not comprehensively assess the pipeline's internal condition. Non-destructive testing techniques are used to provide a more comprehensive picture.

In-line inspection (ILI or "smart pigging") is an advanced robotic technique that propels a purpose-built pipeline inspection unit (called a "pig") fitted with a variety of probes and sensors through a pipeline to detect and measure corrosion, metal loss, cracks, dents, deformations, etc. The ILI unit is equipped with sensors that can detect and measure the thickness of the pipe wall, the presence of corrosion, and other irregularities on the pipe's inner walls. Once collected, the data are analyzed to determine the condition and integrity of the pipeline.

Many other techniques exist that can be used to monitor the emergence of specific risks. For example, soil movements, believed to have contributed to the Satartia, Mississippi, incident (see Section 3.8), could be monitored using geotechnical sensors.

3.4 Repurposing Existing Pipelines to Transport CO_2

Over the last decade, the potential for repurposing existing pipeline infrastructure for transporting CO_2 has received increased attention. Repurposing[4] pipelines is an attractive option, considering both the cost and environmental footprint of new dedicated CO_2 pipeline construction. Repurposed pipelines must meet safety standards and regulatory requirements including PHMSA guidance for pipeline flow reversals, product changes and conversion to service.

Typically, the process involves considering safety issues related to product changes, flow direction changes, physical properties of the product (especially weight), operating conditions, and pipeline age and expected lifetime after conversion. It is important to note that repurposed pipelines must comply with the same requirements as pipelines explicitly designed for CO_2 transportation.

Pipeline requalification is technically feasible but requires a robust process to demonstrate that all elements of the existing pipeline are compatible with CO_2 transport. Considerations in this process include ensuring the suitability of the pipeline materials, design pressure, and overall integrity to carry dense phase CO_2. A typical approach adopted for requalification is shown in Figure 7.

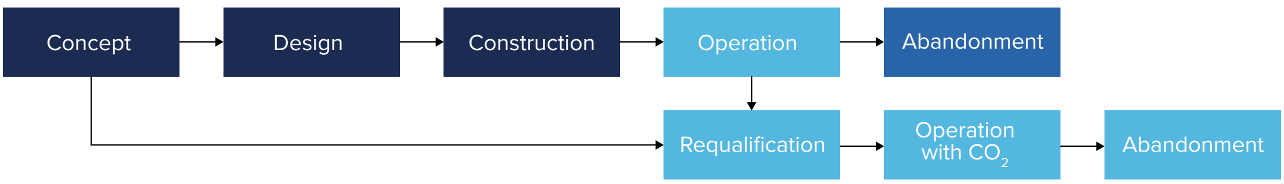


Figure 7. CO_2 pipeline requalification procedure from DNV RP F 104.

[4] Repurposing pipelines is also referred to as "conversion to service."

3.5 Ongoing Research

CO_2 pipeline deployment in the US is expected to grow, so PHMSA, the Pipeline Research Council International (PRCI), and DNV are leading research projects to strengthen understanding of pipeline safety.

DNV has developed its CO2Safepipe Joint Industry Project to collect industry best practices, close knowledge gaps, and provide guidance based on recent developments in topics crucial for the design and operation of CO_2 pipelines. It will build upon prior research to close identified knowledge gaps in CO_2 pipeline transportation, including:

- CO_2 transport in both gas phase and dense phase,
- CO_2 stream composition and its effect on corrosion and materials, and
- risk of running ductile fracture.

Other ongoing research includes the development of an appropriate odorant for CO_2 pipeline applications.

PIPELINE RESEARCH – CO_2 PIPELINE RELEASE TESTING AT DNV'S SPADEADAM RESEARCH AND DEVELOPMENT FACILITY

Existing and new pipeline safety regulations are often developed based on research conducted by academia, industry, and governments. Pipeline research focusing on the design and operation of CO_2 pipelines is extensive, ongoing, and helps ensure a comprehensive understanding of safe and effective CO_2 pipeline operations as well as improved safety standards.

To understand safe operating conditions for CO_2 pipelines and the behavior of CO_2 when it is released, experiments must be conducted to test the limits of various pipeline materials and equipment. This necessarily requires intentionally inducing controlled pipeline failure to understand how pipeline systems and CO_2 will behave were such an event to occur.

Observations and results from failure tests are used to make pipeline operations safer. DNV has performed these types of tests at their Spadeadam Research and Development Facility in Cumbria, United Kingdom.

Figure 8 shows a controlled and deliberate, full-scale CO_2 pipeline release performed at DNV's Spadeadam facility. This test was one of a number performed as part of the 3-year COSHER (CO_2 Safety, Health, Environment, and Risk) Joint Industry research program initiated in 2011 and funded by National Grid, ENI, Equinor, TotalEnergies, Petrobras, and Gassco. It is believed to be the largest such test performed to date.

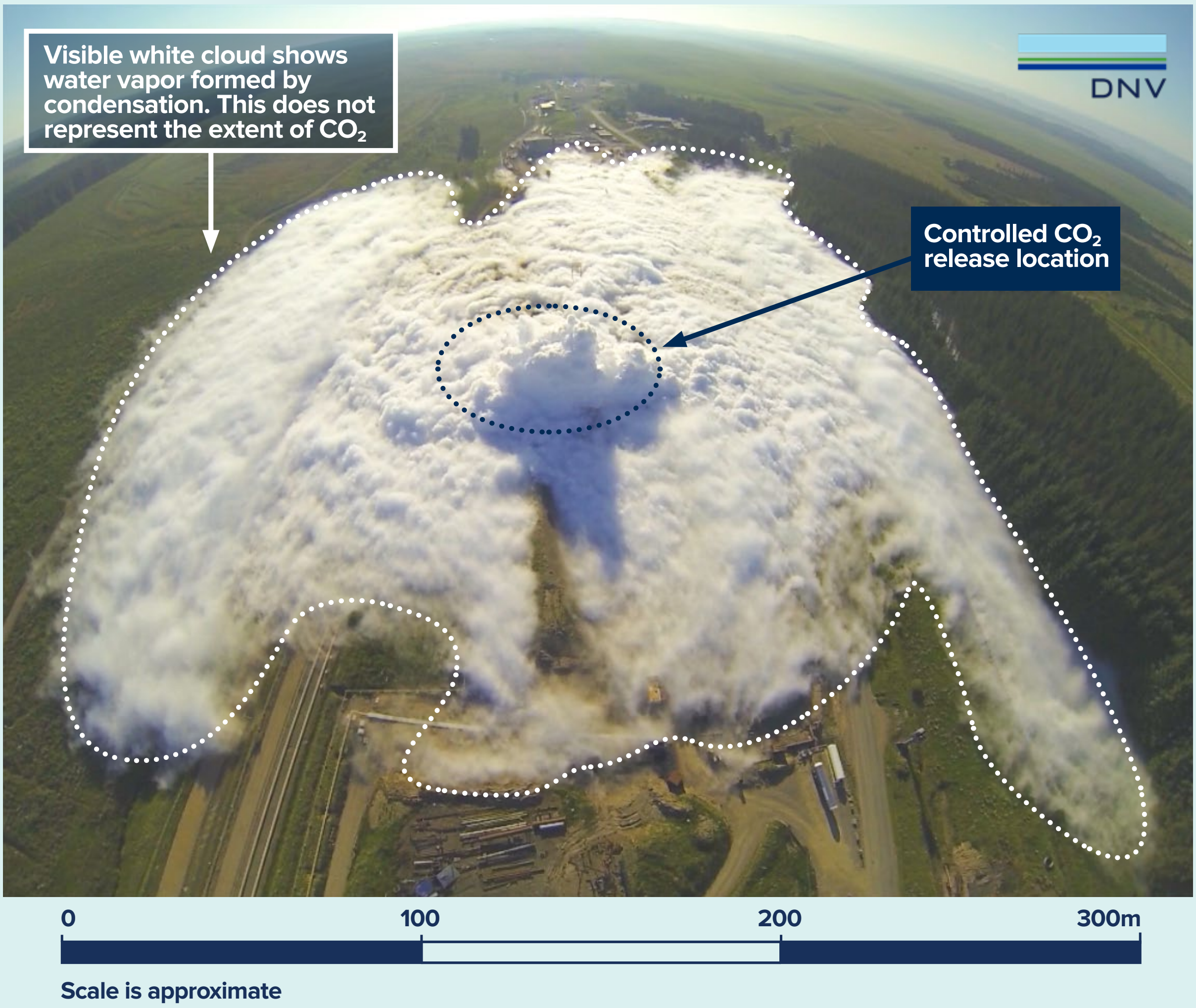


Figure 8. CO_2 pipeline rupture test performed as part of research at DNV's Spadeadam Research and Development facility. This test was controlled and deliberate. NOTE: The white cloud shows water vapor produced as the cold CO_2 condenses moisture in the surrounding air. The cloud does not necessarily represent the extent of the CO_2. Image courtesy DNV.

In this test, a full-scale pipeline rupture was deliberately initiated in an 8” buried pipeline carrying dense phase CO_2 to obtain data regarding various CO_2 characteristics, including CO_2 dispersion. The white cloud shown in Figure 8 does not represent the boundary of the CO_2 but shows water vapor produced as the cold CO_2 condenses moisture in the air surrounding the CO_2 release.

