CO_2 Pipelines

Pipeline Design · Capacity · Risks · Stream Composition · Costs

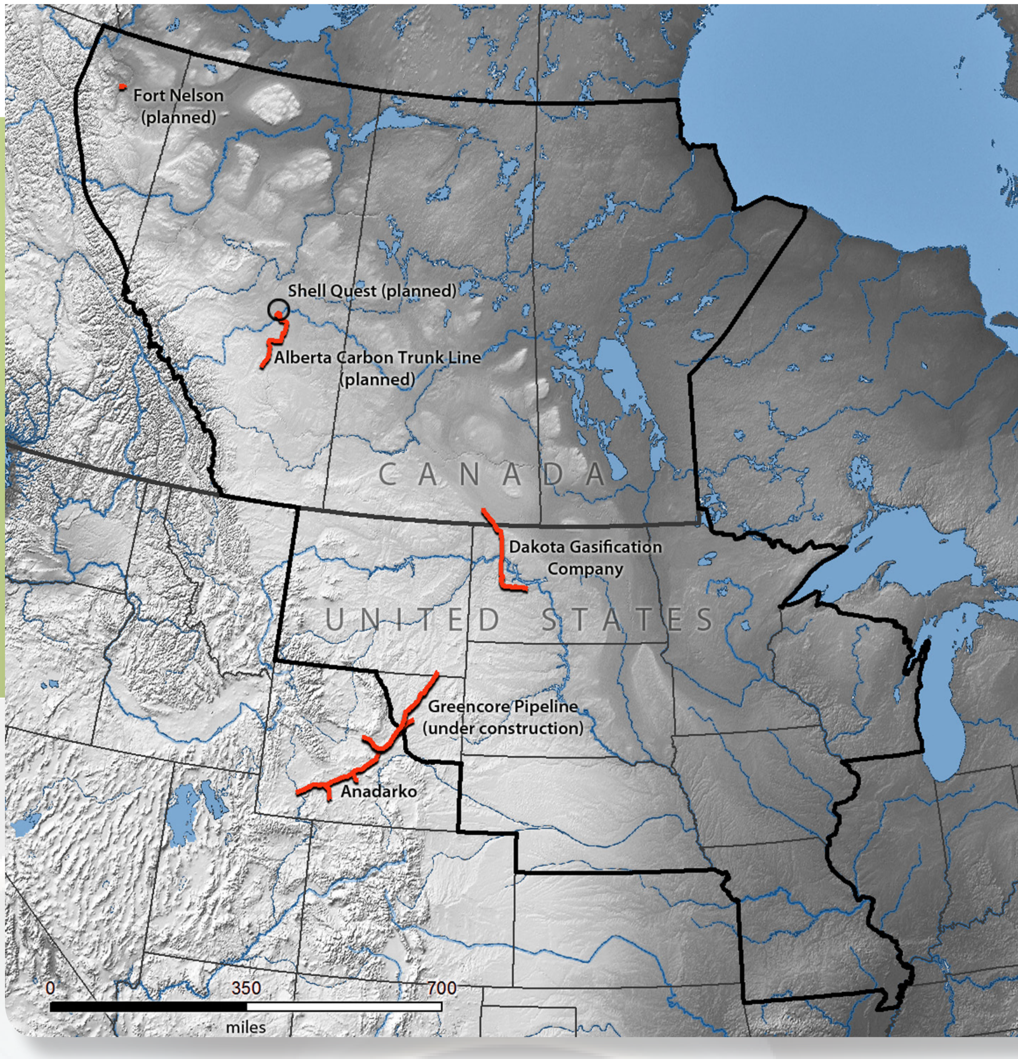
Technical Brief
September 2011

After carbon dioxide (CO_2) is captured, the next step is transporting it to a storage site. For over 30 years, CO_2 has been safely transported via pipeline. Pipelines are a proven technology that requires no new development, only implementation. In fact, CO_2 pipelines are already part of the infrastructure in the Plains CO_2 Reduction (PCOR) Partnership region, with 205 miles of existing CO_2 pipeline and roughly another 400 miles planned or under construction.

As the demand for CO_2 for enhanced oil recovery (EOR) projects grows, the need for more pipelines grows. Construction of new CO_2 pipelines requires significant capital investment that must be supported by the long-term oil production potential of the target basin and by expectations of future oil prices.

Building a regional CO_2 pipeline infrastructure for carbon capture, utilization, and storage (CCUS) activities will require thoughtful planning as to whether to construct specific pipelines connecting individual CO_2 sources with geologic sinks in a one-at-a-time manner or if it will be more advantageous to construct a CO_2 pipeline network that can connect many large stationary sources with major geologic sinks. If a network of shared pipelines is implemented, common carrier issues such as those related to CO_2 stream quality may need to be addressed.

