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National Energy Technology Laboratory
OFFICE OF FOSSIL ENERGY

A Review of the CO_2 Pipeline Infrastructure in the U.S.

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Disclaimer

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Acronyms and Abbreviations

AEO2014	Annual Energy Outlook
BAU	Business as usual
Bcf	Billion cubic feet
Bcf/d	Billion cubic feet per day
BLM	Bureau of Land Management
CAFE	Corporate Average Fuel Economy
CCA	Cedar Creek Anticline
CO_2	Carbon dioxide
CCS	Carbon capture and storage
CTUS	Capture, transport, utilization, and storage
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Agency
EIS	Environmental Impact Statement
EOR	Enhanced oil recovery
EPSA	Energy Policy and Systems Analysis
FERC	Federal Energy Regulatory Commission
GAO	General Accountability Office
GHG	Greenhouse gas
GW	Gigawatt
ICC	Interstate Commerce Commission
ICF	ICF International
IGCC	Integrated gasification combined cycle
in	Inch
ITC	Investment Tax Credit
MBbl/d	Million barrels per day
mi	Mile
MM, mm	Million
MMcfd	Million cubic feet per day
MMBbls	Million barrels of oil
MMBOE	Million barrels of oil equivalent
MMT	Million metric tons
NEJD	North East Jackson Dome
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
PCS	Potash Corp of Saskatchewan
PHMSA	Pipeline and Hazardous Materials Safety Administration
PTC	Production Tax Credit
RCSP	Regional Carbon Sequestration Partnerships
SACROC	Scurry Area Canyon Reef Operators Committee
STB	Surface Transportation Board
TBD	To be determined
U.S.	United States
WPA	Wyoming Pipeline Authority

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1 Executive Summary

Spanning across more than a dozen U.S. states and into Saskatchewan, Canada, a safe and regionally extensive network of carbon dioxide (CO_2) pipelines has been constructed over the past four decades. Consisting of 50 individual CO_2 pipelines and with a combined length over 4,500 miles, these CO_2 transportation pipelines represent an essential building block for linking the capture of CO_2 from electric power plants and other industrial sources with its productive use in oilfields and its safe storage in saline formations. Expanding this system could help to enable fossil-fired power generation in a carbon constrained environment and increase energy security by enhancing domestic oil production.

The vast majority of the CO_2 pipeline system is dedicated to enhanced oil recovery (CO_2-EOR), connecting natural and industrial sources of CO_2 with EOR projects in oil fields. Roughly 80 percent of CO_2 traveling through U.S. pipelines is from natural (geologic) sources; however, if currently planned industrial CO_2 capture facilities and new pipelines are built, by 2020 the portion of CO_2 from industrial-sources could be nearly equal to that from natural sources. In terms of future potential, it is estimated that up to 4 million barrels per day of oil could potentially be produced in the U.S. with CO_2-EOR and that 85% of this would be reliant on industrial CO_2; contributing to significantly fewer oil imports and annual emissions reductions of 400 $MMTCO_2$, by 2030.

Just over 4 percent of total U.S. crude oil production is currently produced through EOR, though this is projected to increase to 7 percent by 2030, and a national carbon policy could significantly change the outlook, creating incentives for electric power plants and other industrial facilities to reduce CO_2 emissions through carbon capture technologies and improving the economics for oil production through EOR. In a low-carbon case, construction through 2030 would more than triple the size of current U.S. CO_2 pipeline infrastructure, through an average annual build-rate of nearly 1,000 miles per year.

The regulation of CO_2 pipelines is currently a joint responsibility of federal and state governments. The U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration, is responsible for overseeing the safe construction and operation of CO_2 pipelines, which includes technical design specifications and integrity management requirements. The development of a national CO_2 pipeline network capable of meeting U.S. GHG emission goals may require a more concerted federal policy, involving closer cooperation among federal, state, and local governments. Federal policy initiatives should build on state experiences, including lessons learned from the effectives of different regulatory structures, incentives, and processes that foster interagency coordination and regular stakeholder engagement.

2 Introduction

A safe, reliable, regionally extensive network of carbon dioxide (CO_2) transportation pipelines is already in place across more than a dozen United States (U.S.) states and into Saskatchewan, Canada. This system could increasingly become an essential building block for linking the capture of CO_2 from industrial power plants with its productive use in oilfields (with CO_2 enhanced oil recovery [CO_2-EOR]) and its safe storage in saline formations. The current CO_2 pipeline system consists of 50 individual CO_2 pipelines with a combined length of 4,500 miles. The bulk of the existing large-volume CO_2 pipelines connect natural sources of CO_2 (e.g., Bravo Dome, New Mexico) with long-running CO_2-EOR projects in large oil fields (e.g., Wasson, West Texas). However, smaller volume pipelines also exist that connect point sources of industrial CO_2 (e.g., Coffeyville Chemical Plant, Kansas) with newer CO_2-EOR projects in oil fields (e.g., North Burbank, Oklahoma).

Today's CO_2 pipeline system had its beginnings in the 1970s, built for delivering CO_2 for CO_2-EOR to oil fields in the Permian Basin of West Texas and eastern New Mexico. With the recent completion of two long-distance CO_2 pipelines – the Green Pipeline in Louisiana and Texas (2010), and the Greencore Pipeline in Wyoming and Montana (2012) – a much more geographically diverse CO_2 pipeline system is in place. A variety of shorter and smaller volume laterals are being constructed to link these two large-scale CO_2 pipelines to surrounding oil fields that are amenable to CO_2-EOR.

The vast majority of the CO_2 pipeline system is dedicated to CO_2-EOR, with a small fraction used for other industrial uses, such as delivering CO_2 to the beverage industry. Of the 3.53 billion cubic feet (Bcf) per day (68 million metric tons per year [MMT]) of CO_2 transported, 2.78 Bcf per day (54 MMT per year) is from natural sources, and the remaining 0.74 Bcf per day (14 MMT per year) is from industrial sources, including gas processing plants. With new industrial CO_2 capture facilities coming on line (e.g., Air Products PCS Nitrogen plant in southern Louisiana, Southern Company's integrated gasification combined cycle (IGCC) plant in Kemper County, Mississippi, etc.) – including over 600 miles of new pipeline – the volume of industrial CO_2 capture and transportation is expected to increase by over 2.5 times the current supply by the year 2020.[1]

The regulation of CO_2 pipelines is currently a joint responsibility of federal and state governments. The federal government regulates only CO_2 safety standards. State governments are largely responsible for the oversight of CO_2 transportation pipeline development and operation. Some states, such as Wyoming and its Pipeline Authority, have begun to plan for and establish corridors for future CO_2 pipelines. However, the development of a national CO_2 pipeline network capable of meeting proposed CO_2 emission goals may require a more organized approach and much closer cooperation among federal, state, and local governments than is currently in place.

[1] This is based on a comparison between 0.74 Bcf per day currently and 1.36 Bcf per day planned to begin construction by 2020 (Exhibit 16).

3 Current CO_2 Pipeline Infrastructure

3.1 Overview

The initial large-scale CO_2 pipeline in the U.S., the Canyon Reef pipeline, was built in the 1970s. Much of the remainder of the current CO_2 pipeline infrastructure was built between the 1980s and 1990s. Today, there are nearly 50 CO_2 transportation pipelines in the U.S. with a combined length of over 4,500 miles, operated by over a dozen different companies. (See Exhibit 32 in the Appendix for the comprehensive list of CO_2 transport pipelines in the U.S.)

At present, about 80 percent of CO_2 used for EOR is from natural sources. However, CO_2 supplies from industrial sources (natural gas processing plants, other chemical processing plants, and electric power facilities) are expected to provide upwards of 43 percent of the CO_2 used for EOR by the year 2020.[2] Exhibit 1 illustrates the major CO_2 transport pipelines that currently exist in the U.S. Exhibit 2 shows the current CO_2-EOR operations and infrastructure in the U.S.

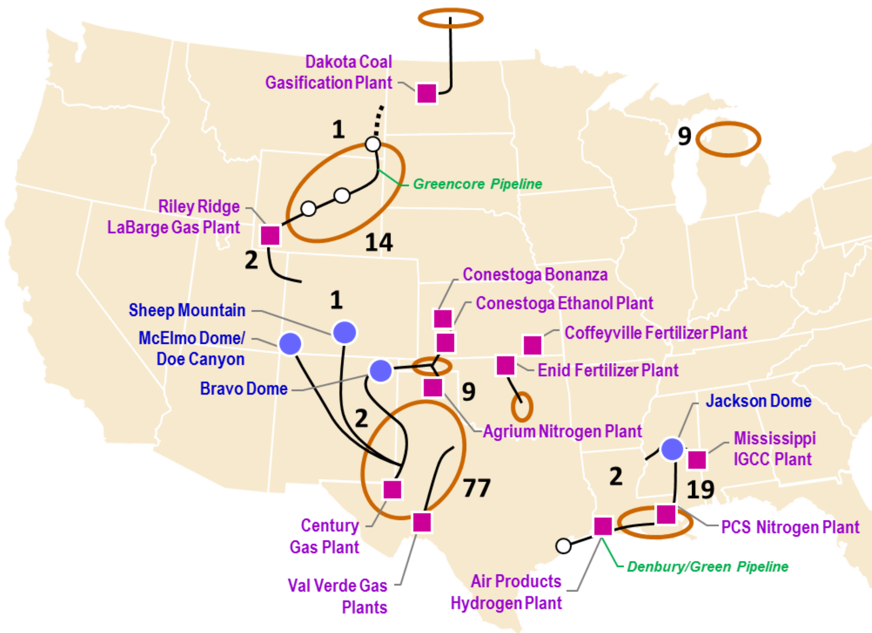
A number of industrial CO_2-capture facilities have been proposed and partially developed for delivering CO_2 to EOR fields over the past several decades. However, the significant amount of capital required by many of these projects has inhibited a number of them from meeting their announced CO_2-capture goals on time, or coming online entirely. But, as new industrial CO_2-capture projects begin to provide greater volumes of CO_2 to the EOR industry, it is anticipated that development costs will begin to decrease. Proven industrial CO_2-capture technology should lower the perceived risk of providing CO_2 supplies to the EOR industry.

Exhibit 1 Geographic areas with large-scale CO_2 pipeline systems operating currently in the U.S.

U.S. Regions with Large-scale CO_2 Pipeline Systems in Operation	Miles of Pipeline
Permian Basin (W. TX, NM, and S. CO)	2,600
Gulf Coast (MS, LA, and E. TX)	740
Rocky Mountains (N. CO, WY, and MT)	730
Mid-Continent (OK and KS)	480
Other (ND, MI, Canada)	215

[2] This is based on a comparison between the 2.78 Bcf per day currently drawn from natural CO2 reservoirs and the total of 2.1 Bcf per day expected from industrial sources by 2020.

Exhibit 2 Current CO_2-EOR operations and infrastructure



Oil Production (2014)	
CO_2-EOR Projects	136
Oil Production (MBbl/d)	300
CO_2 Supplies (2014)	
Number of Sources	17
• *Natural*	*5*
• *Industrial*	*12*
CO_2 Supply (Bcf/d)	3.5
• *Natural*	*2.8*
• *Industrial*	*0.7*

136 No. of U.S. CO_2-EOR Projects
Natural CO_2 Source
Industrial CO_2 Source
CO_2 Pipeline
CO_2 Proposed Pipeline
CO_2-EOR Region

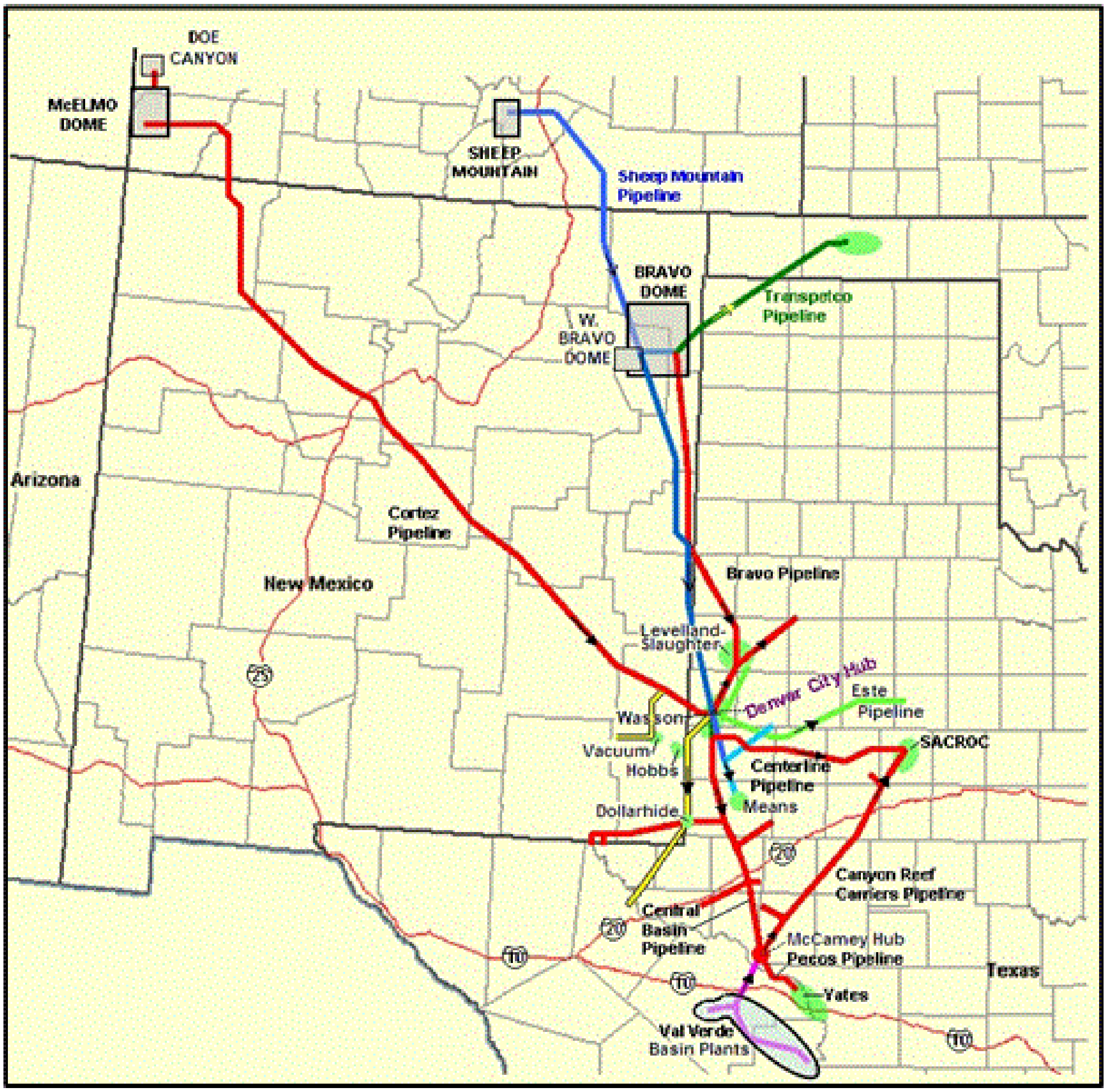
Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2014 and industry sources.