While this test looks dramatic, it reflects what is potentially the most extreme type of failure that a pipeline could encounter and is an extremely unlikely event to occur in practice. Such an event is extremely unlikely because of industry regulations and the best practices, integrity management systems, and safety equipment described in Section 3.3.

The findings from such important testing are used in a number of positive ways, including:

- To refine industry standards for CO_2 pipelines
- To refine software used to model accidental releases of CO_2
- To improve safety procedures used around CO_2 pipelines
- To inform industry guidelines regarding the safe handling of CO_2
- To help inform new regulation development

Industry performs many similar tests on all types of pipelines to understand how failures can occur and what happens when they do. The insight gained from this type of research informs the refinement of industry regulations and standards, including those established by PHMSA. In so doing, such research helps minimize the likelihood of failures in operational facilities and ensures that in the unlikely event a failure occurs, it does so with least potential for harm.

3.6 Pipeline Routing and Development Considerations

CO_2 pipeline development is carefully considered and takes into account a wide variety of engineering, environmental, and societal factors. In this section, we examine some key factors that can influence a pipeline route.

3.6.1 Route selection

Pipeline route selection considers the long-term integrity of a pipeline by identifying threats during the routing process and minimizing them. The terrain any pipeline must cross has important implications for its design and construction. The stability of the underlying ground, its topography, and geographical features must be carefully considered during the design process.

In selecting a pipeline route, avoiding areas with high population density or other susceptible receptors is preferable, though this may not always be possible. Federal regulations provide additional requirements for pipelines in areas containing private dwellings, industrial buildings, and public assembly such as depth of cover requirements (see 49 CFR § 195.210 and § 195.248). State pipeline safety requirements must align with the minimum federal regulations. Pipeline operators consider the potential impact of a release and the distance to sensitive areas during the pipeline design and ongoing integrity management efforts to mitigate safety risks. Other considerations typically considered in route selection include:

- The threat of corrosion due to soil types, proximity to interference currents, and diminished effectiveness of cathodic protection systems.
- The potential for outside force damage in areas of known geo-hazards. These threats include water crossing locations, landslide areas, and/or potential sinkholes.
- Higher-risk land use areas such as croplands subject to regular deep tillage, multiple parallel utilities or crossings, and/or railroad and highway crossings.
- Construction-related defects or damage. The more difficult the pipeline installation, the greater the chance for errors or accidents that could damage the pipe.
- Optimizing right-of-way accessibility and observability. This can impact damage prevention by improving the effectiveness of right-of-way patrols.
- Consideration of emergency response by optimizing access to the pipeline and location of valves.

In May 2023, the US DOE National Energy Technology Laboratory (NETL) released a CCS Pipeline Route Planning Database to guide pipeline routing decisions and increase CO_2 transportation safety (NETL, 2023). The database provides users with datasets critical to pipeline routing, including:

- Boundaries associated with protected areas, parks, monuments, historic sites, and more
- CCS legislation, atlases, and taskforce involvement by state
- Environment, energy, and social justice considerations
- Hydrology
- Infrastructure (oil and gas wells, pipeline rights-of-way, roads, railroads, underground structures, and more
- Natural hazards (earthquakes, floods, wildfires, landslides, slopes, and more)

The database comprises over 90 gigabytes of data and can be downloaded from NETL's Energy Data eXchange (EDX) portal: https://edx.netl.doe.gov/dataset/ccs-pipeline-route-planning-database-v1

3.6.2 Land Access

The process of obtaining a route for constructing a pipeline is often complex and involves several legal and regulatory requirements. The developer must first obtain certain rights to build a pipeline across a piece of land. The specific requirements vary depending on the jurisdiction involved. A developer can negotiate an easement privately or seek the relevant authority to obtain the rights using appropriate statutory powers. When negotiating with a landowner, an agreement is established, setting out specifically how the landowner will be compensated for the use of their land and the specific terms that apply to the operator's use of the land. If a landowner does not agree to grant a pipeline easement, the company may try to acquire the easement through the power of eminent domain. While eminent domain laws vary from state to state, they provide the statutory authority to take private property for public use after paying just compensation.

3.7 Air Dispersion Modelling

In the extremely unlikely event of an accidental release of CO_2, it is crucial to understand how the CO_2 will disperse. This can be affected by the pipeline and operating condition charateristics, weather, terrain, and atmospheric conditions. Dispersion modelling software can be used to determine what will happen if an accidental release occurs. Such software allows a pipeline operator to simulate many scenarios and develop a comprehensive picture of what would happen to the released CO_2 in each scenario. The insight gained can enable pipeline systems to be designed such that there is minimal potential risk to people or the environment and also enable the establishment of measures to minimize impact where such risk cannot be entirely eliminated.

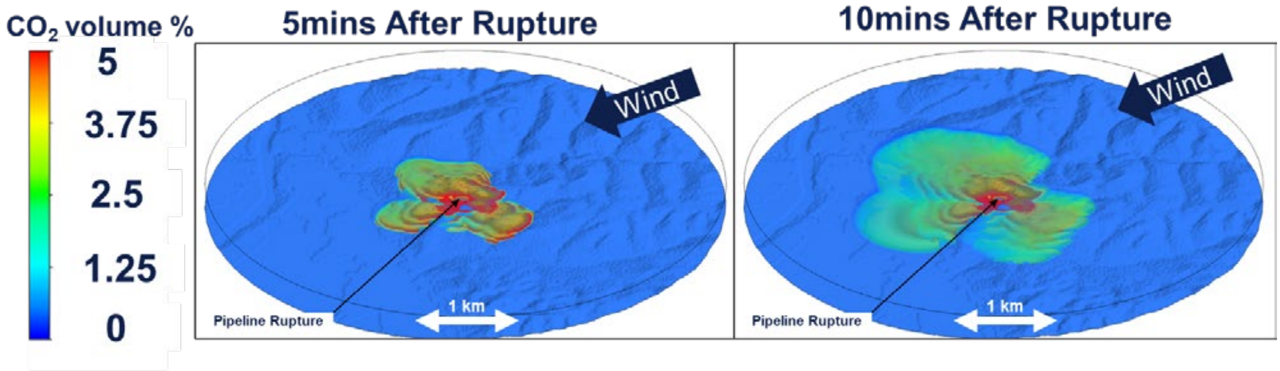


Figure 9. CO_2 dispersion modelling in complex terrain performed by DNV. This shows a theoretical CO_2 release and concentrations from a ruptured dense phase CO_2 pipeline over time.

Figure 9 shows CO_2 dispersion following a rupture in a buried dense phase CO_2 pipeline at two different time periods. The rupture occurs on a hill, and the CO_2, being heavier than air, moves down the topography toward the valley, gently pushed by the wind. The color variations in Figure 9 illustrate how the concentration of CO_2 will vary within the release and how the CO_2 disperses with time.

3.8 The Pipeline Failure Near Satartia, Mississippi

Thousands of miles of CO_2 pipelines have operated safely in the US for decades. However, in 2020, a CO_2 pipeline failure near Satartia, Mississippi, described below, impacted the local community. Lessons learned from this incident help federal, state, and local governments better understand and improve operational and emergency response procedures, which are critically important for building the CO_2 pipeline infrastructure in the US in the safest manner possible.

On 22 February 2020, the CO_2 pipeline "Delta" between Jackson Dome, Mississippi, and Delhi, Louisiana, (operated at the time by Denbury Gulf Coast Pipelines, LLC) experienced a failure and loss of containment. A section of the pipeline ruptured due to nearby soil movement. Although mainline block valves were closed to stop flow, CO_2 already present in the pipeline was released into the atmosphere.

The specific conditions on that day, combined with the unique landscape of the rupture area, resulted in elevated CO_2 concentrations in the air at the release point and in the nearby town of Satartia. The CO_2 did not immediately disperse to normal background levels due to the combined effects of the local weather conditions, the density of the CO_2 (heavier than air), and the volume of CO_2 released. The release point was approximately 90 meters (300 feet) above sea level. Satartia, however, sits approximately 30 meters (100 feet) above sea level, 1.4 kilometers away (0.87 miles) at the bottom of a valley connected to the release point. In total, approximately 30,000 barrels of CO_2 were estimated to have been released, and a portion of that CO_2 followed a path downhill, reaching Satartia. The released CO_2 in Satartia remained at higher-than-normal concentrations, impacting the local community.

PHMSA reported approximately 200 people were evacuated from their homes, and 45 people sought medical attention at local hospitals. Media reports from the night describe instances of lost consciousness; however, those impacted regained consciousness upon rescue. Additional media reports describe ongoing impacts to the community that remain under investigation.