About **600 miles** of CO_2 pipeline either exists or is planned in the PCOR Partnership region.



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Pipeline Infrastructure

About 562 million tons of CO_2 is produced in the PCOR Partnership region each year. Considering that the 205-mile-long Dakota Gasification Company pipeline has a capacity of 3.22 million short tons CO_2/yr,[1] the scale-up challenge facing the widespread development of CCUS is evident.

CO_2 Pipelines in the PCOR Partnership Region

Pipeline	Owner	Location	Approximate Length, mi
Alberta Carbon Trunk Line[a]	Enhance Energy Inc.	Alberta, Canada	150
Anadarko[b]	Howell Petroleum Corporation	Wyoming	125
Dakota Gasification Company	Souris Valley Pipeline, Ltd.	North Dakota to Saskatchewan	205
Greencore Pipeline[a]	Denbury Onshore LLP	Wyoming to Montana	232
Fort Nelson[a]	Spectra Energy	British Columbia	10
Shell Quest[a]	Shell	Alberta	6–37

[a] Planned or under construction.

[b] While not technically within the boundaries of the PCOR Partnership region, this pipeline is regionally significant.

Pipeline Design

CO_2 pipelines are similar in design and operation to natural gas pipelines, although the higher CO_2 pressures require construction using thicker-walled carbon steel pipe. Special-use pipelines designed for specific applications may employ construction requirements that differ from the general rule of thumb. Natural gas pipeline operating pressures range from 200 to 1500 psi, and compressors are used at booster stations along the pipeline route to maintain the necessary pressure.[2] CO_2 is transported as a supercritical (sometimes called "dense-phase") fluid at pressures of 1200 to 2700 psi.[3,4] Because the dense-phase CO_2 behaves as a liquid, pumps (rather than compressors) can be used at booster stations.[5]

Rule of Thumb

A rule of thumb that can be used to estimate capacity for CO_2 pipelines operating at **2200 psi**[6] is:

(Pipeline Diameter)^2 × 1.15 = Maximum Flow Capacity in MMscfd

Higher flow rates can be achieved if the pipeline is operated at higher pressure.

Pipeline Diameters

Pipeline diameters are calculated using rigorous iterative calculations,[7] but estimations correlating pipeline diameter and CO_2 flow rates can be made.

Estimated CO_2 Pipeline Design Capacity[8]

Pipeline Diameter, in.	CO_2 Flow Rate			
	Lower Bound		Upper Bound	
	Mt/yr	MMscfd	Mt/yr	MMscfd
4	–	–	0.19	10
6	0.19	10	0.54	28
8	0.54	28	1.13	59
12	1.13	59	3.25	169
16	3.25	169	6.86	357
20	6.86	357	12.26	639
24	12.26	639	19.69	1025
30	19.69	1025	35.16	1831
36	35.16	1831	56.46	2945

Regulations

- Pipeline safety is regulated under a provision in the federal Pipeline Safety Reauthorization Act of 1988. Pipelines that exist entirely within a single state are regulated by that state's authority, so long as those regulations are as stringent as the federal regulations. Pipelines that continue through more than one state are regulated by the federal Pipeline and Hazardous Materials Safety Administration (PHMSA).
- Code of Federal Regulations (CFR) Title 49, Part 195, Department of Transportation Office of Pipeline Safety regulates pipeline transport of CO_2.
- The Federal Energy Regulatory Commission (FERC) and Surface Transportation Board declined jurisdiction over CO_2 pipelines because they are neither "common carriers" nor "natural gas companies."
- There is no federal eminent domain for CO_2 pipelines.
- If a pipeline crosses federal land, permits need to be acquired and National Environmental Policy Act compliance undertaken.
- The Bureau of Land Management can regulate CO_2 pipelines under the Mineral Leasing Act as a commodity shipped by a common carrier.

Risk

While no industrial activity is without risk, problems with CO_2 pipelines are rare events. According to the National Response Center's accident database, there were 12 accidents in 3500 miles of CO_2 pipelines between 1986 and 2008. No serious human injuries or fatalities were reported for any of these accidents.[9] By contrast, there were 5610 accidents causing 107 fatalities and 520 injuries related to natural gas and hazardous liquid (excluding CO_2) pipelines during the same period.[9] Although the total length of CO_2 pipelines is far less than that of natural gas and hazardous liquid pipelines, injury and property damage data suggest that CO_2 pipelines are safer than natural gas and hazardous liquid pipelines.[10] Strategies undertaken to manage risks include the inclusion of fracture arresters approximately every 1000 feet, block valves to isolate pipe sections that are leaking, the use of high durometer elastomer seals, and automatic control systems that monitor volumetric flow rates and pressure fluctuations.[10] Other methods include ground, aircraft, and/or satellite monitoring of pipelines; implementation of periodic corrosion assessments; and internal cleaning and inspection using pipeline "pigs."