3.2 Permian Basin

The Permian Basin contains the largest network of CO_2 pipelines in the U.S. Over 2,600 miles of CO_2 pipelines in this region carry both natural and industrial CO_2 supplies to CO_2-EOR projects throughout the region.

Three main pipelines deliver CO_2 from four natural sources of CO_2 to the Permian Basin (Exhibit 3). The Cortez pipeline delivers CO_2 from McElmo Dome and Doe Canyon in southwestern Colorado. The Sheep Mountain pipeline delivers CO_2 from the Sheep Mountain CO_2 field in central Colorado, and the Bravo pipeline delivers CO_2 from Bravo Dome in northeast New Mexico to the Permian Basin. All three of these major pipelines meet at the Denver City CO_2 hub, where CO_2 is dispersed through a network of smaller CO_2 pipelines to various oil fields and their CO_2-EOR projects. A smaller pipeline, the TransPetco/Bravo pipeline, transports a modest amount of CO_2 to the Postle CO_2-EOR operation in western Oklahoma, as discussed later in this report.

Exhibit 3 Permian Basin CO_2 pipeline infrastructure



Three other important CO_2 pipelines round out the large-scale pipeline system of the Permian Basin:

- The Canyon Reef Carrier CO_2 pipeline, the initial large-scale CO_2 pipeline, links the CO_2 captured from the gas processing plants in the Val Verde Basin (West Texas) with the pioneering Scurry Area Canyon Reef Operators Committee (SACROC) CO_2-EOR project, 170 miles to the northeast.
- The Centerline and Central Basin CO_2 pipelines deliver natural CO_2 from the Denver City CO_2 hub to the oil fields in West Texas and New Mexico.

Exhibit 4 lists the CO_2 transportation pipelines installed in the Permian Basin region.

Exhibit 4 Permian Basin CO_2 transportation pipelines

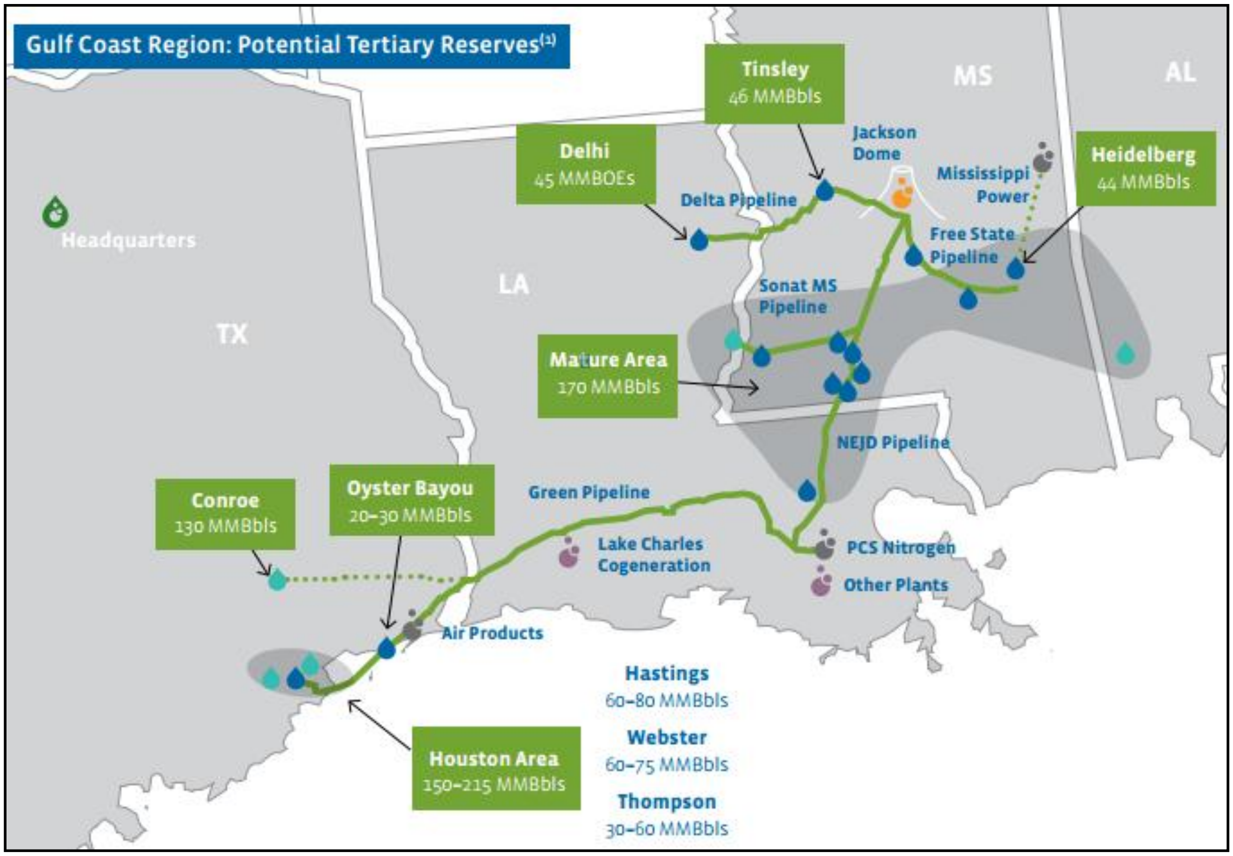
Scale	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
Large-Scale Trunk-lines	Cortez	Kinder Morgan	TX	502	30	1,300
	Sheep Mtn	Oxy Permian	TX	408	24	590
	Bravo	Oxy Permian	NM, TX	218	20	380
	Canyon Reef Carriers	Kinder Morgan	TX	170	16	220
	Centerline	Kinder Morgan	TX	113	16	220
	Central Basin	Kinder Morgan	TX	143	16	220
Smaller-Scale Distribution Systems	Este I - to Welch, Tx	ExxonMobil, et al	TX	40	14	180
	Este II - to Salt Crk Field	Oxy Permian	TX	45	12	130
	Means	ExxonMobil	TX	35	12	130
	North Ward Estes	Whiting	TX	26	12	130
	Slaughter	Oxy Permian	TX	35	12	130
	Mabee Lateral	Chevron	TX	18	10	110
	Val Verde	Oxy Permian	TX	83	10	110
	Rosebud	Hess	NM	50*	12	100*
	Anton Irish	Oxy Permian	TX	40	8	80
	Dollarhide	Chevron	TX	23	8	80
	Llano	Trinity CO_2	NM	53	12	80
	North Cowden	Oxy Permian	TX	8	8	80
	Pecos County	Kinder Morgan	TX	26	8	80
	Pikes Peak	Oxy Permian	TX	40	8	80
	W. Texas	Trinity CO_2	TX, NM	60	12	80
	Comanche Creek	Oxy Permian	TX	120	6	70
	Cordona Lake	XTO	TX	7	6	70
	El Mar	Kinder Morgan	TX	35	6	70
	Wellman	Trinity CO_2	TX	25	6	70
	Adair	Apache	TX	15	4	50
	Ford	Kinder Morgan	TX	12	4	50

*Estimated

3.3 Gulf Coast

The 740 mile Gulf Coast CO_2 pipeline network is owned and operated by Denbury Onshore LLC (Exhibit 5). Two main pipelines service the region, the North East Jackson Dome (NEJD) Pipeline and the Green Pipeline. These two pipelines connect the natural CO_2 source in Jackson Dome, Central Mississippi, to Denbury's CO_2-EOR projects in Mississippi, Louisiana, and East Texas. Several industrial sources of CO_2 are (or soon will be) connected to the Green Pipeline for delivery to CO_2-EOR. Exhibit 6 lists all of the CO_2 transportation pipelines installed in the Gulf Coast region.

Exhibit 5 Gulf Coast CO_2 pipeline infrastructure



(1) Potential, proved, and produced-to-date tertiary reserves estimated as of 12/31/13 based on a range of recovery factors. Proved reserves based on year-end 12/31/13 U.S. Securities and Exchange Commission reporting.

Source: Denbury Onshore LLC (1)

Exhibit 6 Gulf Coast CO_2 transportation pipelines

Scale	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
Large-Scale Trunk-lines	Green Line	Denbury Resources	LA, TX	314	24	930
	Delta	Denbury Resources	MS, LA	108	24	590
	Northeast Jackson Dome (NEJD)	Denbury Resources	MS, LA	183	20	360
Distribution Line	Free State	Denbury Resources	MS	85	20	360
	Sonat	Denbury Resources	MS	50	18	170

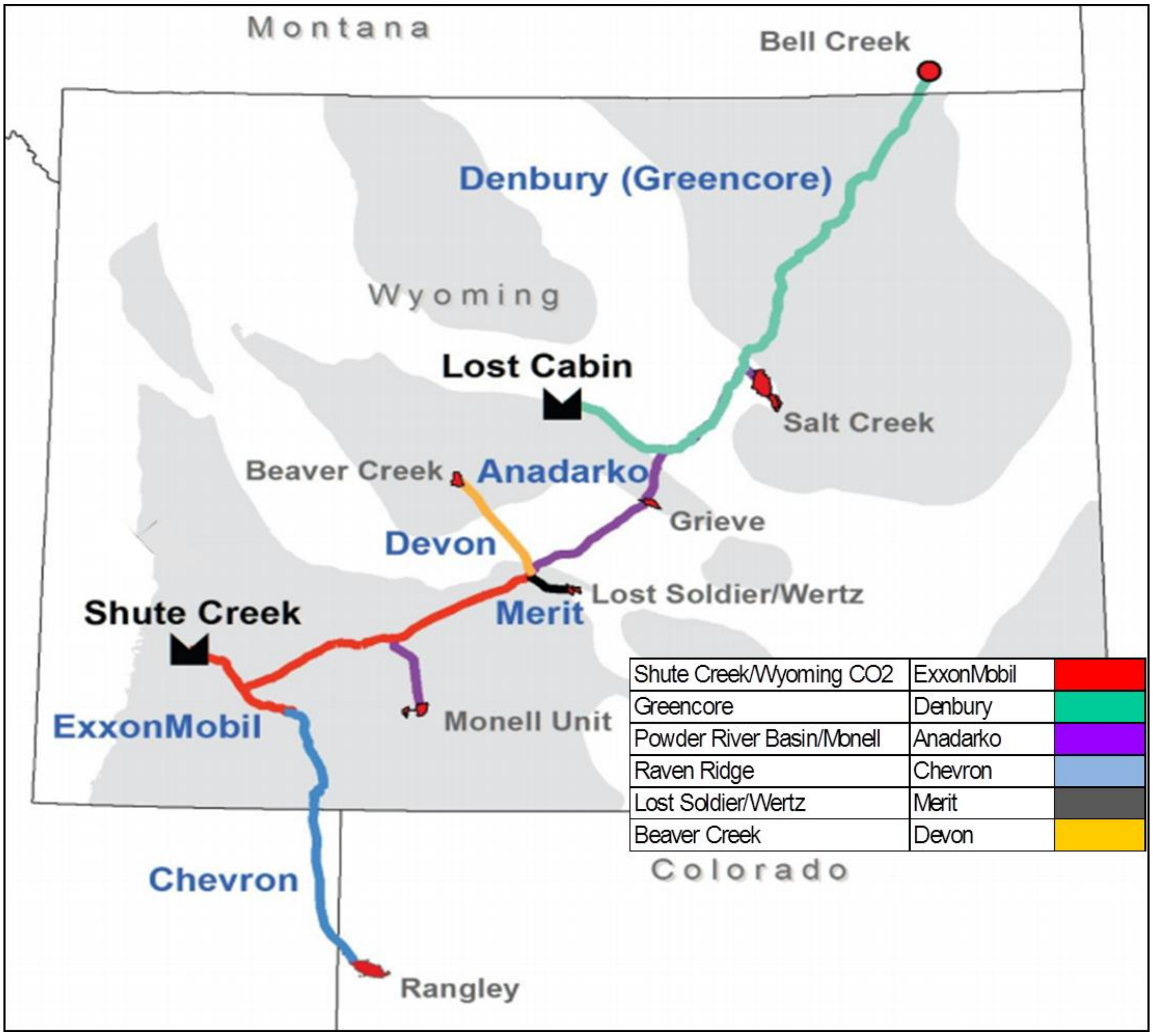
3.4 Rocky Mountains

The CO_2-EOR operations in the Rocky Mountain region are serviced by two major sources of CO_2: the Shute Creek natural gas processing plant and the Lost Cabin Gas Plant (Exhibit 7). The Shute Creek pipeline, operated by ExxonMobil, is the central trunk-line (i.e., a pipeline that originates at a transshipment node) for several smaller pipelines, which deliver CO_2 to CO_2-EOR projects in central Wyoming, as well as the Rangely CO_2-EOR project in northwest Colorado.