As part of the pipeline operator's emergency response, air monitoring was conducted on the night of the rupture, both outdoors and within potentially impacted local buildings. The air monitoring included 21 buildings, with five outdoor and six indoor detections of the 138 conducted exceeding 5,000 ppm – the 8-hour exposure limit set by the Occupational Safety and Health Administration (OSHA). No detections exceeded the Short Term ACGIH Threshold Limit Value of 30,000 ppm, and outdoor CO_2 levels were sustained below 5,000 ppm after initial dispersion. After opening windows and doors to ventilate the buildings with elevated CO_2 readings, no readings exceeded 3,500 ppm. Following the release, CO_2 gradually dispersed to normal background levels of 400 ppm. In all indoor and outdoor monitoring detections, oxygen in the air remained at normal levels of 20.9%. Following the release, CO_2 gradually dispersed to normal background levels of 400 ppm. Following the incident, PHMSA attended the site and investigated. This investigation led to a number of undertakings which are still ongoing, outlined in Table 4, including a failure report released on 26 May, 2022, and a Notice of Probable Violation (PHMSA, 2022a).

PHMSA determined the incident was a result of soil movement, which led to a pipeline weld failure (PHMSA, 2022a). The soil movement is believed to have been caused by heavy rains in the area in the days and hours leading up to the incident, combined with the area's topography and soil type. Accumulated rainfall data from the US National Weather Service for nearby cities was between 31% and 78% greater than the historical average rainfall in the 60 days leading up to the failure. PHMSA also highlighted additional contributing factors in the failure report:

- The operator's dispersion model underestimated the potential affected area from a release, and as a result, Satartia was not included in the operator's public awareness program.
- Aerial patrols alone did not identify a geohazard at the failure location prior to the incident. [Note: The operator now utilises a wider range of monitoring tools, described in the Operator Response below.]
- The operator did not immediately notify local responders to advise of a potential failure and opened external communications once contacted by the local fire chief. [Note: The operator notes that they were in the process of confirming the leak in the field when contacted by local authorities and emergency responders, and that there may be circumstances where the public will be the first onsite to witness and confirm an event, despite having pipeline monitoring technology in place. Communications were sustained with emergency responders once the release was confirmed. (Denbury, 2022)]

- The Operation and Maintenance procedures did not appear to address the potential for pipeline damage due to soil instability. [Note: The operator has contested this factor and has since provided further details of their Operation and Maintenance procedures relating to how they address the potential for pipeline damage due to soil instability (Denbury, 2022).]

- The Integrity Management Program did not appear to address integrity threat identification or assessment for geohazards, or preventative or mitigative measures. The operator has contested this factor and has since provided further details of their Integrity Management Plan relating to threat identification, geohazard assessment, and preventative and mitigative measures they undertake (Denbury, 2022).

In the Operator Response to the Notice, dated 25 July 2022 (Denbury, 2022), the operator noted that they had taken several actions since the event:

- Built a bespoke tool for overland spread analysis of CO_2 to supplement the original air dispersion model.

- Reassessed all segments on its pipelines located within 2 miles of a High Consequence Area where terrain creates a risk that a leak could affect a High Consequence Area.

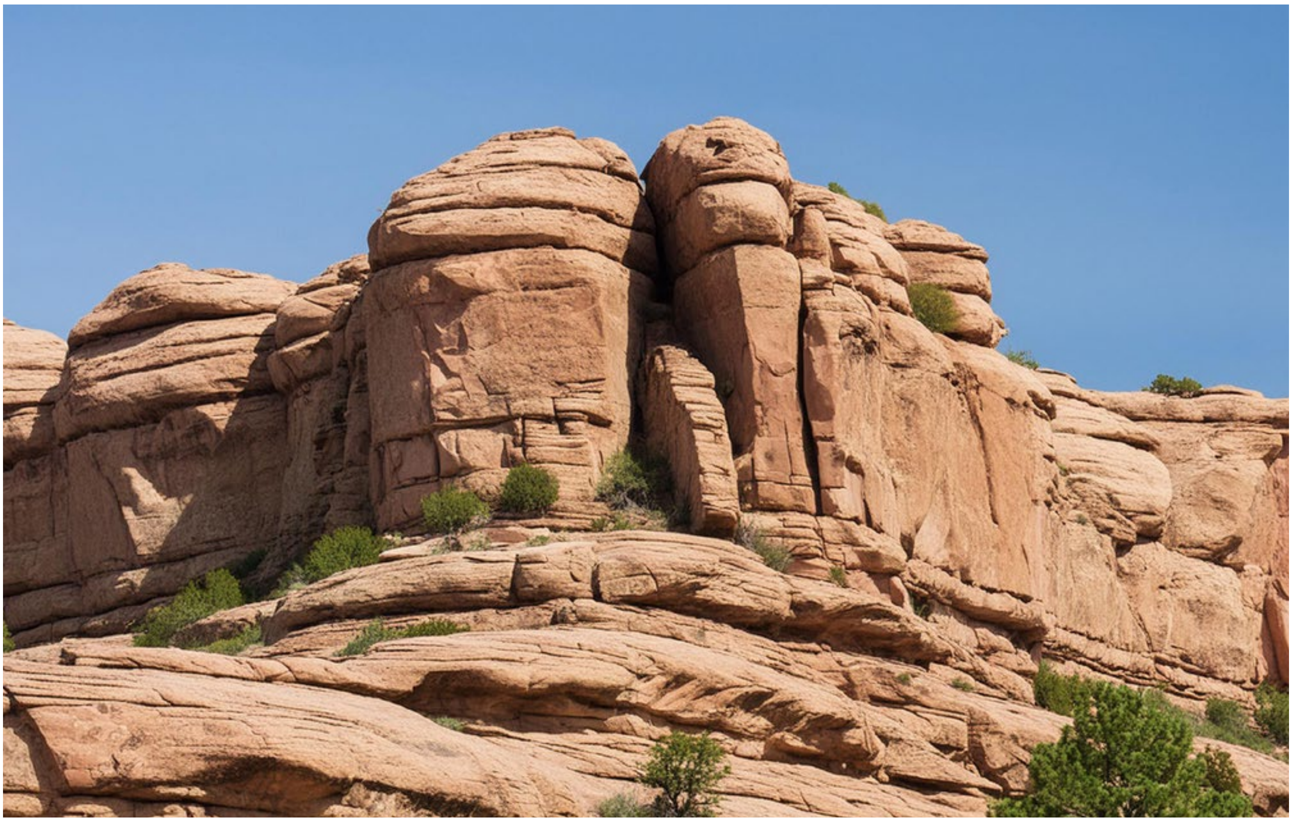
- Based on the results, re-classified Satartia as a “could-affect” High Consequence Area. As a result, included Satartia in the operator’s public awareness program.

- Begun employing additional tools and systems beyond what is required by regulation to identify and assess geohazards, such as the use of LiDAR, strain gauges, and slope inclinometers.

- Deepened their public awareness program to further develop knowledge for relevant authorities and emergency responders at the local, state, and federal levels.

PHMSA held hearings to discuss remedial actions and penalties, and the operator agreed to address the conditions outlined in a Consent Agreement dated 24 March 2023 (PHMSA, 2023a). Within the agreement, four specific paragraphs of “Compliance Requirements” were provided to the operator. They involved improvements to geohazard identification, higher accuracy dispersion modelling, closer communication with agencies and emergency responders at local, state, & federal levels, and improvements to the operator's Patrolling and Leak Detection procedure.

The event has resulted in a re-examination of industry best practices at all levels to reduce risk and ensure public safety, including new rulemaking and research by PHMSA.



POST RELEASE ACTION(S)	UNDERTAKEN BY	STATUS
Soliciting Research to Strengthen Pipeline safety for CO_2 pipelines	PHMSA	Complete*
Completing a Failure Investigation Report	PHMSA	Complete
Issuance of an updated Nationwide Advisory Bulletin to all pipeline operators regarding land movement and geohazards	PHMSA	Complete
Issuance of Notice of Probable Violation	PHMSA	Complete
Entered a Consent Agreement finalizing Compliance Requirements and Civil Penalty	PHMSA and Denbury Gulf Coast Pipelines	Complete
Compliance Requirements from the Consent Order dated 24 March 2023	Denbury Gulf Coast Pipelines	Complete
Initiating New Rulemaking to Update Standards for CO_2 Pipeline	PHMSA	In Progress
Providing Research Results to Strengthen Pipeline Safety for CO_2 Pipelines ("Determination of potential impact radius for CO_2 pipelines using machine learning approach.") **	PHMSA & Texas A&M University	In Progress
Pore space ownership and mineral rights	Local, State, and Federal Government (if Federal lands)	Determined by State-specific law, Federal agency managing Federal Lands to be used
CO_2 injection (and sequestration) permitting	State and/or Federal Government (some states have primacy for Class VI permitting)	State Environmental Department, US Environmental Protection Agency

* First research solicitation is complete, but additional research solicitations will be issued.

** See also: *Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2* and *PHMSA Safety Research Announcement #693JK324RA0001.*

Table 4. Summary of actions undertaken following the CO_2 release incident near Satartia, Mississippi.

It is important to review incidents and update regulations and standards to ensure failures are not repeated. The Satartia event was determined to result from soil movement, which could apply to any pipeline (CO_2 and other fluids). PHMSA referenced this in an advisory bulletin on soil movement sent to all pipeline operators following the Satartia incident.

