Meeting the Dual Challenge:
A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage

Key Excerpts from National Petroleum Council Report:

Chapter 6: CO_2 Transport

The primary mode of large-scale CO_2 transport in the United States today is via pipeline, and in 2017, there were more than 5,000 miles of CO_2 pipelines in operation.

Approximately 90% of the CO_2 pipeline infrastructure in the United States today is used for CO_2 enhanced oil recovery (EOR) operations. These pipelines were constructed to provide a direct link between a CO_2 source and an associated CO_2 sink (a reservoir), creating a pipeline industry that is independent of the ownership of the various assets involved in CO_2 EOR.

Wide-scale deployment of carbon capture, use, and storage (CCUS) across the United States will require expansion of the existing CO_2 pipeline infrastructure through looping, replacement, or other engineering modifications, as well as the construction of new pipelines.

There are several challenges to scaling-up CO_2 transport infrastructure that will need to be addressed to avoid construction delays and cost increases, such as permitting requirements, surface use issues, and environmental group activism. Enabling some form of eminent domain in the states through which construction occurs could help but will not resolve all the issues associated with infrastructure expansion.

Many states have the authority to determine the siting of pipeline infrastructure under the public benefit approach. However, the added cost of construction and the lack of an integrated CO_2 pipeline network will likely be one of the major hurdles for wide-scale deployment of CCUS in the United States.

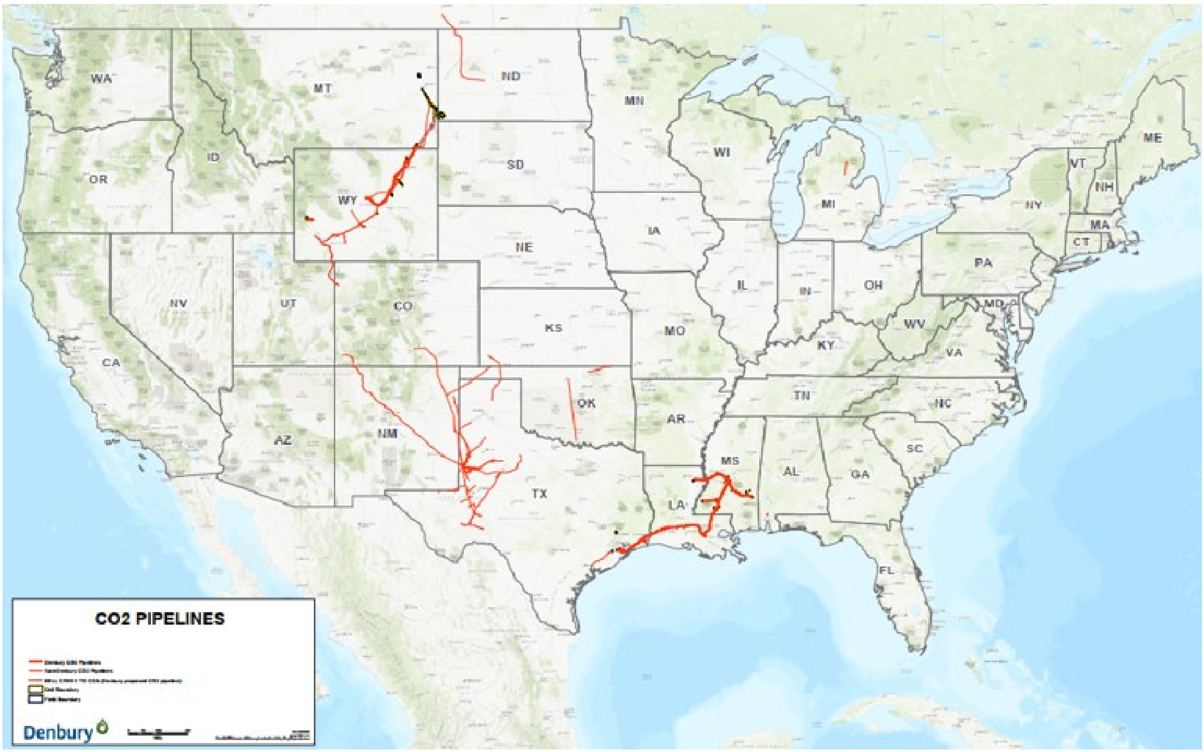

Figure 6-2. CO_2 Pipeline Infrastructure in the United States in 2019
Source: Denbury Resources, Inc.