Denbury completed construction of the Greencore pipeline in 2012, which delivers CO_2 supplies from the Lost Cabin Gas Plant to the Salt Creek, Bell Creek, and other CO_2-EOR projects in the Rocky Mountain region.

Exhibit 8 lists the CO_2 transportation pipelines installed in the Rocky Mountain region, including a short, 40-mile delivery pipeline from McElmo Dome to the Aneth CO_2-EOR project in Utah.

Exhibit 7 Rocky Mountain CO_2 pipeline infrastructure



Source: Denbury Onshore LLC (1)

Exhibit 8 Rocky Mountain CO_2 transportation pipelines

Scale	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
Large-Scale Trunk-lines	Shute Creek/Wyoming CO_2	ExxonMobil	WY	142	30-20	1,220-220
	Greencore	Denbury Resources	WY, MT	230	22	720
Smaller Scale Distribution Systems	Powder River Basin CO_2	Anadarko	WY	125	16	220
	Raven Ridge	Chevron	WY, CO	160	16	220
	McElmo Creek	Kinder Morgan	CO, UT	40	8	80
	Monell	Anadarko	WY	33	8	80
	Lost Soldier/Wertz	Merit	WY	30	16	43
	Beaver Creek	Devon	WY	53	8	30

3.5 Mid-Continent

The Mid-Continent CO_2 pipeline system (Exhibit 9) is mainly a set of fragmented source-to-field pipelines supplying captured CO_2 from industrial sources to individual CO_2-EOR operations. Chaparral owns and operates the majority of these smaller pipelines while Anadarko controls the Enid-Purdy pipeline in Central Oklahoma. A small amount of natural CO_2 from Bravo Dome is delivered to the Postle CO_2-EOR operation via the TransPetco Pipeline. These CO_2 pipelines are listed in Exhibit 10.

Exhibit 9 Mid-Continent CO_2 pipeline infrastructure

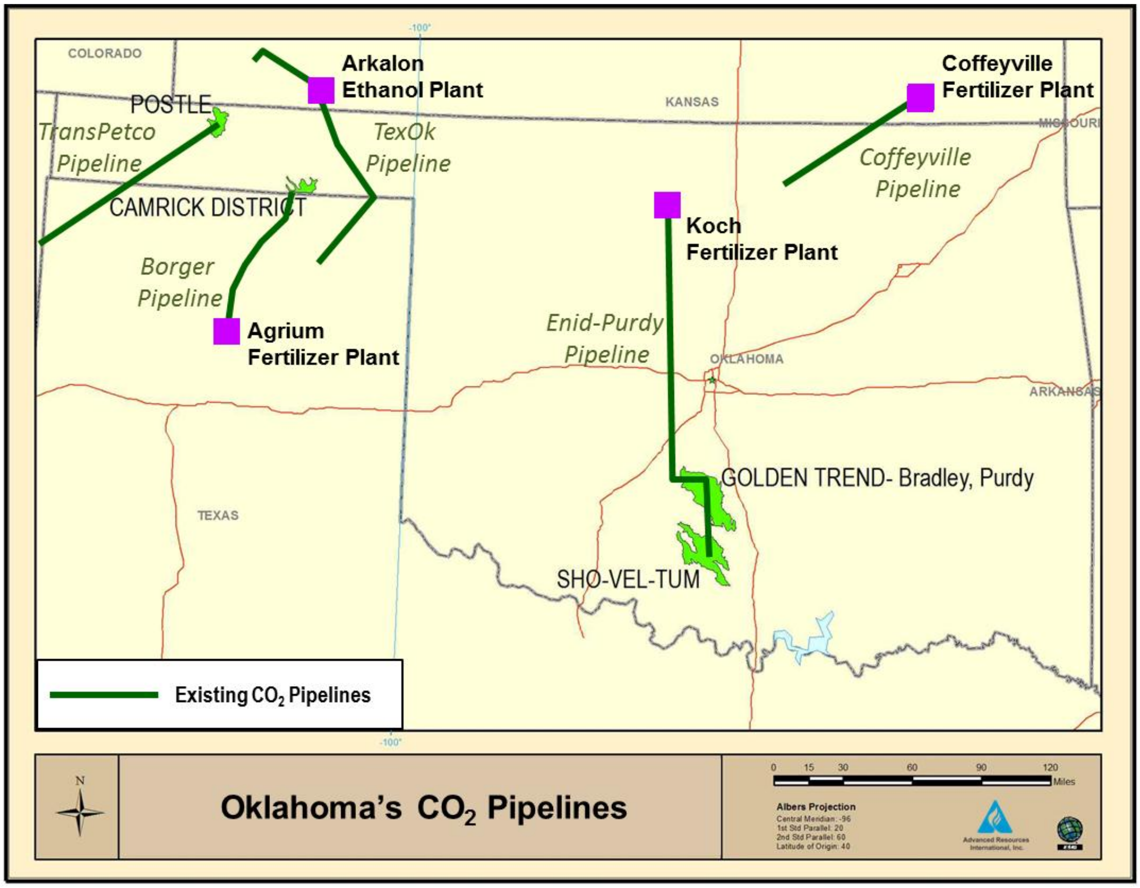


Exhibit 10 Mid-Continent CO_2 transportation pipelines

Scale	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
Small Scale Distribution Systems	Coffeyville- Burbank	Chaparral Energy	KS, OK	68	8	80
	Enid-Purdy (Central Oklahoma)	Anadarko	OK	117	8	80
	TransPetco	TransPetco	TX, OK	110	8	80
	TexOk	Chaparral Energy	OK	95	6	70
	Borger	Chaparral Energy	TX, OK	86	4	50

3.6 Other U.S. CO_2 Pipeline Networks

Two other CO_2 pipeline networks exist, one in North Dakota and one in Michigan. The Dakota Gasification pipeline delivers captured CO_2 from the Great Plains Synfuels plant to the Weyburn CO_2-EOR project in Saskatchewan, Canada. (3) The White Frost pipeline delivers captured CO_2 from the Antrim Gas Processing plant to several small-scale CO_2-EOR projects in Otsego County, Michigan. (4) These CO_2 pipelines are listed in Exhibit 11.

Exhibit 11 Other CO_2 transportation pipelines in the U.S.

Region	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
Other	Dakota Gasification (Souris Valley)	Dakota Gasification	ND, SK	204	14	130
Other	White Frost	Core Energy, LLC	MI	11	6	70

4 Potential CO_2 Pipeline Network Expansion

This section provides industry-announced CO_2 pipeline projects as well as potential CO_2 pipeline expansion based on economic modeling with a Department of Energy (DOE) Energy Policy and Systems Analysis office version of the National Energy Modeling System model (hereafter referred to as EP-NEMS).

4.1 Projections Based on Industry Announcements

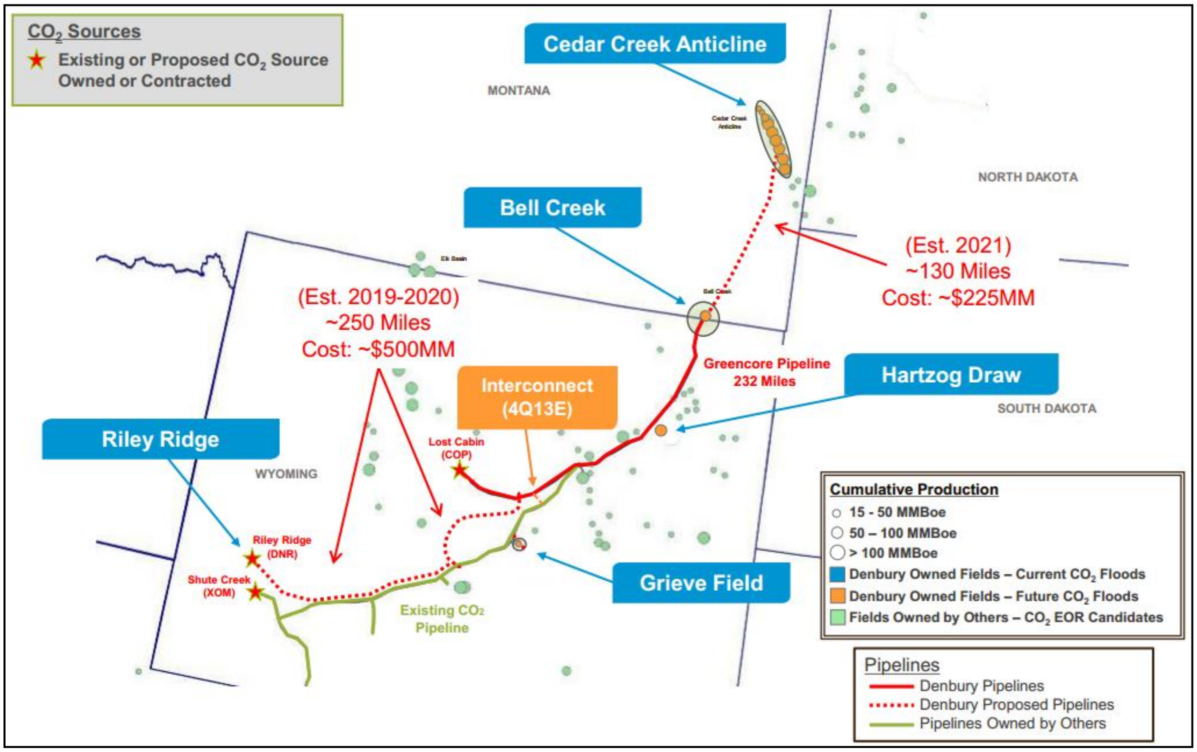
Several new CO_2 pipeline projects have been announced by industry, most of which would connect industrial facilities with CO_2-EOR projects. A summary of these announcements can be found at the end of this section (Exhibit 16).

4.1.1 Wyoming Pipeline Development and Greencore Pipeline Extension

Denbury has announced plans for major CO_2 pipeline developments in Wyoming (Exhibit 12). The company is planning to install a major pipeline to connect new sources of CO_2 at the Riley Ridge Gas Plant to its CO_2-EOR operations in Wyoming. This new pipeline will extend approximately 250 miles, utilizing some existing CO_2 pipeline corridors before linking to the Greencore Pipeline south of the Lost Cabin CO_2 source. Installation of this pipeline is expected between 2019 and 2020 at a cost of approximately $500 million. (6)

Denbury is also planning an extension of the Greencore Pipeline from its current termination at the Bell Creek field to a number of recently acquired oil fields in East Central Montana and Western North Dakota known collectively as the Cedar Creek Anticline (CCA). This new section of the Greencore Pipeline would extend approximately 130 miles from Bell Creek to the CCA, at an estimated cost of $225 million. While the CCA properties were recently acquired, the pipeline extension has been delayed until 2021 while water flooding and field development is conducted in advance of CO_2-EOR operations. (6)

Exhibit 12 Denbury's Wyoming CO_2 pipeline developments



Source: Denbury Onshore LLC (6)

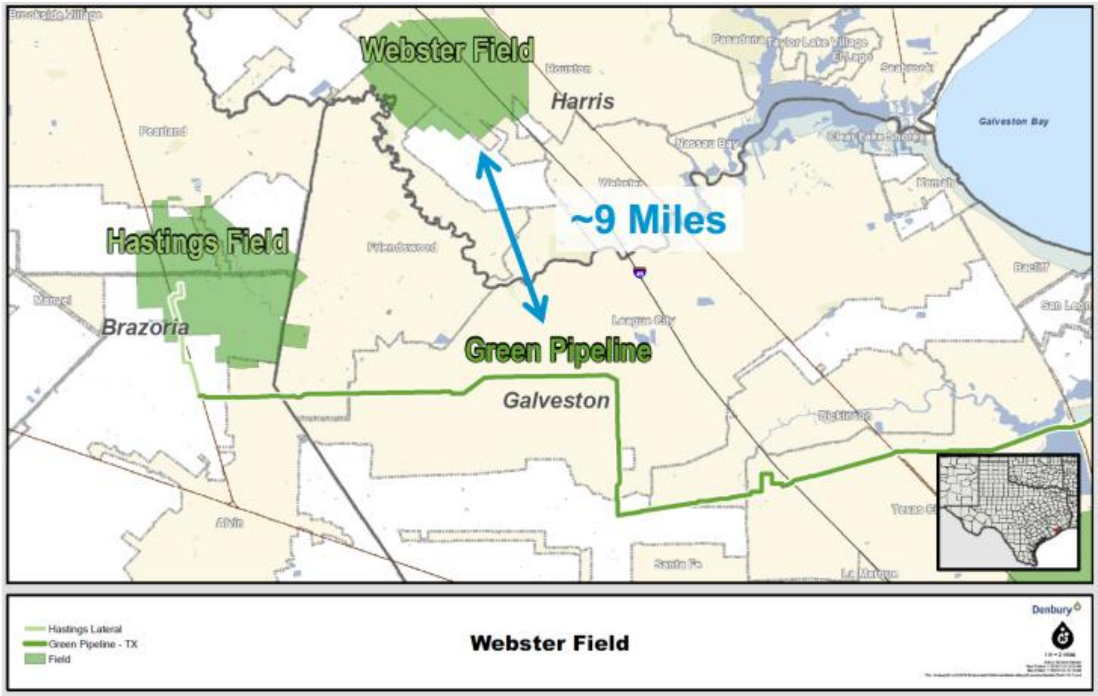
4.1.2 Green Pipeline Laterals

Denbury also has plans to extend two significant CO_2 pipeline laterals from the Green Pipeline to CO_2-EOR operations in East Texas. (6)