PHMSA's response to this incident aims to strengthen safety measures and is supported by industry groups. PHMSA's safety data show that CO_2 pipelines in the US have had lower rates of failure compared with other hazardous liquid pipelines and can be operated safely using best practices.

3.9 Emergency Response

An unintentional release of CO_2 will present emergency response circumstances that differ from responses to more common products, such as natural gas, crude oil, gasoline, and others. Emergency responders must consider a range of risks including, but not limited to asphyxiation hazards, CO_2 vapor dispersion, and effects on internal combustion engines. While CO_2 does not present a flammability risk, operators and first responders should follow outreach strategies outlined below to educate communities about the risks of CO_2 exposure, plans in place to address CO_2 release incidents, and offer actions the public can take to ensure their safety in the unlikely event that a CO_2 release occurs.

3.9.1 Stakeholder Outreach

Operators transporting CO_2 through pipelines are obligated to conduct outreach and awareness efforts with stakeholders along the pipeline's route. The objective is to educate the affected public, emergency responders, public officials, etc., on how to identify a release of CO_2 and assist in enacting the proper response procedures.

Operators should also familiarize themselves with potential public gathering centers such as schools, hospitals, and others along their pipeline rights-of-way. They should proactively devise a plan of action for a large-scale pipeline release in collaboration with local emergency response officials. When developing a course of action with local emergency response officials, the following factors should be taken into account:

- Ability to safely evacuate people from the school, hospital, or other place of gathering
- Visibility limitations caused by the vapor cloud and risk of driving or walking into the vapor cloud
- Potential of vehicles stalling in the dense vapor cloud and increasing exposure to the released CO_2
- Effectiveness of sheltering in place, making sure people stay off the ground or move to an upper floor of a building and not into a basement or low area where CO_2 may enter a building and collect
- Communicating with and educating emergency response personnel who may respond to a release and also responders outside the community but could ultimately respond to a release.

Federal regulation requires pipeline operators to develop and implement a public awareness program. One of the traditional methods of complying is mailing materials with educational information about the location, product, and ownership of pipelines in a given geographic area. As an example, the Dakota Gasification company has developed this brochure to help inform the public where it operates.

Additional information on community engagement and stakeholder outreach is provided in Section 4.

3.9.2 Emergency preparedness and response

A manual of written procedures that encompasses not only the execution of normal operations and maintenance activities but also the management of abnormal operations and emergencies is required for each pipeline system. This includes the capacity to respond to events and collaborate with local, state, and federal response agencies to effectively minimize public exposure. The procedures, typically consolidated into an emergency response plan, should be designed to enable the pipeline operator to simultaneously achieve multiple objectives in a timely manner.

The Incident Command System (ICS) is used by public agencies to manage emergencies per the requirements of the National Incident Management System (NIMS). ICS can be used by private-sector businesses to work together with public agencies during emergencies such as CO_2 pipeline releases. As a result, operators and their personnel should be familiar with the fundamental concepts of the Incident Command System to help coordinate planning and incident management with public emergency services and agencies.

3.9.3 Technical aspects

A pipeline failure requires immediate and effective actions to control and isolate the pipeline. The longer the CO_2 release continues, the higher the risk of public exposure to high concentrations of CO_2. Operators use several methods adapted from natural gas pipelines to detect CO_2 leaks (Table 5).

LEAK DETECTION METHOD	COMMENTS
Acoustic Detection	Ruptures generate sound waves travelling rapidly along a pipeline by conduction. Sensors located periodically along the pipeline length can detect such acoustic signals. Not suitable for detecting slow leaks.
Volume/Mass Balance Monitoring	These methods compare the volume or mass of a product at a pipeline origination point with the volume or mass of the product at intermediate or destination points. Volume balance is best for incompressible fluids. Mass balance is best for compressible fluids.
Computational Pipeline Monitoring	A computer algorithmic-based system for detecting hydraulic anomalies in a pipeline. Pressure, temperature and flowrate data are processed via a statistical or machine learning (digital twin) model. Yields a probability of a leak event and expected magnitude. Model outputs in near real-time. More reliable prediction over longer periods of time (esp. for slow leaks).
Atmospheric CO_2 Sensors	Located strategically near locations with higher risk of leakage (e.g. flanges). Can be slowed/impeded by subsoil moisture absorbing CO_2. For very long pipelines, the need for any CO_2 sensors and cabling can be very expensive.
Distributed temperature sensing	CO_2 leaks form cold spots (via Joule-Thomson expansion cooling). Cold spots are detected by thermocouples placed along the pipeline.

Table 5. Pipeline leakage detection methods

CO_2 releases can be stopped or limited by installation of remote emergency shutdown valves near high-consequence areas, equipping pipeline operators with power tools to speed up manual valve closure, and using line break technology in areas with more people or more vulnerability to a pipeline rupture. When remote isolation valves are available, protocols should be in place to enable controllers to verify that there is no flow.

In some cases, controlled venting of CO_2 from the pipeline at a safe location may be needed to lower the pipeline pressure faster and thereby reduce the amount of CO_2 released.

3.9.4 Emergency response guidelines and training

Several initiatives have emerged to help ensure those who may need to respond to an emergency understand how to do so and are properly equipped to manage the unique characteristics of CO_2.

In 2023, the American Petroleum Institute and the Liquid Energy Pipeline Association published the Carbon Dioxide Emergency Response Tactical Guidance Document. This guide, developed with input from the National Association of State Fire Marshals, outlines best practice guidelines for preparedness and initial response to a pipeline release of CO_2. The guide is intended for pipeline operators and response operations personnel and addresses key considerations, including dispersion modelling, leak detection, notification of CO_2 release, and CO_2 pipeline release response actions.

The industry is responding to emergency response needs as well. In collaboration with the National Association of State Fire Marshals and the Texas A&M Extension Services, ExxonMobil delivered the first CO_2 emergency response training for firefighters that followed the Emergency Response Tactical Guidance Document. The training combines practical and theoretical simulations focused on dealing with various pipeline incidents, including a CO_2 release. First responders from Texas, Louisiana, and Mississippi attended several training courses in 2023. Similarly, the National Association of State Fire Marshalls offers such training through its pipeline emergency response training program.

One of the ways to ensure the effective communication of emergency response procedures is to conduct drills with pipeline operators and the relevant emergency responders. These drills are essential for high-consequence areas and help ensure pipeline operators are well-prepared and rehearsed in the necessary response actions. Pipeline operators can practice and refine their response strategies alongside emergency responders by engaging in drills and exercises.

4.0 THE NEED FOR COMMUNITY ENGAGEMENT

4.1 Introduction

Although CCS is not a new technology, it is a new concept to many people. Therefore, public skepticism about CCS or CO_2 pipelines is understandable, particularly in cases where communities have experienced negative impacts from other industrial project development (See Environmental Justice inset box below). The combination of a lack of readily available, technically accurate, and easy-to-understand information about CCS has led to a commensurate lack of CCS understanding and misperceptions about CO_2 as a substance, CCS projects, and CO_2 pipelines.

Evidence suggests community understanding is low even in cities bolstered by the energy industry, such as Houston, Texas. In June of 2023, Air Alliance Houston published results from a qualitative survey of community knowledge and perspectives about carbon capture technology (Air Alliance Houston, 2023). Although the survey comprised only 49 respondents from residents across Houston, more than half (58%) ranked their confidence in their understanding of carbon capture technology below the midline value (i.e., five or less, on a scale from one to 10, with 10 being very confident). An older but more representative national study conducted in 2018 shows similar results. Among 1,520 American residents surveyed, **57% of respondents had never heard about CCS**, 24% were unsure, and only 19% stated they had heard about CCS before (Pianta et al., 2021).

Therefore, project developers and operators must build and implement robust community engagement plans that include listening to communities, addressing their concerns, and educating them about CCS and potential projects in their communities. This section will describe common concerns expressed by communities, recommended practices for community engagement, and the benefits CCS projects can bring to communities.

4.2 Community Concerns

Community concerns about CO_2 pipeline development are varied and can differ by region. For example, agricultural communities in the Midwest US have concerns unique to their regional land use. At hearings held by the North Dakota Public Service Commission and Iowa Utilities Board regarding a pipeline project under development by Summit Carbon Solutions, community members raised the potential for negative economic impacts on property values and investments (Eller, 2023b; North Dakota PSC, 2023). Community concerns in the North Dakota hearing included the possibility of damage to underground drain tile systems and the ability to obtain liability insurance (North Dakota PSC, 2023).

Other concerns, however, transcend geography and CCS technology. Communities across the country, and even the globe, share a general resistance to energy infrastructure projects, including renewable energy projects in their "backyard." This sentiment is reflected in a study by Eisenson (2023), which documents at least 228 local restrictions and nine state-level restrictions capable of blocking renewable energy projects, including solar, wind, geothermal, and renewable electricity transmission projects. Eisenson (2023) also found that 293 renewable energy projects across 45 states have encountered significant opposition.

Communities also express general concern about CO_2 pipeline safety. The CO_2 pipeline failure in Satartia, Mississippi, described in Section 3.8, has caused some people in the US to fear the same or similar incident will happen in their community. Residents of Louisiana expressed such concerns during public hearings held by the US EPA in June 2023 for the proposed decision to approve Louisiana's Class VI Underground Injection Control (UIC) primacy application (Louisiana was granted Class VI primacy under the UIC program on December 28, 2023).