STATUS OF TRANSPORT TECHNOLOGY

Current CO_2 Transport Options

Aligning regulatory requirements and government incentives with environmental, operational, and financial risks would enable an increase in the captured industrial or combustion CO_2 volumes that could be captured, stored, and used.

Pipeline transportation of CO_2 over longer distances is most efficient and economical when the CO_2 is in the dense (liquid) phase. This means that the pressure in the pipeline must be kept at 1,080 psi and above. CO_2 must also be dehydrated to avoid corrosion of the pipeline.

The cost of CO_2 transport by truck and rail ranges from three to 10 times more per metric ton than by pipeline transport due to economies of scale.

Large-Volume CO_2 Transport via Pipeline

The goal of expanding the $CO_2$2 pipeline network to support wide-scale deployment of CCUS in the United States is one that hinges upon creating favorable economic conditions and permitting regulations. This expansion would need to increase by at least an order of magnitude in the next decade to transport the hundreds of thousands of tonnes of captured industrial or combustion source CO_2 needed to support wide-scale deployment.

Several regions in the United States have large CO_2 pipeline networks, including the Permian Basin, the Gulf Coast, and the Rocky Mountain area. The Permian Basin has the most extensive network. Companies transport nearly 2 BSCF/D (38 Million Tonnes per Annum or Mtpa) of CO_2. "Tonnes" means metric tons.

Kinder Morgan's longest CO_2 pipeline, the Cortez Pipeline, stretches 500 miles from southwestern Colorado to Denver City, Texas, and can transport 1.5 BSCF/D (28 Mtpa). Occidental Petroleum operates the Sheep Mountain and Bravo Dome Pipeline networks, which extend over 500 miles with capacity of nearly 0.7 BSCF/D (13 Mtpa).

RECENT PIPELINE CONSTRUCTION METRICS

In the past 10 years, the construction of CO_2 pipeline infrastructure in the United States has been limited to establishing point-to-point pipelines that connect an identified source of CO_2 to the corresponding sink(s) where the CO_2 is used for either EOR or industry. The Greencore Pipeline is built across private ranchland as well as state and public lands in Wyoming and Montana and cost $68,635 per diameter inch mile. Contrast this with the Webster Pipeline built in a highly concentrated industrial and suburban area just south of Houston, Texas, that cost $199,176 per diameter inch mile. The reason for this broad range in pipeline cost relates to the construction challenges from different types of terrain or conditions (wetlands, flat or mountainous, urbanization) and right of way concerns that restrict access due to pipeline or utility corridors.

TRANSPORT OPTIONS AND CO_2 QUALITY SPECIFICATIONS

CO_2 Pipelines in the United States

PHMSA sets the standards for safe construction and operation of CO_2 pipelines, including technical design specifications and the requirements for mechanical integrity management. States can act as the pipeline regulator if, at a minimum, their regulations comply with federal regulation. The majority of CO_2 pipeline routing, however, is dependent on state law.

To minimize costs, commercial CO_2 pipelines typically operate at pressures between 1,200 pounds per square inch gauge (psig) and 2,200 psig, with some pipelines having a maximum operating pressure of 2,500 psig to 2,800 psig. At these pressures, CO_2 is in a dense phase - either as a liquid or a supercritical fluid - depending on the temperature of the fluid in the pipeline. A dense phase fluid demonstrates properties of both a liquid and a gas. For dense phase CO_2 its density is like a liquid, which results in increased flow capacity for the pipeline. This flow capacity enables use of higher efficiency pumps, instead of compressors, to recover pressure losses in the pipeline due to friction and elevation changes.

Gas compression is used in the natural gas and process industries. CO_2 compression equipment is similar to the equipment used for natural gas, but the chemical and physical properties of CO_2 require modifications to compressor design, construction materials, and sizing. Factors such as water content and corrosivity, discharge pressures, and inlet volumes may require different combinations of equipment and processes. The equipment can be powered by electricity, natural gas or diesel engines, steam, or a combination of these. Many factors must be considered when choosing which equipment may be the best fit.