Construction of the first lateral began in mid- 2014. This is a 9-mile, 16-inch lateral from the Green Pipeline to the Webster oil field near Harris, Texas (Exhibit 13). Delivery and injection of CO_2 is scheduled for 2016. The cost for construction of this pipeline is estimated at $23 million. The Webster CO_2-EOR project is expected to produce roughly 15,000 barrels of oil per day from a potential 68 million barrels of CO_2-EOR oil. (6)

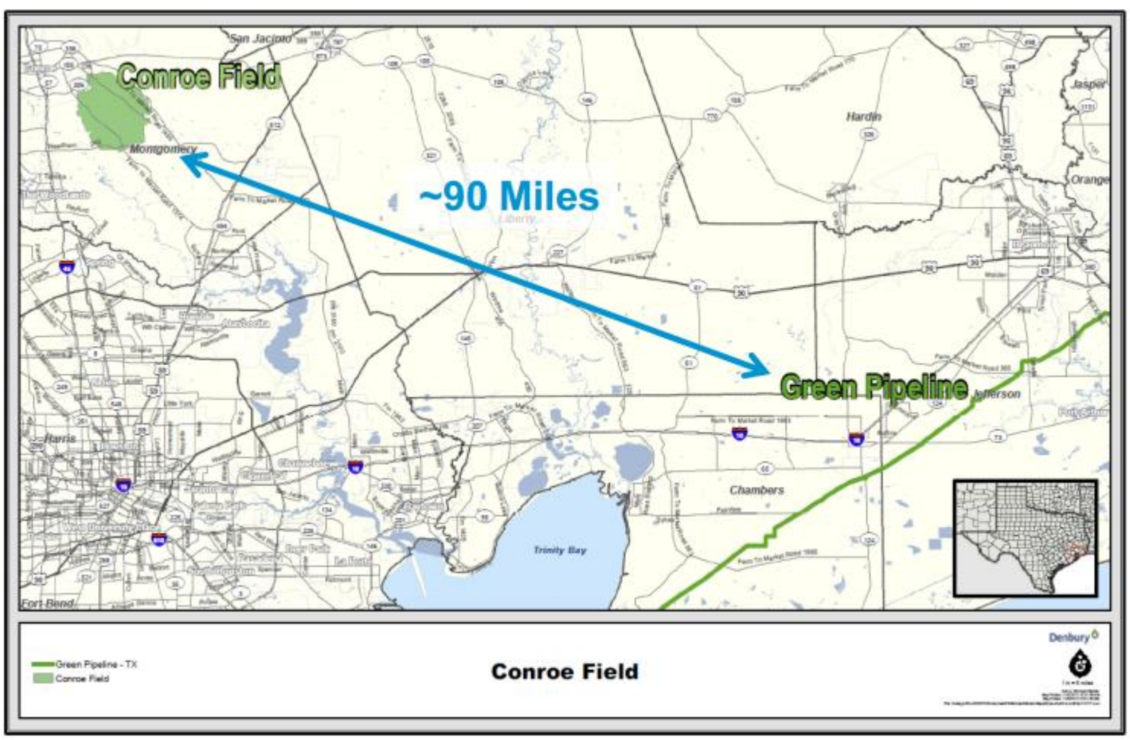
A second lateral to connect the Conroe CO_2-EOR project to the Green Pipeline is also underway (Exhibit 14), with permitting and route selection currently ongoing. The lateral is expected to extend roughly 90 miles from the Green Pipeline near the border of Texas and Louisiana to the Conroe oil field. Construction on the 20-inch pipeline is expected to begin in 2016, with first delivery and injection of CO_2 in 2017, and first oil production in 2018. The Conroe CO_2-EOR operation is expected to yield a peak production of between 15,000 and 20,000 barrels of oil per day from a potential 130 million barrels of CO_2-EOR oil. (6)

Exhibit 13 Planned Webster CO_2 lateral pipeline



Source: Denbury Onshore LLC (6)

Exhibit 14 Planned Conroe CO_2 lateral pipeline

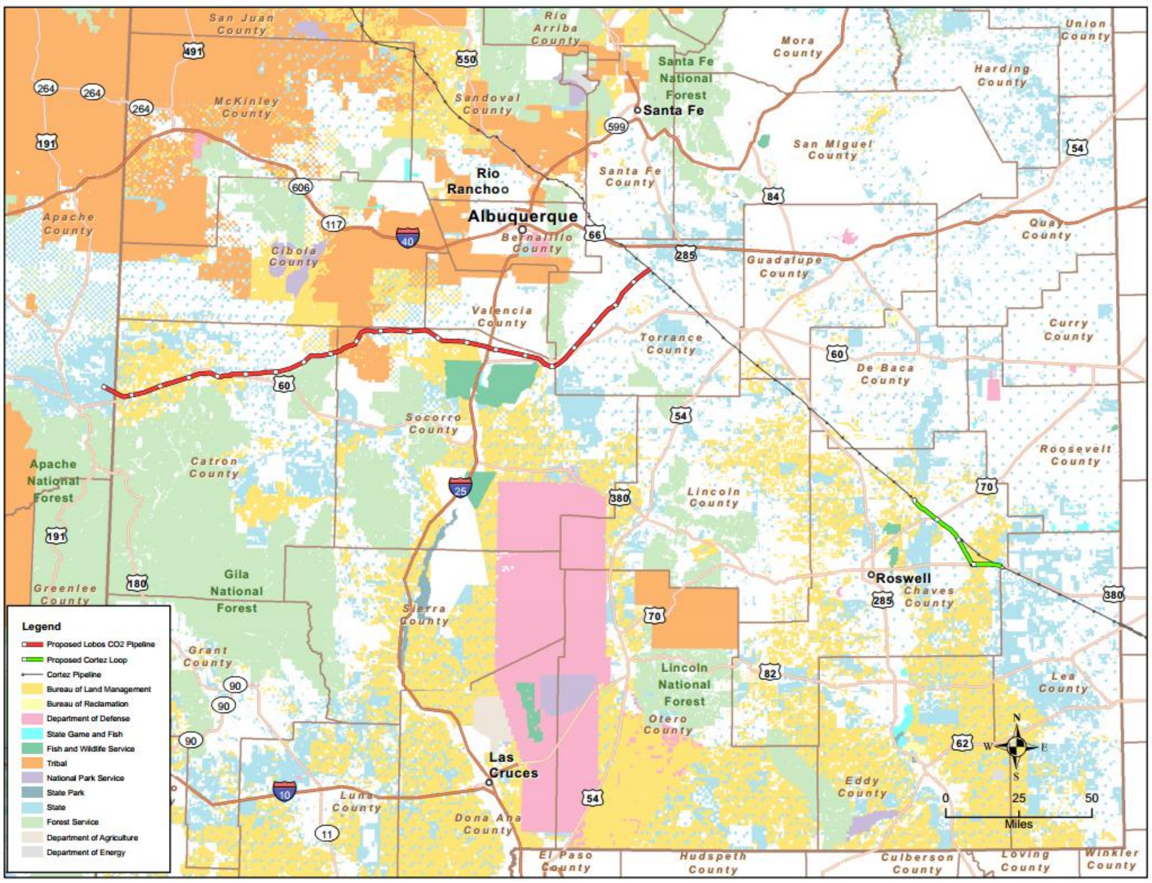


Source: Denbury Onshore LLC (6)

4.1.3 Potential Additional CO_2 Supplies from Natural Sources

Kinder Morgan planned to invest approximately $310 million in a new 16-inch CO_2 pipeline to connect St. Johns Dome, a large natural CO_2 source located on the border of Arizona and New Mexico, to CO_2-EOR projects in the Permian Basin (Exhibit 15).[3] The pipeline would have extended approximately 214 miles from St. Johns Dome to Torrance County, New Mexico, where it will link with the Cortez Pipeline. Kinder Morgan also planned to expand the capacity of the Cortez pipeline by 300 million cubic feet per day to accommodate additional CO_2 volumes from St. Johns Dome. However, Kinder Morgan recently has withdrawn their Right-of-Way request with the BLM for Lobos pipeline construction. They cite the decline in oil price and a shift in their business strategy as reasons for withdrawal, however the opportunity is open for future development[4].

Exhibit 15 Planned Lobos CO_2 pipeline in New Mexico



Pending permission from Kinder Morgan

[3] http://www.kindermorgan.com/business/CO_2/lobospipeline/default.cfm

[4] http://www.blm.gov/nm/st/en/prog/more/lands_realty/lobos_co2_pipeline.html

4.1.4 Additional CO_2 from Industrial Sources

Based on recent announcements[5] (Exhibit 16), industry is on the brink of capturing significant volumes of CO_2 from industrial sources, in addition to the 740 million cubic feet per day of industrial CO_2 utilized for CO_2-EOR. Using industrial data and published reports, the volume of CO_2 supplies from industrial facilities could reach 3,060 million cubic feet per day by the end of the decade, an increase of over four times the current CO_2 capture and transportation volume.

Many of the proposed industrial capture facilities are being developed with CO_2-EOR in mind. The locations of a number of proposed facilities are within a moderate distance (less than 100 miles) from viable CO_2-EOR oil fields. The construction of these facilities will include pipelines directly to the proposed CO_2-EOR facilities. For example, the Petra Nova Capture Project will capture CO_2 emissions from the W.A. Parish power plant in Thompson, Texas and deliver CO_2 supplies to the CO_2-EOR project at the West Ranch field in Vanderbilt, Texas, via an 80-mile CO_2 pipeline.

Several other proposed industrial capture projects will tie into existing CO_2 pipelines for delivery of CO_2 to established CO_2-EOR operating areas. These projects will require shorter (less than 50 miles) lateral pipelines to connect directly with major CO_2 trunk-lines. For example, CO_2 captured from the Lake Charles Gasification facility in Calcasieu Parish, Louisiana will be transported to the Green Pipeline via a 12-mile lateral. This CO_2 will eventually be utilized by CO_2-EOR facilities in East Texas.

Exhibit 16 provides the CO_2 transportation pipelines associated with proposed industrial CO_2 capture projects.

Exhibit 16 Planned CO_2 transportation pipelines

Project Name	Project Type	Location	Est. Start Date	Length (mi)	Est. CO_2 Transport Capacity Required (MMcfd)
Illinois Industrial Carbon Capture	CCS	Decatur, Il	2015	1	50
Petra Nova	CO_2-EOR	Thompson, TX	2016	82	70
Sargas Texas	CO_2-EOR	Point Comfort, TX	2017	50	40
Lake Charles Co-Generation	CO_2-EOR	Calcasieu Parish, LA	2018	12	200
Medicine Bow CTL	CO_2-EOR	Medicine Bow, WY	2018	TBD	130
Quintana Syngas	CO_2-EOR	South Heart, SD	2018	TBD	108

[5] http://www.globalccsinstitute.com/projects/large-scale-ccs-projects#overview

Project Name	Project Type	Location	Est. Start Date	Length (mi)	Est. CO_2 Transport Capacity Required (MMcfd)
Hydrogen Energy California (HECA)	CO_2-EOR	Kern County, CA	2019	3	124
Indiana Gasification	CO_2-EOR	Rockport, IN	2019	430	285
Texas Clean Energy Project	CO_2-EOR	Penwell, TX	2019	1	140
Mississippi Clean Energy Project	CO_2-EOR	TBD	TBD	TBD	210

4.2 Projections using the EIA NEMS analysis

Three cases were run using EP-NEMS to provide a range of potential CO_2 pipeline expansion scenarios. The first case used a similar set of assumptions to EIA's Annual Energy Outlook (AEO2014) Reference Case projection. In this case, EP-NEMS projects limited additional expansion of U.S. CO_2 pipeline infrastructure, from 2015 through 2040. However, analysis of scenarios that examine the implications of illustrative national climate policies reveals that such policies could significantly change the outlook for CO_2 pipelines. A national carbon policy would create incentives for electric power plants and other industrial facilities to reduce CO_2 emissions through carbon capture technologies, improving the economics for oil production through CO_2-EOR.

Reference Case

The AEO2014 Reference Case, which assumes no new policies or changes to current policies, deployed carbon capture and storage (CCS) to a level below a minimum threshold at which new pipelines were constructed. Since NEMS did not build out new pipelines due to the lack of CO_2 capture, the following discussions include no further comparisons between the Reference Case and the two other cases.