Another concern expressed by communities relates to the use of **eminent domain laws**. In most US States, eminent domain laws can allow CO_2 pipeline companies to obtain an easement or a full title to a property in cases where the project provides a public benefit and after paying just compensation to the property owner (Lockman, 2023; Righetti, 2017). While federal and state eminent domain laws have protections for landowners, states can delegate eminent domain authority to private entities for a valid public purpose.

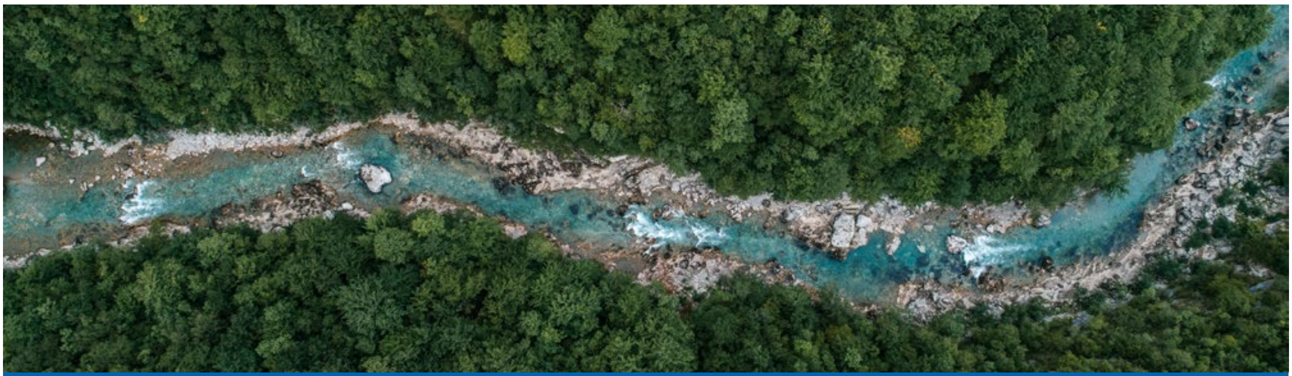
Implementing eminent domain laws for CO_2 pipeline development can be controversial and is a state-level legal decision because the US federal government has no siting authority for CO_2 pipelines other than rights-of-way on federal lands (see Section 2.1) (Righetti, 2017). North Dakota and Iowa landowners have been vocal in opposition to using eminent domain to develop pipeline projects in their states. A recent survey of 805 Iowa adults showed that 78% of Iowan respondents oppose using eminent domain to build CO_2 pipelines (Eller, 2023a).

Some community resistance to CO_2 pipelines and CCS projects stems from climate skepticism and circulated misinformation about CCS. Individuals who don't believe there is a need to take action to address climate change or that CCS doesn't work may not support or actively oppose CO_2 pipeline projects.

This underscores the need for operators and regulators alike to include education and provide accurate and up-to-date information in their community engagement. Careful consideration of language and audience knowledge is essential when conducting education sessions. To those outside of scientific institutions or industry, words or phrases such as "**supercritical CO_2**," "**well abandonment**," or even the word "**plume**" may not be well understood and leave audiences confused or, even worse, fearful of things that do not pose a risk. It is critical for any person working with a community, including regulators and operators, to be sensitive to the layperson's perspective and potential misunderstanding of industry jargon.

Some opponents to CO_2 pipelines argue they are simply a means to perpetuate the use of fossil fuels in the global energy system. For example, in Louisiana, where predominantly African American communities co-located with petrochemical facilities have collectively been given the name "Cancer Alley" due to their higher rates of cancer risk, opposition to carbon capture projects is strong because some fear the technology will only extend the life of an industry they want to phase out (James et al., 2012; Puko, 2023).

All of these concerns underscore the need for robust community engagement and education. Governments, industry, academia, research institutions, and non-governmental organizations all share the responsibility to reduce bias, provide technically accurate and transparent access to project information, and increase confidence in the information that is provided.



ENVIRONMENTAL JUSTICE (EJ) AND CURRENT FEDERAL EJ INITIATIVES

In many communities across the US, there is a record of injustice, including environmental pollution, discriminatory practices, such as redlining[5], and economic disinvestment. Various communities have protested these injustices and called for change. Agyeman et al. (2016) provide several examples:

- In the 1970s, -80s, and -90s, African American communities protested the disproportionate siting of toxic waste facilities in their communities
- Native American communities protested the infringement and desecration of sacred sites, land appropriation, sovereignty threats, and loss of traditional fishing, hunting, and gathering rights
- Latino communities protested unsafe workplace practices, particularly farmworker exposure to pesticides

Collectively, these events contributed to what has grown into today's Environmental Justice Movement.

Researchers have since studied and described how these communities have been repeatedly exposed to environmental and social stressors, which are compounded by climate change. This pattern results in **cumulative impacts**, such as poorer health outcomes compared to other communities, increased susceptibility to damage caused by climate change, and a reduced ability to cope and recover from that damage (Islam & Winkel, 2017; Lee, 2020; Morello-Frosch et al., 2011).

Calls for change are increasing and manifesting in multiple forms. Corporations are now expected to publicly report their environmental, social, and governance (ESG) performance. Non-governmental organizations are establishing entities, such as the Frontline Resource Institute, focused on empowering frontline communities with the resources, funding, and technical assistance needed to advance Environmental Justice (FRI, 2023). And US local, state, and federal governments are establishing new policies and regulations to address Environmental Justice in communities across the US.

Definitions of Environmental Justice vary among scholars, organizations, and governments. For this paper, we use the definition provided by the current Administration.

On April 21, 2023, the current Administration issued Executive Order (E.O.) 14096, defining **Environmental Justice** as,

"...the just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other federal activities that affect human health and the environment so that people:

(i) are fully protected from disproportionate and adverse human health and environmental effects (including risks) and hazards, including those related to climate change, the cumulative impacts of environmental and other burdens, and the legacy of racism or other structural or systemic barriers; and

(ii) have equitable access to a healthy, sustainable, and resilient environment in which to live, play, work, learn, grow, worship, and engage in cultural and subsistence practices."

[5] Redlining is the policy or practice of denying credit or providing credit on more onerous terms to people in particular neighborhoods for reasons unrelated to creditworthiness such as their race or ethnicity (Squires & Woodruff, 2019).

4.3 Recommendations and Requirements for Community Engagement

4.3.1 Industry Recommendations

The American Petroleum Institute (API) has developed guidance for effective pipeline public engagement. The API Recommended Practice (RP) 1185, Pipeline Public Engagement, is a consensus document drafted with input from members of the public, government, and industry. RP 1185's guidelines for community engagement were reviewed by the US DOE and are based on the following core principles (Minifie, 2023):

- **Openness and Transparency:** frank discussion, sharing of truthful, timely, and relevant information, and willingness to listen and learn and nurturing an environment of transparency
- **Respect:** considering and respecting others' points of view by listening to questions, understanding concerns, and allowing each other to share perspectives
- **Reciprocity:** communication and action for mutual benefit, listening as well as speaking, being responsive to inquiries and interests, and sharing responsibility for interactions and relationships
- **Inclusiveness:** a deliberate effort to involve parties interested in the subject or action
- **Accessibility:** commitment to provide a variety of methods and opportunities for all interested stakeholders to participate
- **Equity:** deliberation and decision-making that take into account the needs, circumstances, and resources of all stakeholders

The RP 1185 framework comprises six engagement elements intended to be applied throughout the pipeline lifecycle, from early siting and design through abandonment or decommissioning. The six engagement elements are:

- **Commit and Align** – describes how operators, through their management, demonstrate the organization's commitment to stakeholder engagement
- **Identify, Understand, and Confirm** – describes stakeholders who should be engaged
- **Plan and Prepare** – describes how operators get ready for stakeholder engagement activities
- **Share Information** – describes what operators should share as part of baseline information
- **Ask, Listen, and Respond** – describes how operators will engage with stakeholders
- **Monitor, Evaluate, and Adjust** – describes how operators assess, document, verify, and improve stakeholder engagement performance

RP 1185 provides additional detailed guidance for each of these six elements. The report also provides descriptions of stakeholders and examples of community engagement methods.

4.3.2 Federal Agency Guidance and Requirements

Federal agencies are providing Environmental Justice guidance or establishing Environmental Justice requirements, both of which include community engagement in response to Executive Orders issued by the current Administration.

Executive Order (E.O.) 14096 enacted several policies aimed at building a whole-of-government effort to address Environmental Justice, including adding Environmental Justice to each government agency's mission and creating a new White House Office of Environmental Justice. This builds on earlier Executive Orders, including Executive Order 14008, which established the **Justice40 Initiative** in January of 2021.