CO_2 pipelines are built using externally coated steel line pipe in accordance with PHMSA regulations. CO_2 composition quality specifications have been established to avoid pipeline corrosion. If liquid water is not present, the CO_2 is not corrosive and will not form corrosive products. Accordingly, CO_2 is dehydrated before introduction into pipelines. Oxygen and hydrogen sulfide concentrations are controlled to remain below the levels that can cause corrosion or stress cracking in the specific grade of steel used in the pipeline. In addition to external coatings, cathodic protection is also used to protect the pipelines from external corrosion.

In 2019, more than 3.5 billion cubic feet of CO_2 was transported daily in the United States, equivalent to 66 Mtpa. The majority of CO_2 transported by pipeline is used in the EOR industry and travels in more than one pipeline during the journey from its source to a destination.

Is Repurposing Natural Gas Pipelines an Option?
The use of an existing natural gas pipeline is not a practical option for CO_2 transport for large flow rates of 1 BSCF/D (19 Mtpa) or more over long distances of hundreds of miles and more. Existing natural gas pipelines have a maximum pressure rating of 1,480 psig, which are defined by the American National Standards Institute (ANSI) as Class 600 pipelines. A pipeline built for CO_2 service is designed for 2,200 psig, which is an ANSI Class 900 pipeline. There are a few examples of an existing pipeline that was converted to CO_2 service for lower flow rates and/or shorter distances (less than 100 miles). For longer distances, however, the lower rating of an existing gas pipeline requires many more pump stations along the route compared with a pipeline built for CO_2 service.

For this reason, it is not anticipated that repurposing existing natural gas pipelines would significantly help develop an expanded CO_2 pipeline network in the United States. There may be some short sections of pipeline, or pipeline laterals, that could use a repurposed natural gas line, but project-specific engineering would be required to evaluate if this would be technically and economically viable.

ENABLING WIDESPREAD DEPLOYMENT OF CCUS
The Need for Planned Expansion
In a more recent analysis by DOE in 2015, it was projected that **the scale of U.S. CO_2 pipeline infrastructure would need to triple by 2030** to enable the delivery of carbon captured by the U.S. power sector to oil fields for CO_2 EOR and, to a lesser extent, for geologic storage in underground saline formations. The report also notes that while this scenario would involve an unprecedented scale-up of CO_2 pipeline infrastructure, the pace would be comparable to what has been projected for pipeline construction in other sectors (in which many of the same companies operate).

There is currently some interest in Congress in providing financial support for construction of CO_2 transportation infrastructure, e.g. HR 4905, "Investing in Energy systems for the Transport of CO_2 Act of 2019." As this bill was just recently introduced in Congress, neither the NPC nor the CCUS study team have analyzed the details of the proposed legislation; however, it is encouraging that there appears to be growing interest in supporting CO_2 infrastructure.

A strategic, planned approach will not only help the build-out of pipeline and other transport infrastructure, but will also facilitate the building of CO_2 capture projects in the future. In addition, project proponents - many of whom may not have knowledge nor interest in entering the pipeline business - may be able to tap into trunk lines with minor investment.

CONCLUSIONS

The transport of CO_2 involves well understood technologies and has been done safely at scale for more than 40 years. CO_2 can be transported via pipeline, rail, truck, ship, and barge. In the United States, the primary mode of large-scale CO_2 transport is via pipeline, and there is a network of more than 5,000 miles of CO_2 pipelines operating today. Conclusions of this chapter include the following:

- Wide-scale deployment of CCUS in the United States will require a significant expansion of existing CO_2 pipeline infrastructure.
- Streamlined permitting would facilitate building strategic CO_2 trunk lines in key industrial and oil and gas regions of the country and could best be accomplished on a consultative basis between federal and state governments.
- Federal and state eminent domain authority for pipeline projects would facilitate faster development of infrastructure.
- U.S. industry already has extensive experience constructing and operating large-capacity CO_2 pipelines.
- PHMSA sets the standards for safe construction, operation, and technical design specifications and requirements for mechanical integrity management of CO_2 pipelines.
- Rail and truck transport of CO_2 can be solutions for shorter distances and more point-to- point options.
- The right government incentives (term/value of tax credits) will reduce risk for economic recovery of the development capital required for pipeline construction and operation.