Extended Policies Case (Cap40)

In the EIA Extended Policies Case, existing tax credits that have sunset dates are assumed not to sunset, and other policies (i.e., Corporate Average Fuel Economy [CAFE] standards, appliance standards, and building codes) are expanded beyond current provisions. The EP-NEMS run for this report is not an EIA side case. It was developed for DOE's Energy Policy and Systems Analysis (EPSA) office, using the standard EIA Extended Policy Case as the basis for the run and including additional assumptions and modifications affecting several sectors. In particular, in the transportation sector, aviation efficiency was assumed to improve by 1.5 percent per year. In addition, heavy duty vehicle fuel economy (measured in miles per gallon) was assumed to improve by 9 percent by 2040. Biofuels were assumed to realize a 20-30 percent reduction in cost while biomass was assumed to experience a 20 percent decrease in fuel supply costs. (7)

The Extended Policies Case further assumed higher building efficiency standards and a significant reduction in energy consumption by the industrial sector. The Production Tax Credit (PTC) and the Investment Tax Credit (ITC) for wind and solar were assumed to be extended indefinitely and an economy-wide CO_2 emissions cap was imposed, reducing emissions by 40 percent from 2005 by 2030 and a total of 80 percent from 2005 levels by 2050. Finally, nuclear at risk retirements that were stated in the Reference case were removed from this case. (7)

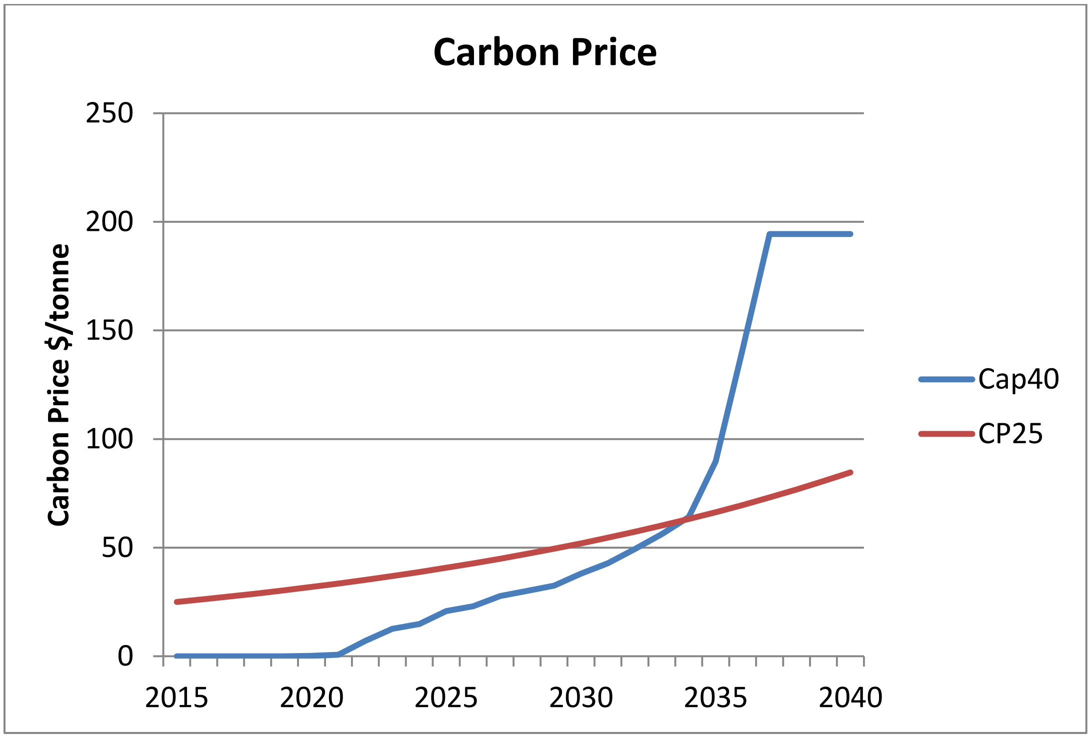
AEO2014 Early Release Case with a carbon price of $25/tonne (CP25)

The CP25 case assumes a $25/tonne price on CO_2 emissions. The price on is economy wide, begins in 2015, and increases by 5 percent annually through 2040. This pathway matches the EIA's AEO2014 $25 Carbon Price side case. (8) This illustrative national carbon policy is not intended to represent any actual or proposed policy, but instead is used as a means to understand the extent to which a climate policy would drive growth in CO_2-EOR demand, and consequently in CO_2 pipeline infrastructure. Currently, just over 4 percent of total U.S. crude oil production is currently produced through EOR, though this is projected to increase to 7 percent by 2030. (5)

4.2.1 CO_2 Price and CO_2 Emissions Results

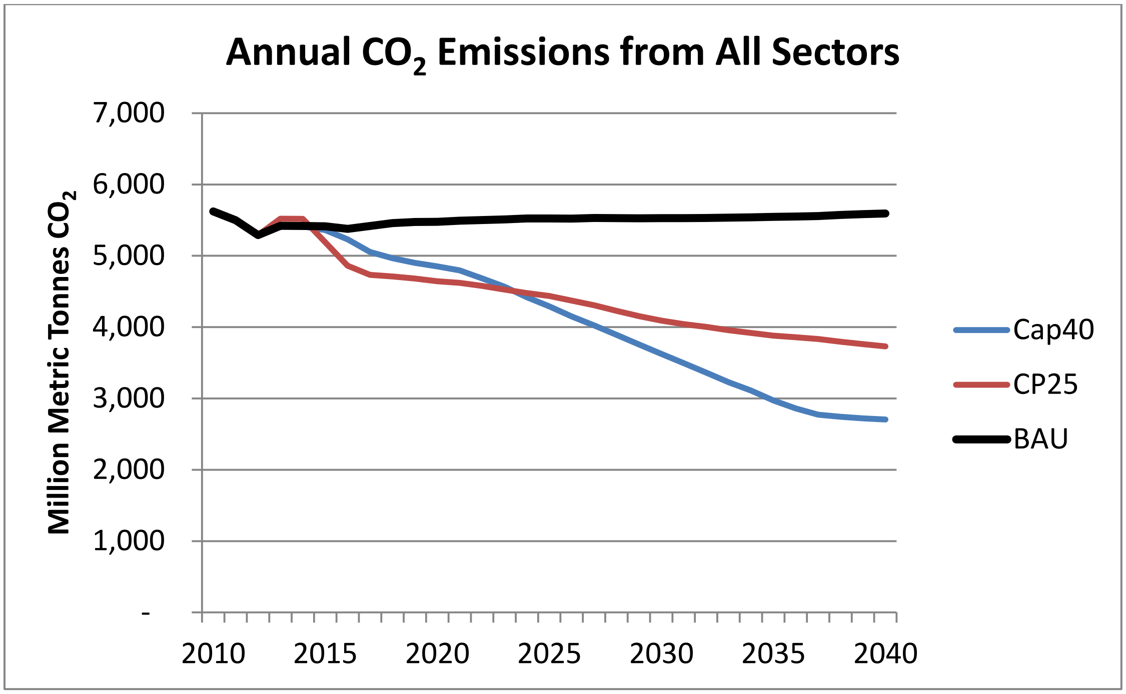
The price of CO_2 in the CP25 case, as stated above, begins at $25/tonne in 2015 and increases to $52/tonne in 2030, and nearly $85/tonne by 2040, as seen in Exhibit 17. The Cap40 CO_2 price begins at $0/tonne and does not increase until the 2021 time frame. The price then increases at an exponential rate, reaching $38/tonne by 2030 and nearly $200/tonne by 2036, where it remains for the rest of the model time horizon.

Exhibit 17 CO_2 Price under the Cap40 and CP 25 scenarios



As the price per tonne of CO_2 increases, the amounts of CO_2 emissions decrease in each case. Exhibit 18 shows that the Cap40 reduces CO_2 emissions at a greater rate than the CP25 case, and by 2040, reduces CO_2 emissions by nearly 1 billion more tonnes cumulatively than the CP25 case and almost 3 billion more tonnes than the Reference case.

Exhibit 18 CO_2 Emission reductions for all sectors under the Cap40 and CP 25 scenarios

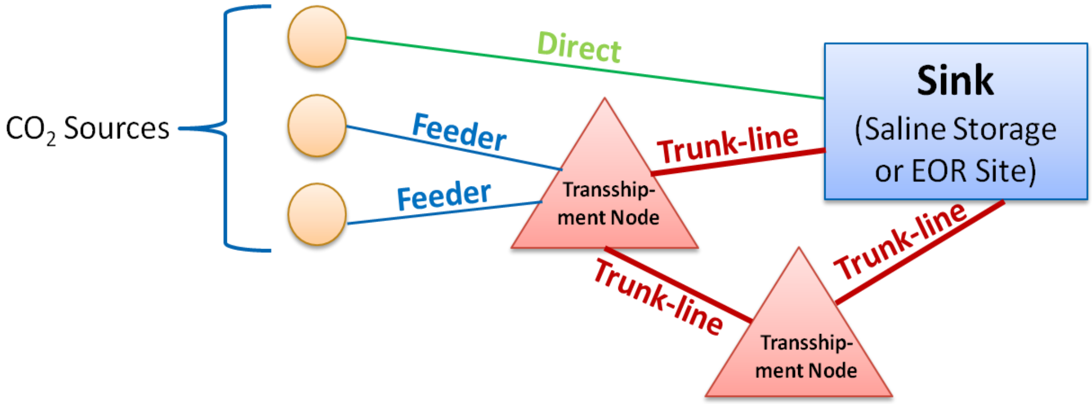


4.2.2 CO_2 Pipeline Expansion Results

CO_2 pipelines are segmented into different types depending on where in the supply chain they are located and how they are used. The following is a list of how different segments of pipeline are defined, and Exhibit 19 provides a schematic of the CO_2 pipeline infrastructure.

- Direct – Dedicated pipeline from CO_2 source to sink
- Feeder – Dedicated pipeline from source to transshipment node
- Trunk-line – Shared pipeline from transshipment node to any other node or sink
- Interstate – Pipeline that crosses between two states
- Intrastate – Pipeline that stays within one state

Exhibit 19 CO_2 pipeline schematic



In the CP25 case, by 2030, EP-NEMS projects over 11,000 miles of new CO_2 pipelines (Exhibit 35), primarily from electric power plants to EOR projects and saline storage sites. By 2030, there are 56 new pipeline segments in use to transport captured CO_2 from its source to a terminal sink (EOR or Saline Storage). Under this scenario, regional oil production from EOR occurs predominantly in the Southwest; however, production also significantly increases in the Midcontinent, West Coast and Gulf Coast regions.

In terms of sources for the CO_2, by 2030, the CP25 case projects a tripling of CO_2 capture in the U.S., with over 99 percent of this coming from the power sector (Exhibit 37). Under this scenario, an 11 percent reduction in CO_2 emissions (94 MMT CO_2) from the U.S. power sector (Exhibit 36) would come through the application of carbon capture technologies to over 32 GW of generation capacity (Exhibit 38)[6].

In terms of sinks for the CO_2, oil production from CO_2-EOR is projected to increase to over 10 percent of total U.S. production by 2030 (Exhibit 39). This would account for nearly 95 percent of CO_2 sequestration, with the balance being stored in underground saline formations.

In the CP25 case, direct pipelines make up 48 percent of the total pipeline miles and 23 percent of the tonne-miles transported. This is significantly less than the 79 percent of total miles dedicated to direct pipelines in the Cap40 case. Additionally, there is about 5,000 miles more of pipeline in the CP25 than in the Cap40 case; nearly all of that difference comes from an increase in the use of shared trunk-lines. While the CP25 results in fewer GWs of power plant capacity with capture (about 71 GW vs. 79 GW in the Cap40 case), they are distributed over a greater number of plants, thus increasing the total pipeline mileage in the CP25 case (Exhibit 20).

Exhibit 20 CO_2 transportation by market segment (2040)

Cap40 Results					
Pipe Type	Total Miles	%	Average Miles	Million Tons CO_2	%
Total	15,194	100	205	468,906	100
Direct	11,977	79	244	269,674	58
Feeder	2,458	16	123	65,309	14
Trunk-lines	760	5	152	133,923	29
Interregional	7,448	49	219	221,823	47
Intraregional	8,411	55	210	247,083	53
CP25 Results					
Pipe Type	Total Miles	%	Average Miles	Million Tons CO_2	%
Total	21,496	100	197	841,086	100
Direct	10,355	48	280	194,038	23
Feeder	5,475	25	112	125,794	15
Trunk-lines	5,666	26	246	521,254	62
Interregional	11,478	53	239	370,276	44
Intraregional	10,018	47	164	470,810	56

[6] Of this 32 GW, 5.9 GW is coal-fired and 26.5 GW is gas-fired.

In the Cap40 case, 12-inch pipes are used exclusively in direct connections; however, 85 percent of them crossed state lines. 60 percent of the 16-inch pipeline miles are associated with direct connections, with 45 percent of them being interstate pipelines. All of the pipes greater than 16 inches were used as either feeders into trunk-lines or as trunk-lines, 27 percent of which were interstate lines (Exhibit 21).

In the CP25 case, 12-inch pipes make up almost 90 percent of all the direct pipelines, with the balance carried by 16-inch pipelines. As in the Cap40 case, in the CP25 case, 12-inch pipes are used exclusively in direct connections and a large majority (78 percent in this case) cross state lines. The larger plants (those with emissions >3.25 MMT/yr – approximately equivalent to the emissions of a 500 MW coal plant) fed into trunk-lines while most of the smaller plants used direct pipelines.

Exhibit 21 CO_2 transportation by miles as a function of pipeline diameter (2040)

Cap40					
Pipeline Miles					
Pipe Type	Pipeline Diameter (in)				
	12	16	20	24	36
Total	8,623	5,632	192	582	165
Direct	8,623	3,354	-	-	-
Feeder	-	2,171	192	94	-
Trunk-lines	-	107	-	488	165
Interregional	3,866	3,488	-	94	-
Intraregional	4,758	2,145	192	488	165
MMT-Miles	135,434	185,295	13,101	97,877	43,199
% of Total	29	40	3	20	9
CP25					
Pipeline Miles					
Pipe Type	Pipeline Diameter (in)				
	12	16	20	24	36
Total	9,251	6,706	158	4,370	1,011
Direct	9,251	1,104	-	-	-
Feeder	-	5,317	158	-	-
Trunk-lines	-	285	-	4,370	1,011
Interregional	6,693	2,014	-	2,006	765
Intraregional	2,558	4,692	158	2,365	246
MMT-Miles	147,141	186,374	4,840	322,990	179,740
% of Total	17	22	1	38	21

Total CO_2 pipeline development costs depend on a number of variables, including length, pipeline diameter, terrain, and other regional variations. However, total cost for a CO_2 pipeline project in a given region can be determined by examining a similar project in the Permian Basin.

