



PDH-Pro.com

Carbon Dioxide Storage

Course Number: SU-02-506

PDH: 9

Approved for: AK, AL, AR, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

State Board Approvals

Florida Provider # 0009553 License #868

Indiana Continuing Education Provider #CE21800088

Maryland Approved Provider of Continuing Professional Competency

New Jersey Professional Competency Approval #24GP00025600

North Carolina Approved Sponsor #S-0695

NYSED Sponsor #274

How Our Written Courses Work

This document is the course text. You may review this material at your leisure before or after you purchase the course.

After the course has been purchased, review the technical material and then complete the quiz at your convenience.

A Certificate of Completion is available once you pass the exam (70% or greater).

If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained).

If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH Pro.com.



Module 4: Transport of CO₂

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the technical requirements for transporting CO₂ via pipeline and marine tanker systems.
- **Select** appropriate materials and design pressures based on CO₂ stream purity and phase behavior.
- **Analyze** the cost-benefit trade-offs between pipeline and ship transport based on distance and volume.

Executive Summary: Transport is the critical link in the Carbon Capture and Storage (CCS) chain. While pipeline transport is a mature technology—evidenced by over 2,500 km of existing lines—marine transport offers a scalable alternative for long-distance, trans-oceanic requirements. Successful implementation depends on maintaining high-pressure dense phase states, managing moisture to prevent corrosion, and navigating evolving international regulatory frameworks.

Introduction

Carbon dioxide is commercially transported in three states: **gas**, **liquid**, and **solid**. For industrial-scale CCS, pipelines and ships are the primary modalities.

- **Gaseous Transport:** At atmospheric pressure, CO₂ occupies excessive volume. To optimize transport, gas is **compressed** for pipelines.
- **Liquid Transport:** Volume is further reduced via liquefaction. This is an established technology for LPG and LNG, which serves as a direct technical analog for liquid CO₂.
- **Solid Transport:** Solidification (dry ice) requires significantly higher energy inputs and is generally considered **economically inferior** for large-scale CCS.

Infrastructure Requirements

Significant climate mitigation will require a vast network of pipelines. Securing **rights-of-way** is a primary challenge, especially in highly populated zones. While existing experience is largely in low-density areas (e.g., West Texas), safety and regulatory complexities increase in urban environments.

Pipeline Systems

CO₂ movement is most efficient in the **dense phase** (supercritical or liquid).

Box 4.1. Specimen CO2 quality specifications

The Product delivered by Seller or Seller’s representative to Buyer at the Canyon Reef Carriers Delivery Meter shall meet the following specifications, which herein are collectively called ‘Quality Specifications’:

- (a) **Carbon Dioxide.** Product shall contain at least ninety-five mole percent (95%) of Carbon Dioxide as measured at the SACROC delivery meter.
- (b) **Water.** Product shall contain no free water, and shall not contain more than 0.48 9 m³ in the vapour phase.
- (c) **Hydrogen Sulphide.** Product shall not contain more than fifteen hundred (1500) parts per million, by weight, of hydrogen sulphide.
- (d) **Total Sulphur.** Product shall not contain more than fourteen hundred and fifty (1450) parts per million, by weight, of total sulphur.
- (e) **Temperature.** Product shall not exceed a temperature of 48.9 °C.
- (f) **Nitrogen.** Product shall not contain more than four mole percent (4%) of nitrogen.
- (g) **Hydrocarbons.** Product shall not contain more than five mole percent (5%) of hydrocarbons and the dew point of Product (with respect to such hydrocarbons) shall not exceed –28.9 °C.
- (h) **Oxygen.** Product shall not contain more than ten (10) parts per million, by weight, of oxygen.
- (i) **Glycol.** Product shall not contain more than 4 x 10⁻³ L m⁻³ of glycol and at no time shall such glycol be present in a liquid state at the pressure and temperature conditions of the pipeline.