The Justice40 Initiative seeks to ensure 40 percent of the overall benefits of certain federal investments – including, but not limited to, clean energy and the reduction of legacy pollution – flow to disadvantaged communities (Exec. Order No. 14008, 2021). Described as a whole-of-government approach, the Justice40 Initiative covers hundreds of federal funding programs across all major government agencies, including the Department of Energy (US DOE), and billions of dollars of funding made available through the 2021 Infrastructure Investment and Jobs Act (also known as the Bipartisan Infrastructure Law) and the 2022 Inflation Reduction Act (The White House, 2023).

Under the Justice40 Initiative, applicants for funding opportunity announcements (FOAs) and loans through the US DOE are required to submit a **Community Benefits Plan (CBP)**. CBPs must prioritize the following four core policies (US DOE, 2023a):

1. Engaging communities and labor
2. Investing in America's workforce
3. Advancing diversity, equity, inclusion, and accessibility, and
4. Implementing the Justice40 Initiative

Although CBPs are intended to be flexible to allow applicants to generate the best plans for their projects, they must be specific, actionable, and measurable.

For example, the Justice40 Implementation section of a CBP must identify the disadvantaged communities to which project benefits will flow, how and when those anticipated benefits will flow, and discuss the anticipated negative and cumulative environmental impacts a project will have on applicable disadvantaged communities (US DOE, 2023a).

Community benefits plans typically comprise 20% of an overall US DOE grant application technical merit score and are a significant factor in determining funding awards. In addition to specific, actionable, and measurable goals, features of high-scoring CBPs include (Climate Now, 2023):

- Mechanisms for accountability and transparency
- Clear metrics to measure success
- Matching proposed actions to community needs and priorities
- Robustly addressing the four core policy areas (above)
- Minimizing and mitigating negative impacts and harm
- Creation of quality jobs, equitable access, and investment in workforce development

Conversely, low-scoring CBPs (Climate Now, 2023):

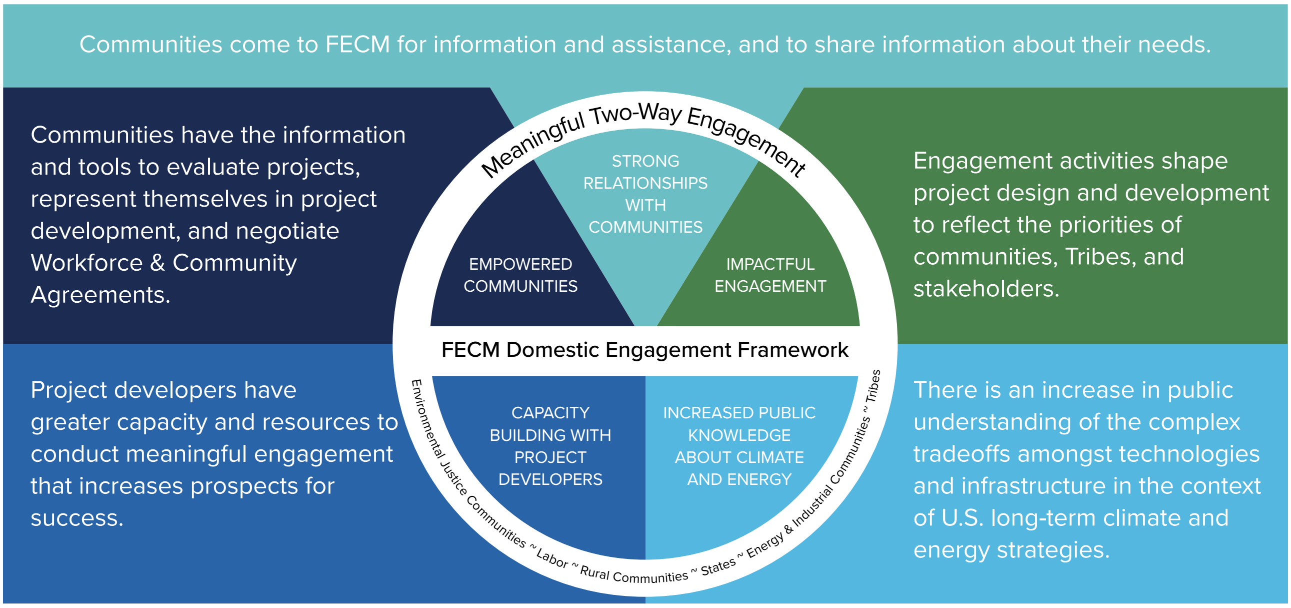
- Do not reflect an understanding of local context or history
- Narrowly focus on certain types of stakeholders
- Rely on one-way information sharing
- Inadequately resource implementation steps
- Lack specificity and accountability regarding diversity, equity, inclusion, and accessibility commitments and benefits

More information about CBPs can be found at the US DOE website here, and a template for drafting a standard CBP for funding opportunity announcements (FOAs) is available for download from the US DOE here.

To help project developers build their community engagement strategy, the US DOE Office of Fossil Energy and Carbon Management (FECM) has released a framework outlining its vision for meaningful two-way community engagement (US DOE, 2022a). The framework involves five principles described in Figure 10.

In March of 2023, the White House Council on Environmental Quality (CEQ) *announced* members of two task forces charged with enabling the efficient, orderly, and responsible permitting and deployment of CCUS projects and CO_2 pipelines in the US. The first task force meeting will take place in May 2024. The task forces are required by the Utilizing Significant Emissions with Innovative Technologies (USE IT) Act, passed in 2020.

Vision for Successful Engagement



PRINCIPLE	DESCRIPTION OF PRINCIPLE	EXAMPLES OF PRACTICES
Two-way engagement	Dialogue where there is back-and-forth, open and equal exchange	Listening sessions and working with community groups to develop and conduct engagement
Proactive, early engagement	Involve the community early so that the project design can reflect community input at the outset of the project, improve design, and minimize disruptions	Reaching out to communities for dialogue before project characteristics are set; inviting a community advisory board
Place-based engagement	Ensure place-based energy solutions by considering the unique circumstances, geographies, resources, priorities, and desires of the people living there	Participatory mapping with community members to understand what is unique about their community, including existing burdens and areas of cultural importance
Community-based knowledge	Support communities in collecting and modeling data on carbon management projects and energy pathways	Working with educational and community-based organizations to gather and analyze data
Build engagement capacity	Pursuing capacity-building opportunities that help others like universities, non-profits, and other federal agencies scale engagement activities	Creating technically accurate materials that organizations can use when conducting engagement; sharing information on regulatory engagement opportunities

Figure 10. US DOE FECM framework for domestic community engagement. Source: (US DOE, 2022b)

Additionally, in July of 2023, the White House CEQ issued a proposal for the Bipartisan Permitting Reform Implementation Rule, requiring agencies to consider Environmental Justice and the cumulative impacts of pollution in environmental reviews (CEQ, 2023). In August of 2023, the US Environmental Protection Agency (EPA) followed with a [Memorandum on Environmental Justice Guidance for UIC Class VI Permitting and Primacy](#) (so-called Class VI well permitting under the EPA's Underground Injection Control Program, UIC) (US EPA, 2023). While separate from CO_2 pipelines, CO_2 injection wells are linked to pipelines; therefore, these EPA guidelines bear on CO_2 pipeline development projects. The Memorandum presented five themes for states, tribes, and permit applicants and operators to incorporate into their well or primacy programs (primary enforcement authority under the UIC program):

1. Identify communities with potential Environmental Justice concerns
2. Enhance public involvement
3. Conduct appropriately scoped Environmental Justice assessments
4. Enhance transparency throughout the permitting process
5. Minimize adverse effects to underground sources of drinking water (USDWs)

4.4 CCS and CO_2 Pipeline Co-Benefits

CCS projects can provide benefits to communities, ranging from potential improvements to air quality to economic improvements.

New research by the Great Plains Institute and Carbon Solutions, LLC, suggests the CCS projects linked to, and enabled by, CO_2 pipelines may have positive impacts on local air quality (Bennett et al., 2023). CO_2 emissions from existing point-source facilities are often accompanied by other air pollutants ("co-pollutants"), such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter ($PM_{2.5}$). In addition to reducing CO_2 from emissions streams at point-source facilities, CCS technology can reduce air pollution if the equipment to remove co-pollutants is installed during carbon capture retrofit. Bennett et al. (2023) considered changes in adult and infant mortality and asthma exacerbations due to the reduction of NO_x, SO_2, and $PM_{2.5}$ co-pollutants, as well as the economic impact of all health benefits modeled by the US EPA CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). The study only considered a limited number of facilities (54) but found that co-pollutant removal resulted in positive health benefits in all industries and regions, with an economic value ranging from $6.8 to $481 million US dollars per year for each region (Bennett et al., 2023).

A similar study by the Clean Air Task Force (CATF) found similar co-benefits. CATF considered the impact of adding carbon capture technology to two cement facilities and two refinery facilities on conventional air pollution (CO_2, NO_x, SO_2, and $PM_{2.5}$). Results varied depending on the facility type and existing emissions profile; however, in all cases, modeled CO_2 emissions were reduced by close to 90%, SO_2 emissions were nearly eliminated, and particulate emissions were cut by more than 90% (Brown et al., 2023). Impacts of NO_x emissions were minimal at the cement facilities but were reduced at the refinery facilities. While the study is limited to a desktop analysis, the modeled reductions in conventional air pollutants resulted in reduced annual mortality according to the same COBRA tool used in the GPI study by Bennett et al. (2023). Reduced mortality was highest for facilities with high emissions rates and close proximity to populated areas.