Similar to oil field infrastructure development, capital costs for CO_2 pipelines are lowest in the Permian Basin. For example, the 214 mile, 16-inch Lobos pipeline is expected to cost approximately $300 million. Other announced CO_2 pipelines in the Gulf Coast and Rocky Mountain regions are expected to cost between 25 percent and 33 percent more per inch-mile than the Lobos pipeline. These additional costs are likely due to harsher terrain, navigation through denser populations, and less competition among developers capable of undertaking such technically-demanding work.

Based on recent announcements[7], industry is on the brink of capturing significant volumes of CO_2 from industrial sources, including the 740 million cubic feet per day of industrial CO_2 utilized for CO_2-EOR. Using industrial data and published reports, the volume of CO_2 supplies from industrial facilities could reach 3,060 million cubic feet per day by the end of the decade, an increase of over four times the current CO_2 capture and transportation volume from industrial sources.

Exhibit 22 shows that the average cost per mile of pipeline is $562,000 in the CP25 case, which is about 40 percent higher than in the Cap40 case. This difference is largely attributed to the greater use of larger diameter trunk-lines in the CP25 case. A trunk-line is built when it is more economical (on a $/tonne basis) for more than one source to share a pipeline than build a dedicated (direct) pipeline. Because the trunk-line carries the combined volume of two or more sources, a larger diameter pipeline is required. The larger the diameter of a pipeline, the greater the cost per mile, although the cost per tonne of CO_2 carried may be less than a smaller pipeline (depending upon utilization). Exhibit 33 and Exhibit 34 in the Appendix provide state-level detail for inter- and intra-state pipeline segments.

[7] http://www.globalccsinstitute.com/projects/large-scale-ccs-projects#overview

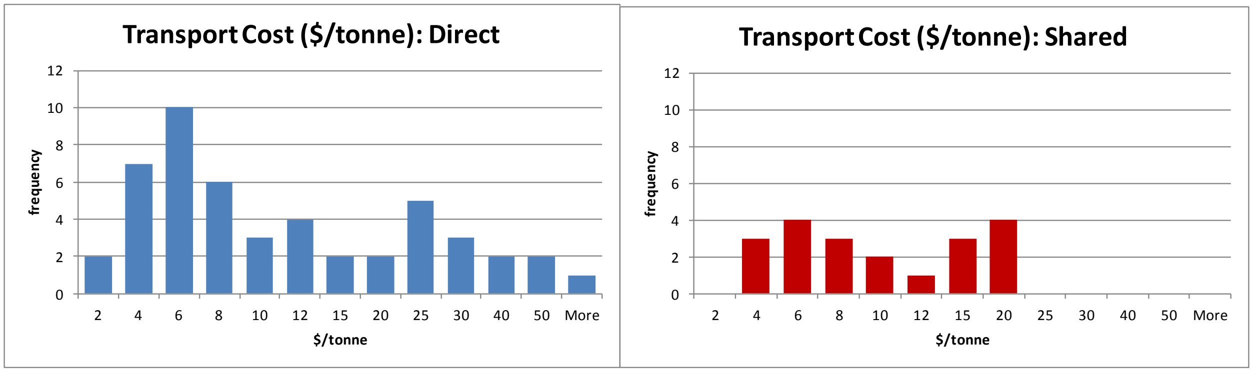
Exhibit 22 Inter- and Intrastate pipeline segments (2040)

Cap40				
	Units	Interstate Pipelines	Intrastate Pipelines	Total/Average
Number of Links		37	37	74
Direct		30	19	49
Feeder		6	14	20
Trunk-lines		1	4	5
Average Distance	mi	278	133	243
Average Cost	MM$	119	49	105
Total Miles	mi	10,278	4,916	15,194
Total CO_2	MMT	1,059	1,181	2,240
Total Tonne-miles	MMT-mi	10,880,053	5,803,705	16,683,758
Average Cost/mi	($1000)	362	203	330
CP25				
	Units	Interstate Pipelines	Intrastate Pipelines	Total/Average
Number of Links		60	49	109
Direct		24	13	37
Feeder		20	29	49
Trunk-lines		16	7	23
Average Distance	mi	251	132	244
Average Cost	MM$	199	73	173
Total Miles	mi	15,036	6,460	21,496
Total CO_2	MMT	1,960	2,380	4,340
Total Tonne-miles	MMT-mi	29,477,059	15,378,094	44,855,153
Average Cost/mi	($1000)	624	323	562

Transportation costs are calculated as the cost to transfer one tonne of CO_2 from its origin (capture point) to its terminus. There are only two path options: direct (a dedicated pipeline from origin to terminus) and shared (where several sources of CO_2 are collected at a transshipment point and then transported via a trunk-line to the terminus).

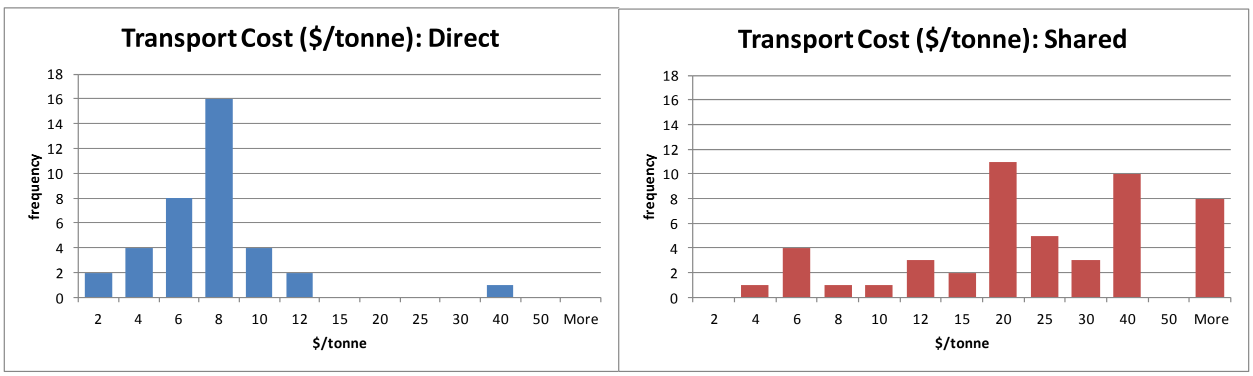
In the Cap40 case, for both direct and shared pipelines, the majority of the costs are below $8/tonne (Exhibit 23). While the distribution of costs is much greater for the direct pipelines versus shared, the median cost of transport is similar between the two: $7.92 for direct pipelines and $8.46 for shared.

Exhibit 23 Transportation Costs for the Cap40 case



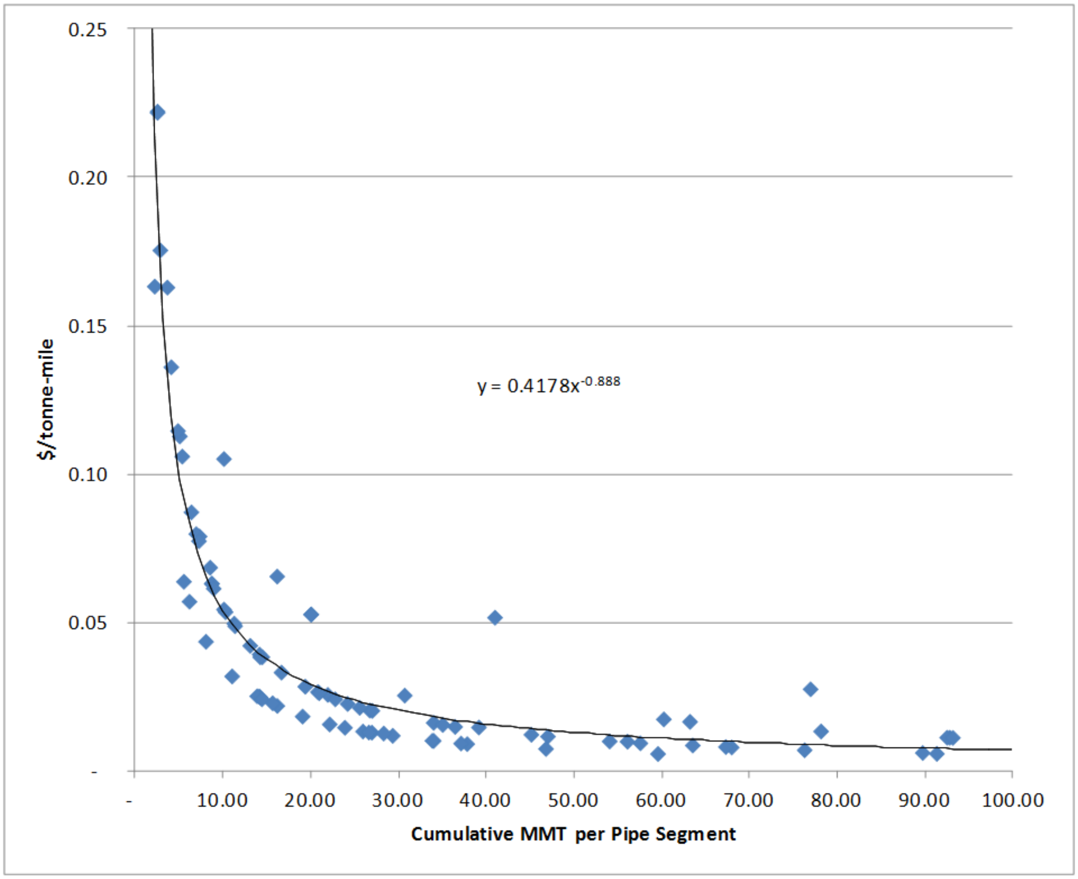
Unlike the Cap40 case, which saw similar costs per tonne between the direct and the shared pipelines, there is a greater difference between the pipeline types in the CP25 case with the median cost of a direct pipeline at $6.38/tonne and that of a shared pipeline being $20.75/tonne (Exhibit 24).

Exhibit 24 Transportation costs for the CP25 case



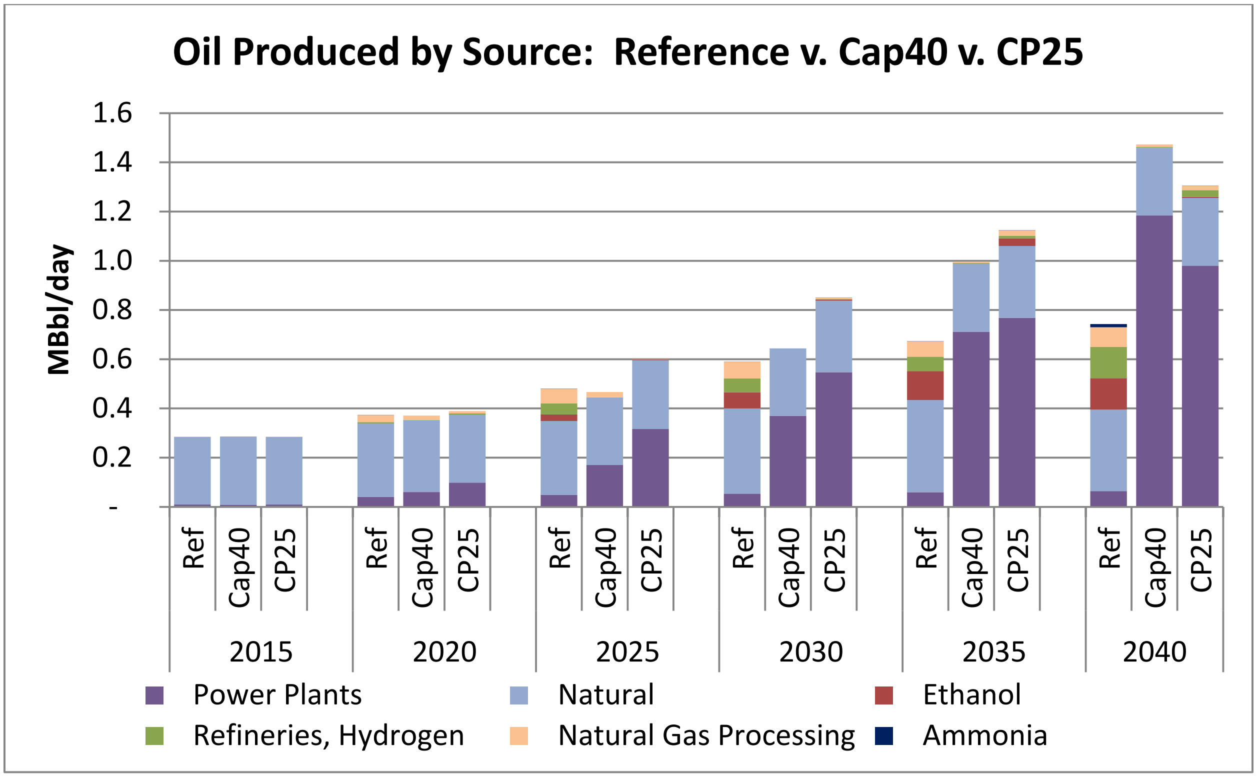
Pipeline transportation costs are heavily reliant on the volume of product moved through them. Exhibit 25 shows that as the amount of CO_2 that is transported increases, there is a notable decrease in costs per MMT of CO_2 delivered due to economies of scale.

Exhibit 25 Transportation cost as a function of CO_2 throughput



Despite more miles of pipeline being built in the CP25 case, less CO_2 is captured compared to the Cap40 case. This ultimately results in less oil produced from EOR. Exhibit 26 shows that in 2040, there are 1.3 MMBbls/day of oil produced under the CP25 case, while 1.5 MMBbls/day is produced in the Cap40 case. For each case, this represents over 16 percent of total oil production in 2040, with the majority of the CO_2 captured for EOR production coming from power plants, while the amount of naturally sourced CO_2 decreases in the Cap40 case and remains nearly constant from 2015 - 2040 in the CP25 case. By comparison, the Reference case sees a very small increase in CO_2 production from power plants over the modeled period.