No serious human injuries or fatalities have been reported as the result of CO_2 transportation via pipeline.

Composition of CO_2 Streams

The composition of CO_2 streams varies depending on the source of the CO_2. Stream quality issues become important when the CO_2 enters a pipeline containing CO_2 from other sources or if the CO_2 in the pipeline is delivered to different sinks with other quality requirements. If a national pipeline network were to be developed, common carrier issues would most likely force some type of quality specification to be employed.

Several compounds can impact the end use of a CO_2 stream. It is important that the nitrogen and methane concentrations in a CO_2 stream be low (generally 5% each; 10% total maximum) so as not to rule out dense-phase operations.[11] Higher concentrations of nitrous oxide or methane render CO_2 unacceptable for use

CO_2 Stream Compositions

Component	Kinder Morgan CO_2 Pipeline Specs[12]	Ethanol Plant[13]	Great Plains Synfuels Plant[4,7]	Gas-Processing Plant[14]	Coffeyville Resources Ammonia–UAN Fertilizer Plant[15]	Food-Grade CO_2 Specs[16]
CO_2	≥95 vol%	>98 vol%	96.8 vol%	≥96 vol%	99.32 vol%	≥99.9 vol%
Water	≤30 lb/MMcf	dry	<25 ppm	≤12 lb/MMcf	0.68 vol%	≤20 ppmw
H_2S	≤20 ppmw	–	<2 vol%	≤10 ppmw	–	≤0.1 ppmv
Total Sulfur	≤35 ppmw	40 ppmv	<3 vol%	≤10 ppmw	–	≤0.1 ppmv
N_2	≤4 vol%	0.9 vol%	0 ppm		–	None
Hydrocarbons	≤5 vol%	2300 ppmv	1.3 vol%	≤4 vol%	–	CH_4: ≤50 ppmw; others: ≤20 ppmw
O_2	≤10 ppmw	0.3 vol%	0 ppm	≤10 ppmw	–	≤30 ppmw
Other	Glycol: ≤0.3 gal/MMcf	–	0.8 vol%		–	≤330 ppmw
Temperature	≤120°F	120°F	100°F	≤100°F	100°F	–

in EOR.[11] Sulfur compounds such as H_2S can be hazardous to both humans and wildlife and, therefore, require robust safety strategies. High oxygen content can lead to microbially induced corrosion of iron and steel as well as chemical reactions and/or aerobic bacterial growth within the injection tubular or in the geologic formation.[11] Oil concentrations are usually limited to less than 10–20 ppm. Finally, minimization of water within the CO_2 stream is crucial to avoid corrosion. The typical maximum allowable water vapor concentration is in the range of 20–30 lb/MMcf.[11]

Capital Costs

Pipeline cost depends on its diameter (a function of the CO_2 mass and pressure) and length, as well as other factors such as terrain and river crossings. Pipeline capital costs have increased dramatically in the last decade, primarily because of steel and labor costs. Some examples are listed below.

Approximate Capital Costs for Pipelines

Project	Year	Cost, $/inch diameter/mile
Dakota Gasification[17]	2000	37,300
Hall-Gurney (KS)[18]	2001	22,000
Regression Analysis of FERC Data[19]	2003	33,800
Coffeyville Resources[5,20]	2007, 2009	52,100–83,300
Green Pipeline[21]	2009	93,750

The PCOR Partnership is a group of public and private sector stakeholders working together to better understand the technical and economic feasibility of sequestering CO_2 emissions from stationary sources in the central interior of North America. The PCOR Partnership is managed by the Energy & Environmental Research Center (EERC) at the University of North Dakota and is one of seven regional partnerships under the U.S. Department of Energy's National Energy Technology Laboratory Regional Carbon Sequestration Partnership Initiative. New members are welcome.

To learn more, contact:

Charles D. Gorecki, Senior Research Manager
(701) 777-5355, cgorecki@undeerc.org

Melanie D. Jensen, Research Manager
(701) 777-5115, mjensen@undeerc.org

Edward N. Steadman, Deputy Associate Director for Research
(701) 777-5279, esteadman@undeerc.org

John A. Harju, Associate Director for Research
(701) 777-5157, jharju@undeerc.org

www.undeerc.org/PCOR

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University of North Dakota
Grand Forks