Another recent study found that developing a local CCS market can have a significant positive economic impact on communities. Dismukes et al. (2023) studied the economic impacts of construction and maintenance of the Gulf Coast Sequestration (GCS) CCS hub project planned for Calcasieu Parish in southwest Louisiana. The GCS project comprises three phases and will collectively capture and store 300 $MtCO_2$ from regional industrial CO_2 emitters. Phase I is expected to be operational in 2025.

Dismukes et al. (2023) estimate construction and operation of the GCS CCS hub will provide the following economic benefits:

- The potential to abate $11.3 billion of climate damage (social cost of greenhouse gases) over the project's 30-year life
- Net present value (NPV) payment of $560 million in earnings and $980 million in Gross State Product (including Texas and Louisiana)
- NPV payment of $698 million in earnings and $1.2 billion in US Gross Domestic Product

- $43 to $71 million in tax revenue to Calcasieu parish (NPV at 8% and 2% discount rate, respectively)
- 977 regional jobs and 1149 national jobs during project construction
- 268 regional jobs and 375 national jobs during project operations
- The potential decarbonization of 6500 jobs

In addition to providing positive economic impacts on communities, pipeline and CCS projects can help safeguard local industries and skilled labor forces. Skills developed by geoscientists, engineers, and operations and maintenance workers in the fossil fuel industry are directly transferrable to the CCS industry. Their skills are, in fact, vital to the CCS industry. Project Cypress, for example, is a planned DAC project in Calcasieu Parish, Louisiana, which is expected to generate 2,300 jobs and aims to hire 10% of its overall workforce from workers formerly employed in the fossil fuel industry (US DOE, 2023d). Similarly, the South Texas DAC Hub project, planned for Kleberg County, Texas, expects to create approximately 2,500 jobs and has agreements to hire locally (US DOE, 2023d).

5.0 CONCLUSIONS

- Alongside new renewable energy production, new energy transmission, and energy storage projects, new CCS project infrastructure – specifically new CO_2 pipelines – must be planned, permitted, and built as rapidly as possible to reach net-zero goals and avoid the worst impacts of climate change. Models estimate the current CO_2 pipeline network needs to increase in size by four to 18 times by 2050 to meet the CO_2 transportation demand of a net-zero economy. **The US must build its way to net-zero.**

- Barriers to CO_2 pipeline deployment, such as complex permitting processes, a large queue of CO_2 injection well permit applications and lack of staff within relevant authorities can delay projects, resulting in unabated CO_2 emissions. The Institute estimates that cumulative unabated CO_2 emissions from facility retrofits in the US could reach 91 Mt by 2030 if permitting delays announced projects and projects in development by just one year.

- CO_2 transportation via pipeline is well-understood and regulated. State and federal regulations include significant safety standards governing pipeline design, construction, and operations. Additionally, PHMSA is developing new safety rules for CO_2 pipelines, expected in 2024. For more than 50 years, CO_2 pipelines have been operating in the US with zero fatalities.

- Early and sustained community education and engagement is critical to any CCS project. Studies suggest the general public is unfamiliar with CCS, so CCS project operators, government officials, and community stakeholders should utilize published Environmental Justice tools and community engagement guidelines to improve CCS understanding during project development. Failure to engage communities, or conducting ineffective community engagement, can result in opposition to projects.

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APPENDIX 1 LISTING OF PIPELINE LEGISLATION BY US STATE

Hyperlinks to legislation are sourced directly from PHMSA. An asterisk (*) next to a state's name implies that one or more hyperlinks may not be current because PHMSA has not updated its records (Pipeline & Hazardous Materials Safety Administration & US Department of Transportation, 2023).

STATE	LEGISLATION
Alabama	Alabama Statutes (See Sections 37-4-80 and 37-4-90)
Alaska	OPS inspects and enforces the pipeline safety regulations for interstate and intrastate gas and hazardous liquid pipeline operators in Alaska.
Arizona	See Title 40, Chapter 2, Article 10, Sections 40-441 - 40-442
Arkansas	Arkansan Statutes (See Title 23, Chapter 15, Subchapter 2)
California	No data
Colorado	Colorado Statutes
Connecticut	Connecticut Statutes
Delaware	Delaware Statutes
District of Columbia	District of Columbia Statutes (See Title 34, Subtitle IV, Chapter 34-16)
Florida	Florida Statutes (See Chapter 368 of Title XXVII)
Georgia	Georgia Statutes
Hawaii	OPS inspects and enforces the pipeline safety regulations for Hawaii's interstate and intrastate gas and hazardous liquid pipelines.
Idaho	Idaho Statutes
Illinois	Illinois Statutes
Indiana	Indiana Statutes
Iowa	Iowa Statutes
Kansas	Kansas Statutes
Kentucky	Kentucky Statutes (see Kentucky Revised Statutes (KRS) Chapter 278)
Louisiana	Louisiana Statutes
Maine	Maine Statutes
Maryland	Maryland Statutes
Massachusetts	Massachusetts Statutes
Michigan	Michigan Statutes

STATE	LEGISLATION
Minnesota	Minnesota Statutes (M.S. 216D)
Mississippi	Mississippi Statutes (See Title 77)
Missouri*	Missouri Statutes
Montana	Montana Statutes
Nebraska	Nebraska Statutes (See Revised Statutes 81-542 to 81-550)
Nevada	Nevada Statutes
New Hampshire	New Hampshire Statutes
New Jersey	New Jersey Statutes (See Statutes, Title 48)
New Mexico	New Mexico Statutes (See Chapter 62 NMSA Unannotated)
New York	New York Statutes
North Carolina*	North Carolina Statutes
North Dakota	North Dakota Statutes
Ohio*	Ohio Statutes
Oklahoma*	Oklahoma Statutes
Oregon	Oregon Statutes
Pennsylvania	Pennsylvania Statutes
Rhode Island	Rhode Island Statutes (See Titles 39 and 42, Chapter 42-14.3)
South Carolina	South Carolina Statutes
South Dakota	South Dakota Statutes
Tennessee	Tennessee Statutes (See Title 65, Chapters 1, 28, and others)
Texas	Texas Statutes (See "Utilities Code" Titles 3 & 5)
Utah	Utah Statutes
Vermont	Vermont Statutes
Virginia	Virginia Statutes
Washington	Washington Statutes
West Virginia	West Virginia Statutes
Wisconsin	Wisconsin Statutes
Wyoming	Wyoming Statutes
Puerto Rico (US Territory)	Puerto Rico Statutes

APPENDIX 2 LISTING OF PIPELINE REGULATIONS AND ASSOCIATED AGENCIES BY US STATE

Hyperlinks to regulations and state agencies are sourced directly from PHMSA. An asterisk (*) next to a state's name implies that one or more hyperlinks may not be current because the PHMSA has not updated its records.

STATE	REGULATION	STATE AGENCY
Alabama	Alabama Pipeline Safety Regulations/Rules	Energy Division of the Alabama Public Service Commission
Alaska	No data	Joint Pipeline Office (JPO)
Arizona	Arizona Pipeline Safety Regulations/Rules	Pipeline Safety Section of the Arizona Corporation Commission
Arkansas	Arkansas PSC Pipeline Safety Regulations/Rules Arkansas Oil & Gas Commission Regulations/Rules	Pipeline Safety Office of the Arkansas Public Service Commission Arkansas Oil and Gas Commission (Reference 49 CFR §192.9)
California	California PUC Pipeline Safety California OSFM Pipeline Safety Regulations/Rules	California Public Utilities Commission (CPUC) California Office of the State Fire Marshal (OSFM)
Colorado	Colorado Pipeline Safety Regulations/Rules (See Department 700, Agency 723, CCR Title: 4 CCR 723-4)	Colorado Public Utilities Commission's (COPUC) Gas Pipeline Safety Section (GPS)
Connecticut	Connecticut Pipeline Safety Regulations/Rules	Connecticut Public Utilities Regulatory Authority
Delaware	Delaware Pipeline Safety Regulations/Rules	Delaware Public Service Commission
District of Columbia	District of Columbia Pipeline Safety Regulations/Rules	District of Columbia Public Service Commission
Florida	Florida Pipeline Safety Regulations/Rules	Florida Public Service Commission
Georgia	Georgia Pipeline Safety Regulations/Rules	Facility Protection Unit of the Georgia Public Service Commission
Hawaii	OPS inspects and enforces the pipeline safety regulations for Hawaii's interstate and intrastate gas and hazardous liquid pipelines.	
Idaho	Idaho Pipeline Safety Regulations/Rules	Gas Pipeline Safety Division of the Idaho Public Utilities Commission