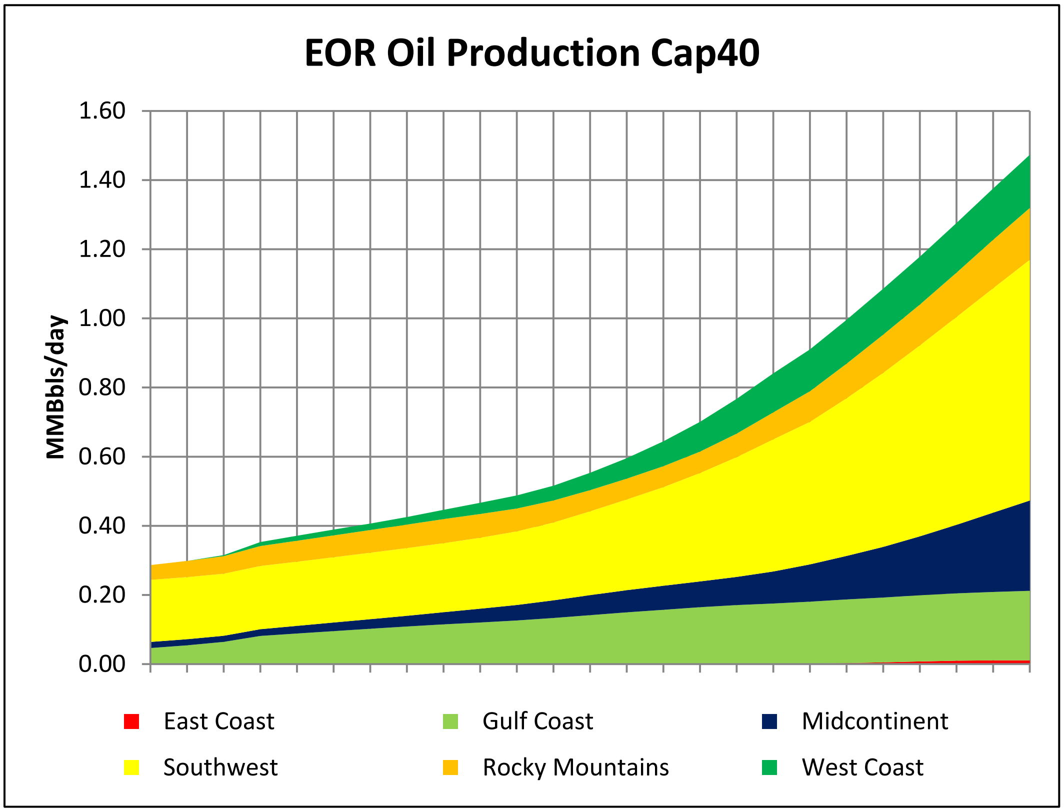
Exhibit 26 Oil produced by source for all three cases*



* Approximately 0.4 tonnes CO_2/barrel oil

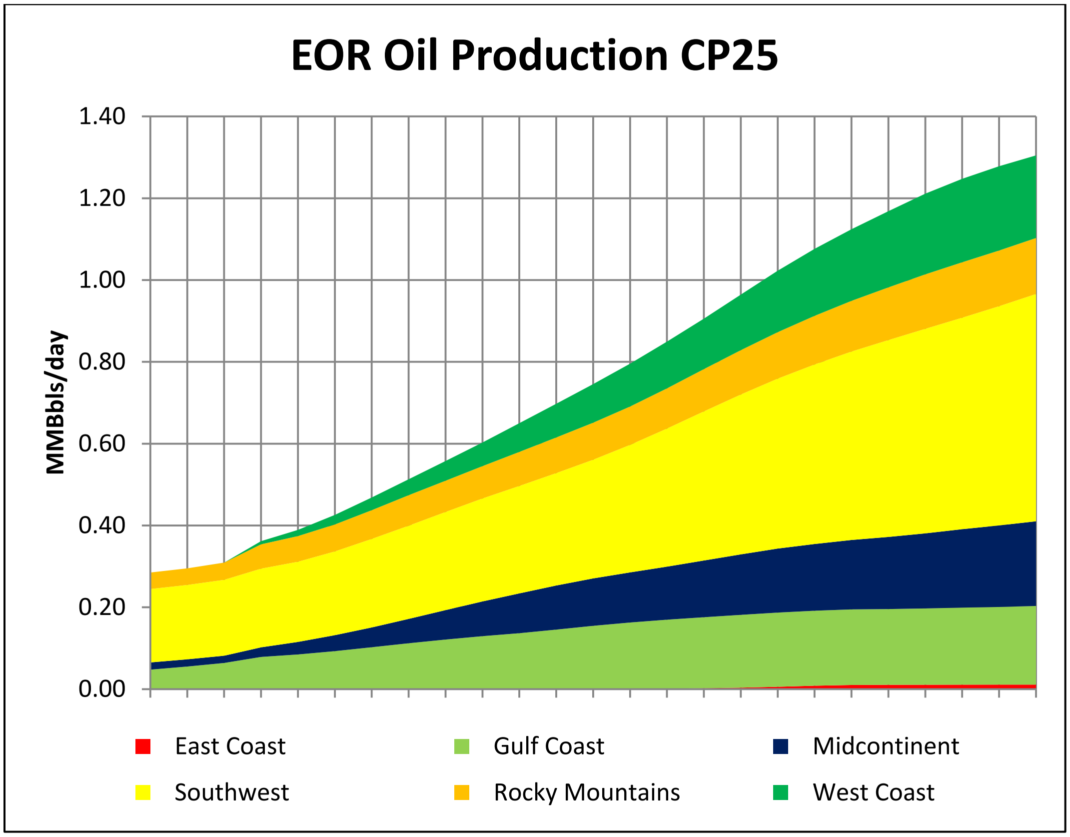
Regional oil production from EOR in the Cap40 case is dominated by the Southwest, where nearly half of the EOR oil production is derived. The Midcontinent and Gulf Coast regions also significantly increase production. There is a small increase in production on the West Coast, while the Rocky Mountain region remains steady through the 2040 period (Exhibit 27).

Exhibit 27 Oil Production by EOR in the Cap40 case



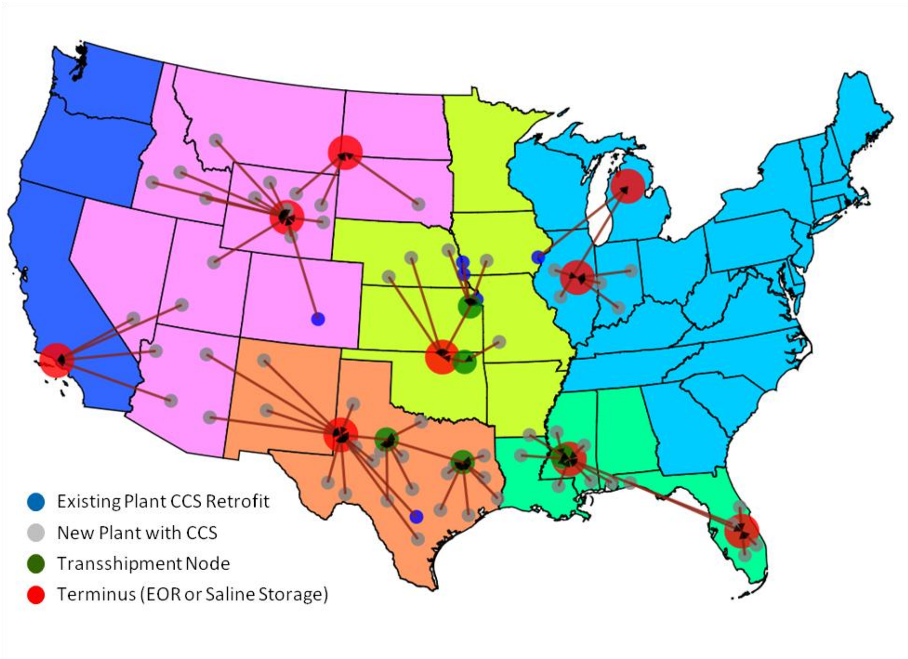
The regional distribution of CO_2 is similar in the CP25 when compared to the Cap40 case, as Exhibit 28 shows, with the Southwest playing the most significant role (followed by the Midwest and the West Coast)

Exhibit 28 Oil Production by EOR in the CP25 case



In the Cap40 case, by 2040, there are 73 new pipeline segments in use for CO_2 capture, transport, utilization, and storage (CTUS) from its source to a terminal sink (EOR or Saline Storage). The greatest activity occurs in Texas, where EOR activity in the Permian basin attracts CO_2. Trunk-lines are typically employed where there are a relatively high concentration of sources, such as Texas, Mississippi, and Louisiana (Exhibit 29).

Exhibit 29 Power plant pipeline build-out by 2040 for the Cap40 case



In the CP25 case (Exhibit 30), by 2040, there are 107 new pipeline segments in use to transport captured CO_2 from its source to a terminal sink (EOR or Saline Storage). As in the Cap40 case, the greatest activity occurs in Texas, where EOR activity in the Permian basin attracts CO_2, and trunk-lines are typically employed where there are a relatively high concentration of sources, such as Texas, Mississippi, and Louisiana.

Exhibit 30 Power plant pipeline build-out by 2040 for the CP25 case

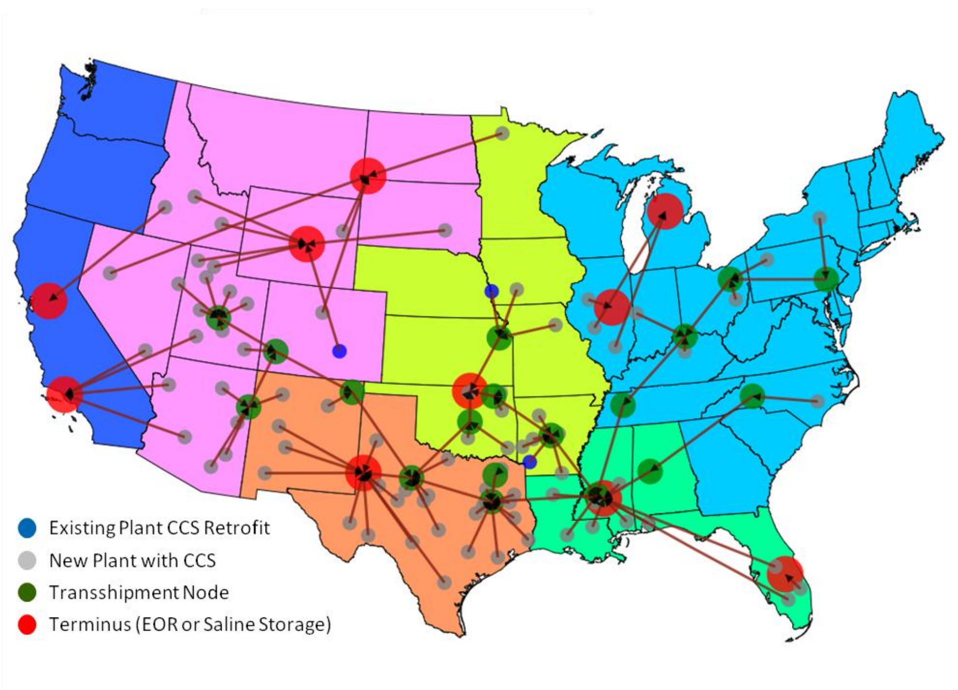
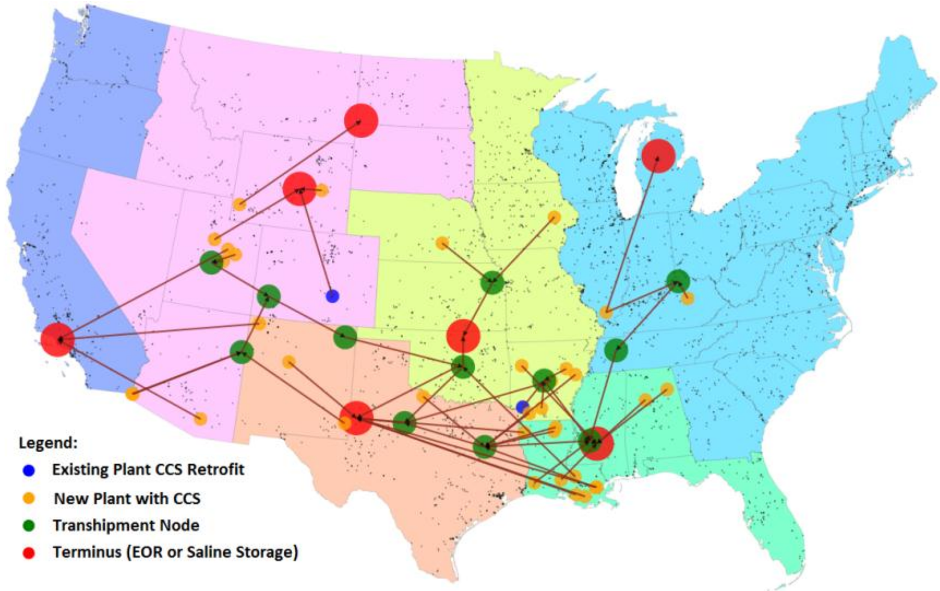


Exhibit 31 Power plant pipeline build-out by 2030 in the $25/tonne CO_2, low carbon scenario



4.2.3 Rates of Projected Pipeline Construction

In the CP25 case, construction through 2030 would more than triple the size of current U.S. CO_2 pipeline infrastructure, through an average annual build-rate of nearly 1,000 miles per year. As noted above, just over 600 miles (or 5 percent) of additional pipelines are coming online[8] (i.e., not modeling projections, but actual projects) for construction by the end of this decade, which would be consistent with the pace of CO_2 pipeline construction in the past, averaging roughly 100 miles per year.