Existing Experience

The Permian Basin in the USA contains over 90% of the world's active CO2 floods. Key existing infrastructure includes:

Table 4.1: Existing long-distance CO2 pipelines

Pipeline	Location	Operator	Capacity (MtCO ₂ yr ⁻¹)	Length (km)	Year finished	Origin of CO ₂
Cortez	USA	Kinder Morgan	19.3	808	1984	McElmoDome
Sheep Mountain	USA	BP Amoco	9.5	660	-	Sheep Mountain
Bravo	USA	BP Amoco	7.3	350	1984	Bravo Dome
Canyon Reef Carriers	USA	Kinder Morgan	5.2	225	1972	Gasification plants
Val Verde	USA	Petrosource	2.5	130	1998	Val Verde Gas Plants
Bati Raman	Turkey	Turkish Petroleum	1.1	90	1983	Dodan Field
Weyburn	USA & Canada	North Dakota Gasification Co.	5	328	2000	Gasification Plant
Total			49.9	2591		

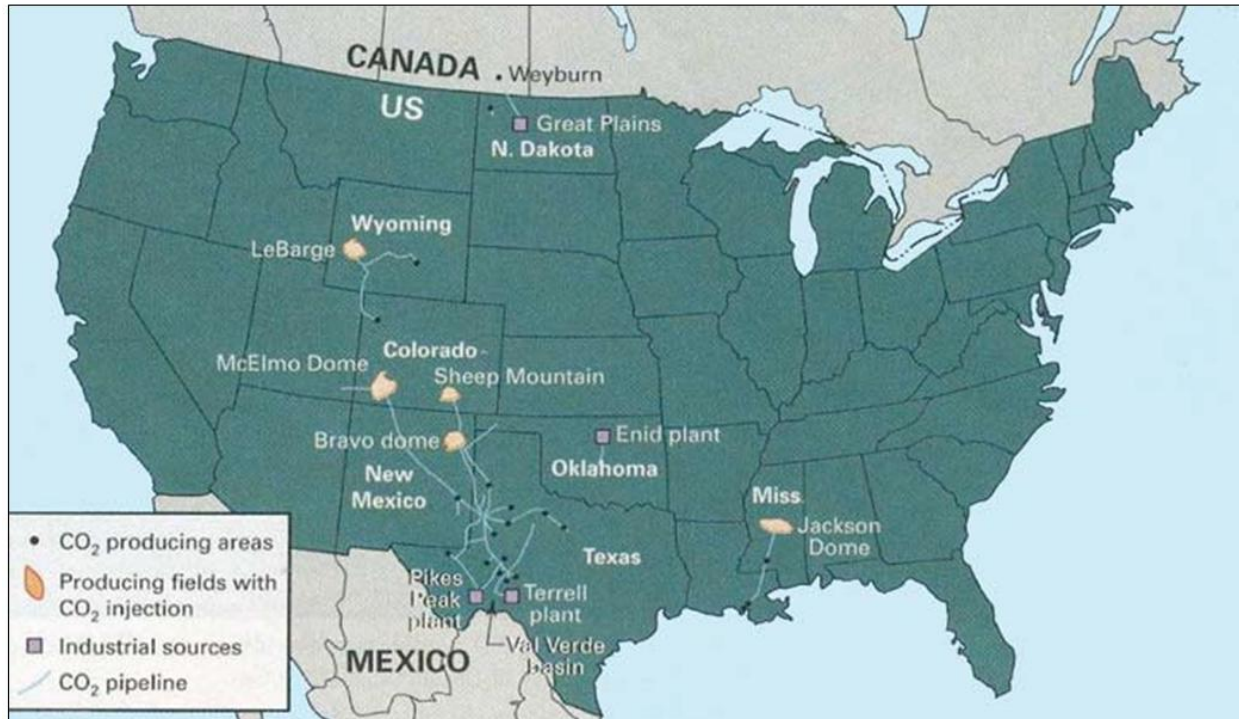


Figure 4.1: CO₂ pipelines in North America. (Courtesy of Oil and Gas Journal).

Design Fundamentals

The design basis must integrate physical, environmental, and social factors.

Material Selection & Corrosion

⚠ Safety Constraint: CO₂ streams should be **dry** and free of H₂S. In the presence of free water, CO₂ forms carbonic acid, which is highly corrosive to carbon-manganese steel.

- **Dry CO₂:** Corrosion rates for X-60 carbon steel are minimal (< 0.5 micrometers/yr).
- **Wet CO₂:** Requires **corrosion-resistant alloys** (stainless steel) or robust dehydration (e.g., glycol units) to meet "pipeline quality" specifications.