STATE	REGULATION	STATE AGENCY
Illinois	Illinois Pipeline Safety Regulations/Rules	Pipeline Safety Division of the Illinois Commerce Commission
Indiana	Indiana Pipeline Safety Regulations/Rules	Pipeline Safety Division of the Indiana Utility Regulatory Commission
Iowa	Iowa Pipeline Safety Regulations/Rules	Safety and Engineering Section of the Iowa Utilities Board
Kansas	Kansas Pipeline Safety Regulations/Rules	Pipeline Safety Section of the Kansas Corporation Commission
Kentucky	Kentucky Pipeline Safety Regulations/Rules (see PSC Regulations (Title 807 of Ky. Administrative Regulations, KAR 5:022 – 5:027)	Kentucky Public Service Commission
Louisiana	Louisiana Pipeline Safety Regulations/Rules	Office of Conservation, Louisiana Department of Natural Resources
Maine	Maine Pipeline Safety Regulations/Rules Maine Laws & Rules	Maine Public Utilities Commission
Maryland	Maryland Pipeline Safety Regulations/Rules	Maryland Public Service Commission
Massachusetts	Massachusetts Pipeline Safety Regulations/Rules	Pipeline Engineering and Safety Division of the Massachusetts Department of Public Utilities
Michigan	Michigan Pipeline Safety Regulations/Rules	Michigan Public Service Commission
Minnesota	Minnesota Pipeline Safety Regulations/Rules Common Ground Alliance	Minnesota Office of Pipeline Safety
Mississippi	Mississippi Pipeline Safety Regulations/Rules	Pipeline Safety Division of the Mississippi Public Service Commission
Missouri*	Missouri Pipeline Safety Regulations/Rules (See Chapter 40)	Missouri Public Service Commission
Montana	Montana Pipeline Safety Regulations/Rules	Montana Public Service Commission
Nebraska	Nebraska Pipeline Safety Regulations/Rules	Nebraska State Fire Marshal
Nevada	Nevada Pipeline Safety Regulations/Rules	Nevada Public Utilities Commission.
New Hampshire	New Hampshire Pipeline Safety Regulations/Rules	Safety Division of the New Hampshire Public Utilities Commission
New Jersey	New Jersey Pipeline Safety Regulations/Rules (See Title 14)	Division of Reliability and Security within the New Jersey Board of Public Utilities.
New Mexico	New Mexico Pipeline Safety Regulations/Rules	Pipeline Safety Bureau in the Transportation Division of the New Mexico Public Regulation Commission

STATE	REGULATION	STATE AGENCY
New York	New York Pipeline Safety Regulations/ Rules	New York Public Service Commission
North Carolina*	North Carolina Pipeline Safety Regulations/Rules	Operations Division, Pipeline Safety Section of the North Carolina Utility Commission
North Dakota	North Dakota Pipeline Safety Regulations/ Rules	North Dakota Public Service Commission
Ohio*	Ohio Pipeline Safety Regulations/Rules	Public Utilities Commission of Ohio
Oklahoma*	Oklahoma Pipeline Safety Regulations/ Rules	Pipeline Safety Department of the Oklahoma Corporation Commission
Oregon	Oregon Pipeline Safety Regulations/Rules	Energy Division of the Oregon Public Utility Commission
Pennsylvania	Pennsylvania Pipeline Safety Regulations/ Rules	Gas Safety Section of the Bureau of Investigation and Enforcement within the Pennsylvania Public Utilities Commission
Rhode Island	Rhode Island Pipeline Safety Regulations/ Rules	Rhode Island Division of Public Utilities and Carriers
South Carolina	South Carolina Pipeline Safety Regulations/Rules	Pipeline Safety Department of the South Carolina Office of Regulatory Staff
South Dakota	South Dakota Pipeline Safety Regulations/ Rules	Pipeline Safety Program of the South Dakota Public Utilities Commission
Tennessee	Tennessee Pipeline Safety Regulations/ Rules	Gas Pipeline Safety Division of the Tennessee Public Utility Commission
Texas	Texas Pipeline Safety Rules° (Texas Administrative Code, Title 16, See Chapters 8 & 18)	Pipeline Safety Department of the Texas Railroad Commission
Utah	Utah Pipeline Safety Regulations/Rules	Pipeline Safety Group of the Utah Division of Public Utilities
Vermont	Vermont Pipeline Safety Regulations/Rules	Vermont Public Utility Commission
Virginia	Virginia Pipeline Safety Regulations/Rules	Division of Utility and Railroad Safety of the Virginia State Corporation Commission
Washington	Washington Pipeline Safety Regulations/ Rules	Washington Utilities and Transportation Commission
West Virginia	West Virginia Pipeline Safety Regulations/ Rules	Gas Pipeline Safety Section of the Engineering Division of the Public Service Commission of West Virginia
Wisconsin	Wisconsin Pipeline Safety Regulations/ Rules	Public Service Commission of Wisconsin
Wyoming	Wyoming Pipeline Safety Regulations/ Rules	Wyoming Public Service Commission
Puerto Rico (US Territory)	Puerto Rico Pipeline Safety Regulations/ Rules	Puerto Rico Public Service Commission

APPENDIX 3 FEDERAL- AND STATE-LEVEL ENVIRONMENTAL JUSTICE MAPPING TOOLS

Visualization Tools

Research shows communities with high social vulnerability tend to have higher pipeline densities than those with lower social vulnerability (Emanuel et al., 2021). To address cumulative impacts and Environmental Justice in planning new projects, we must be able to visualize geographic areas where environmental and social stressors intersect frontline communities. Numerous tools are available from federal and state agencies and academic institutions to assist in this analysis. A selection of these tools is listed below.

Climate and Economic Justice Screening Tool

https://screeningtool.geoplatform.gov/en/

The White House Council on Environmental Equality developed the Climate and Economic Justice Screening Tool in 2021, as directed by Exec. Order No. 14008 (2021). The tool maps indicators of community burdens in eight categories: climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development. Users can use this tool to identify overburdened and underserved communities.

US EPA EJScreen Tool

https://www.epa.gov/ejscreen

The US EPA developed the EJScreen Tool in 2010 and released the tool to the public in 2015. The tool utilizes publicly available demographic, socioeconomic, and environmental data for a given geographic region to calculate an EJ index. The tool includes 13 environmental indicators, seven socioeconomic indicators, 13 EJ indexes, and 13 supplemental indexes. Users can explore indicator maps and produce standard reports for a selected area. This is a screening tool only and is not intended to provide a risk assessment.

PHMSA Disadvantaged Communities Site

https://dac-phmsa-usdot.hub.arcgis.com/

This site plots gas distribution, gas transmission, excavation damage, and hazardous liquid pipeline incidents along with disadvantaged communities in the US. This tool is an outgrowth of the Justice40 Initiative described above.

CalEnviroScreen Tool

https://oehha.ca.gov/calenviroscreen

The CalEnviroScreen Tool utilizes environmental, health, and socio-economic data to score census tracts in California to help identify vulnerable communities disproportionately impacted by multiple sources of pollution.

TOOL	OPERATING BODY
Climate and Economic Justice Screening Tool	White House Council on Environmental Quality
Screening Tool for Equity Analysis of Projects (STEAP)	US Department of Transportation
Energy Justice Dashboard (Beta)	US Department of Energy
NOAA's EJ Tools and Resources	National Oceanic and Atmospheric Administration
Environmental Justice Index	The Centers for Disease Control and the Agency for Toxic Substances and Disease Registry

Additional US federal-level Environmental Justice mapping tools.

STATE	TOOL	OPERATING BODY
California	CalEnviroScreen	California Office of Environmental Health Hazard Assessment
Colorado	Colorado EnviroScreen	Colorado Department of Public Health and Environment
Colorado	Environmental Justice Demo Map	Mapping for Environmental Justice
Connecticut	Connecticut Environmental Justice Communities	Connecticut Department of Energy and Environmental Protection
Delaware	DNREC EJ Area Viewer	Department of Natural Resources and Environmental Control
Illinois	Environmental Justice Communities	Illinois Solar For All
Illinois	Illinois EJStart	Illinois EPA
Indiana	Hoosier Resilience Index	Indiana University
Maryland	MD EJSCREEN	Maryland Environmental Health Network
Maryland	MDE EJ Screening Tool	Maryland Department of the Environment
Massachusetts	Environmental Justice Map Viewer	Massachusetts Department of Environmental Protection
Michigan	Screening Tool for Environmental Justice in Michigan	University of Michigan
Michigan	MiEJScreen	Michigan Department of Environment, Great Lakes, and Energy
Minnesota	Understanding Environmental Justice in Minnesota	Minnesota Pollution Control Agency
New Jersey	New Jersey EJMAP Tool	New Jersey Department of Environmental Protection
New Mexico	EJ Mapping Tool	New Mexico Environment Department
New York	Potential Environmental Justice Areas	New York Department of Environmental Conservation
North Carolina	North Carolina Community Mapping System	North Carolina Department of Environmental Quality
Pennsylvania	Environmental Justice Areas Viewer	Pennsylvania Department of Environmental Protection
Rhode Island	RIDEM Environmental Resource Map	Rhode Island Department of Environmental Management
Utah	Utah Environmental Interactive Map	Utah Department of Environmental Quality
Virginia	Environmental Justice Map	Mapping for Environmental Justice
Washington	Washington Tracking Network	Washington Department of Health

US state-level Environmental Justice mapping tools.

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