Phase Control

High-pressure transport (typically **9.6 MPa** or higher) ensures the CO₂ remains in a dense phase.

📊 Calculation Note: Avoid the intermediate pressure range (4.8 to 9.6 MPa) to prevent **two-phase flow**, which can cause mechanical vibration and metering inaccuracies.

Safety Features

- **Fracture Arresters:** Installed at ~500m intervals to stop longitudinal running fractures.
- **Depth of Cover:** Typically 1m; increasing to 2m can reduce damage frequency by a factor of 10 in rural areas.

Construction and Underwater Pipelines

Onshore construction follows standard hydrocarbon practices: trenching, welding (often in 24m double joints), testing, and backfilling.

Offshore Methods

- **Lay-barge Method:** Most common for large diameters; pipe is welded on a barge and lowered via a "stinger."
- **Reel Method:** Suitable for lines up to 450mm; pipe is welded onshore and wound onto a ship-mounted reel.
- **Horizontal Directional Drilling (HDD):** Used for shore crossings to minimize environmental impact on the surf zone.

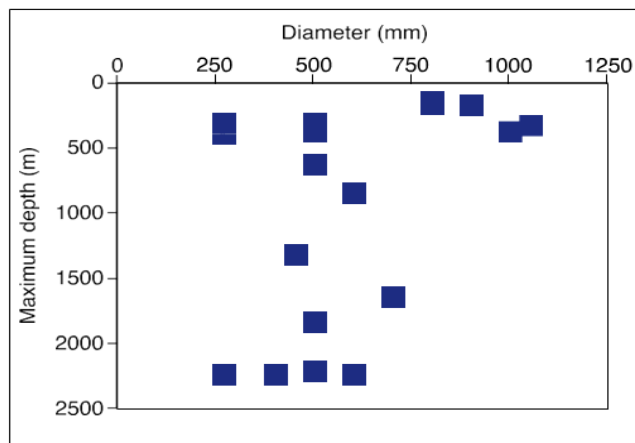


Figure 4.2: Pipelines in deep water.

Operations

Modern pipelines utilize **SCADA** (Supervisory Control and Data Acquisition) systems for real-time monitoring of mass balance and pressure drops.

- **Internal Inspection:** Conducted via "**pigs**" (piston-like devices) to detect corrosion or deformation.
- **External Monitoring:** Aerial patrols for land lines; Remotely Operated Vehicles (ROVs) for sub-sea lines.

Ships for CO2 Transportation

Marine transport is discrete rather than continuous, requiring **temporary land storage** and liquefaction facilities at the loading terminal.

Design & Construction

Ships are designed under the **International Gas Carrier Code**.

- **Tank Type:** Semi-refrigerated is preferred, operating near the triple point (approx. **-54 degrees C at 6 bar**).
- **Scalability:** Existing yards that build LPG/LNG tankers can build CO2 carriers. A 200,000 m3 vessel could carry ~230 kt of liquid CO2.

💡 **Design Tip:** To prevent the formation of dry ice or contamination by humid air, cargo tanks must be pressurized with **gaseous CO2** before loading liquid.

Risk, Safety, and Monitoring

CO2 is non-flammable but acts as an **asphyxiant**. Because it is denser than air, it can accumulate in low-lying areas following a leak.

Table 4.2: Statistics of serious incidents, depending on the ship type.

Ship type	Number of ships 2000	Serious incidents 1978-2000	Frequency (incidents/ship year)
LPG tankers	982	20	0.00091
LNG tankers	121	1	0.00037
Oil tankers	9678	314	0.00144
Cargo/bulk carriers	21407	1203	0.00250

Legal Issues, Codes, and Standards

- **International:** Governed by UN Law of the Sea, London Convention, and the Basel Convention (if impurities are present).
- **Technical Standards:** ASME B31.4 and DNV-RP-F101 specifically address CO2 liquid transportation.

Costs

Costs are highly sensitive to **distance** and **terrain**.

- **Pipelines:** Higher upfront capital (CAPEX). Costs increase by 50-100% in congested or urban areas.
- **Ships:** Higher operating costs (OPEX) due to liquefaction and fuel.
- **Break-even:** Ship transport becomes cost-competitive with offshore pipelines at distances greater than ~1,000 km.



Purchase this course to
see the remainder of
the technical materials.