Over a dozen different companies currently operate in this sector, including ExxonMobil, Kinder Morgan, Chevron, Devon, and Anadarko. Among the most active is Denbury Resources, which recently completed two long-distance CO_2 pipelines – the Green Pipeline in Louisiana and Texas and the Greencore Pipeline in Wyoming and Montana, totaling roughly 550 miles in length – both of which were constructed between 2009 and 2013. As another point of reference, it is worth noting that ICF International (ICF) (9) projects significant expansions in large-diameter petroleum product and natural gas pipelines over the next two decades (through 2035): up to 17,000 and 47,000 miles total, respectively; at average annual rates greater than 1,000 miles per year.[9]

[8] New industrial CO_2 capture facilities coming on line (e.g., Air Products PCS Nitrogen plant in southern Louisiana, Southern Company's integrated gasification combined cycle (IGCC) plant in Kemper County, Mississippi, etc.)

[9] This total includes ICF estimates of all new pipelines greater than 8 inches in diameter. If smaller diameter pipelines (e.g., gathering lines) are included, the estimated miles of new natural gas and petroleum product pipelines is nearly an order of magnitude greater.

5 Permitting, Regulations, and Policies

5.1 Overview

The process of designing and constructing a CO_2 pipeline is a significant task, requiring the involvement of numerous agencies and stakeholders. Based on discussions with industry and information from the 2013 Global CCS Institute survey of large-scale integrated CO_2 capture, transportation and utilization; it takes between one and two years for a project to navigate the necessary permits for construction to begin on a CO_2 pipeline. (10) Much of this time requirement depends on the terrain and location of the pipeline. The majority of CO_2 pipeline projects are sited on farmland and industrial areas, which require the least amount of time for permitting. Pipelines sited within populated areas, federal lands, protected areas, and rough terrain require a more rigorous permitting process. If a pipeline crosses Federal land, permits from the relevant Federal agencies and the accompanying environmental review under NEPA, in addition to notifying potential stakeholders, are required by the Bureau of Land Management (BLM) prior to siting and construction[10].

CO_2 transportation pipelines are subject to federal safety regulations set forth by the U.S. Department of Transportation. However, except for safety, the federal agencies have asserted limited direct oversight of CO_2 pipeline infrastructure. Oversight of siting, construction, and operations of CO_2 pipelines is largely administered at the state level. State with laws that are specific to CO_2 pipelines, EOR and underground storage are varied and generally limited to those regions with CO_2-EOR projects. (11)

5.2 Federal Regulation

5.2.1 General Oversight

The Federal Energy Regulatory Commission (FERC) is responsible for regulating the sale and transportation of natural gas under the Natural Gas Act, Chapter 15B §717(b). (12) However, FERC has rejected oversight of CO_2 transportation pipelines following an inquiry by the Cortez Pipeline Company in 1979. In its ruling, FERC determined that high-purity CO_2, in this case used for CO_2-EOR, cannot be considered natural gas at the compositional level, and therefore is not subject to FERC regulation. (13)

Similarly, the Interstate Commerce Commission (ICC) determined that its oversight does not include CO_2 transportation pipelines following a similar petition by the Cortez Pipeline Company in 1981. In its ruling, the ICC confirmed that interstate pipeline transportation of gas, oil, or water is exempt from ICC oversight and concluded that CO_2 is ultimately transported as a gas (although it is typically in a supercritical liquid phase during transportation). (14)

Following these two decisions, the U.S. Government Accountability Office (GAO) determined that ultimate oversight of CO_2 transportation pipelines falls under the U.S. Department of Transportation's (DOT) Surface Transportation Board (STB), even though this office is primarily responsible for regulating interstate transportation by rail or pipeline of commodities

[10] "Currently, the Bureau of Land Management regulates CO2 pipelines under the Mineral Leasing Act as a commodity shipped by a common carrier. See: 30 U.S.C. § 185(r)."

"other than water, oil, or gas." (15) The STB has yet to be asked to hear a case involving the transportation of CO_2, so its oversight status remains unaddressed following the GAO decision. (15)

5.2.2 Safety Oversight

CO_2 transportation pipelines are subject to federal safety regulations that are administered by the U.S. DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA). PHMSA directly oversees pipeline safety for all interstate lines, while intrastate pipelines are subject to state agency oversight (as long as the standards are at least as stringent as the federal rules). (13)

The major risks of a CO_2 pipeline incident are prolonged exposure to high CO_2 concentrations. However, of nearly 2,000 hazardous liquid and CO_2 transport pipeline accidental release incidents reported between 2010 and the March, 2015, a total of 21 incidents occurred for CO_2 transport pipelines, none of which resulted in either fatality or injury. (16)

While CO_2 is not considered a hazardous material by DOT, CO_2 transportation pipelines are regulated under 49 CFR Part 195, Transportation of Hazardous Liquids by Pipeline. This distinction is made due to the nature of the transportation pipelines, which carry the highly pressurized CO_2 in a liquid phase similar to other hazardous material transportation pipelines. Smaller CO_2 distribution lines, which transport the CO_2 from the trunk-line to individual wells, are generally not subject to these PHMSA safety standards.

5.3 Pipeline Siting and Eminent Domain

Builders are not required to obtain federal siting authority for construction of new CO_2 transportation pipelines. However, the federal government also has no power of eminent domain regarding CO_2 pipelines, except when CO_2 pipelines are to be built on federal lands. All CO_2 pipeline issues of siting and eminent domain are subject to individual state regulation. (17)

5.3.1 Texas/New Mexico

In Texas, an operator may exercise its right of eminent domain if it has declared itself a common carrier, which deems the CO_2 pipeline open to transport for hire by the public. (18) This provision does not limit the carrier to transporting CO_2 specifically for EOR purposes. On the other hand, New Mexico allows for any person, firm, or corporation to exercise eminent domain to secure a right-of-way for a pipeline on both public and private lands. (19) The operator need not be considered a common carrier to exercise eminent domain. Any disputes over eminent domain are given to the State legislature to determine whether the property in question is obtained for public use. (15) The state of Texas also has policy incentives, including a reduction in its severance tax rate by eighty percent for oil produced from EOR using anthropogenic CO_2.

5.3.2 Mississippi

The state of Mississippi exercises a more limited use of eminent domain for the construction of CO_2 transportation pipelines. Eminent domain in this case is reserved for pipelines transporting CO_2 for secondary or tertiary recover of liquid hydrocarbons. (20) Pipelines intended for use in transporting CO_2 solely for storage purposes will not be granted eminent domain rights as the rule is currently written.

5.3.3 Other States

Many states have yet to fully address the issue of CO_2 pipeline siting and eminent domain. It will be up to the pipeline operators to engage the proper authorities and ensure compliance with federal and state regulations as necessary. The time required to develop a CO_2 pipeline project will be determined by the familiarity of state agencies with proper pipeline regulation. An additional learning curve could apply to states that are not familiar with pipeline oversight of any kind, increasing the overall time necessary for development.

5.4 Other State Policies

The Wyoming Pipeline Authority (WPA) was created to "plan, finance, construct, develop, acquire, maintain and operate a pipeline system or systems within or without the state of Wyoming to facilitate the production, transportation, and distribution and delivery of natural gas and associated natural resources produced in (the) state…" (21)

Rather than leave future pipeline planning up to individual operators, the WPA assists pipeline developers through the pipeline construction process by serving as a facilitator and information provider to industry, state government, and the public. As such, the WPA serves as one example for states in terms of conducting early planning for potential CO_2 pipeline projects and thus helping advance CO_2-EOR.

6 Conclusions

The bulk of the existing large-volume CO_2 pipelines connect natural sources of CO_2 with CO_2-EOR projects in large oil fields. In the coming 5 to 10 years, the completion of several planned projects could deliver a five-fold increase in the capture of CO_2 by industrial facilities, up to levels that could exceed the scale of CO_2 production from natural sources. This is expected to be accompanied by a 12 percent increase in the total miles of CO_2 pipeline infrastructure over the period. While these new pipeline projects are primarily for the CO_2-EOR industry, they will provide valuable infrastructure for additional utilization of CO_2 as well as potential future transportation and storage of CO_2 in saline formations.

However, under a U.S. climate policy case (i.e., \$25/ton CO_2), by 2030 the scale of U.S. CO_2 pipeline infrastructure is projected to triple 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 storage in underground saline formations. While this scenario would involve an unprecedented scale-up of CO_2 pipeline infrastructure, the pace would be comparable to that projected for pipeline construction in other sectors (in which many of the same companies operate).

The development of a national CO_2 pipeline network capable of meeting the Administration's greenhouse gas (GHG) emission goals may require a more concerted federal policy, involving much closer cooperation among federal, state, and local governments than is currently in place. In the low-carbon cases, several states that are projected to site new CO_2 pipeline infrastructure by 2030 do not yet have policies in place for permitting and operations. More can be learned from Texas' experience, as well as recent state policies like the WPA, under which early planning, interagency coordination, and stakeholder engagement efforts are key government actions for enabling CO_2 pipeline project development and construction.

7 Topics for Further Study

7.1 Development of Oversight Authority

Reducing atmospheric carbon emissions with CO_2 capture and geologic storage will require a significant expansion of the existing CO_2 pipeline network. Early planning for these future CO_2 transportation needs will help facilitate this process, as has been done in Wyoming. The large-scale CO_2 pipeline systems linking major emission areas, such as the Ohio Valley and its coal-fired power plants, with safe, reliable, large-scale CO_2 storage (or utilization) settings will require large-scale CO_2 pipelines to cross state lines (often times several state lines). As such, a national or regional CO_2 pipeline planning and coordination system may be required.

One approach could be to establish regional partnerships for developing common models for CO_2 pipeline regulation and oversight guidelines that could be shared by the member states. This approach could mirror the current approach taken by DOE in its creation of the Regional Carbon Sequestration Partnerships (RCSP).

These regional CO_2 pipeline partnerships could provide technical assistance to individual states and serve as an intermediary between pipeline operators and federal, state, and local governments, similar to that of the WPA. Furthermore, a regional CO_2 pipeline planning group could provide such assistance, given the unique demographic, land use, terrain, and geologic issues facing each region.

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Appendix

Exhibit 32 Comprehensive List of U.S. CO_2 Pipelines

Scale	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
Large-Scale Trunk-lines	Bravo	Oxy Permian	NM, TX	218	20	380
	Canyon Reef Carriers	Kinder Morgan	TX	139	16	220
	Centerline	Kinder Morgan	TX	113	16	220
	Central Basin	Kinder Morgan	TX	143	16	220
	Cortez	Kinder Morgan	TX	502	30	1,300
	Delta	Denbury Resources	MS, LA	108	24	590
	Green Line	Denbury Resources	LA, TX	314	24	930
	Greencore	Denbury Resources	WY, MT	230	22	720
	Northeast Jackson Dome (NEJD)	Denbury Resources	MS, LA	183	20	360
	Sheep Mtn	Oxy Permian	TX	408	24	590
	Shute Creek/Wyoming CO_2	ExxonMobil	WY	30	30-20	1,220-220
Smaller Scale Distribution Systems	Adair	Apache	TX	15	4	50
	Anadarko Powder River Basin CO_2 PL	Anadarko	WY	125	16	220
	Anton Irish	Oxy Permian	TX	40	8	80
	Beaver Creek	Devon	WY	53	8	30
	Borger	Chaparral Energy	TX, OK	86	4	50
	Coffeyville- Burbank	Chaparral Energy	KS, OK	68	8	80
	Comanche Creek	Oxy Permian	TX	120	6	70
	Cordona Lake	XTO	TX	7	6	70
	Dakota Gasification (Souris Valley)	Dakota Gasification	ND, SK	204	14	130
	Dollarhide	Chevron	TX	23	8	80
	El Mar	Kinder Morgan	TX	35	6	70
	Enid-Purdy (Central Oklahoma)	Anadarko	OK	117	8	80
	Este I - to Welch, TX	ExxonMobil, et al.	TX	40	14	180
	Este II - to Salt Crk Field	Oxy Permian	TX	45	12	130

Scale	Pipeline	Operator	Location	Length (mi)	Diameter (in)	Estimated Flow Capacity (MMcfd)
	Ford	Kinder Morgan	TX	12	4	50
	Free State	Denbury Resources	MS	85	20	360
	Llano	Trinity CO_2	NM	53	12	80
	Lost Soldier/Wertz	Merit	WY	30	16	40
	Mabee Lateral	Chevron	TX	18	10	110
	McElmo Creek	Kinder Morgan	CO, UT	40	8	80
	Means	ExxonMobil	TX	35	12	130
	Monell	Anadarko	WY	33	8	80
	North Cowden	Oxy Permian	TX	8	8	80
	North Ward Estes	Whiting	TX	26	12	130
	Pecos County	Kinder Morgan	TX	26	8	80
	Pikes Peak	Oxy Permian	TX	40	8	80
	Raven Ridge	Chevron	WY, CO	160	16	220
	Rosebud	Hess	NM	50*	12	100*
	Slaughter	Oxy Permian	TX	35	12	130
	Sonat	Denbury Resources	MS	50	18	170
	TexOk	Chaparral Energy	OK	95	6	70
	TransPetco	TransPetco	TX, OK	110	8	80
	Val Verde	Oxy Permian	TX	83	10	110
	W. Texas	Trinity CO_2	TX, NM	60	12	80
	Wellman	Trinity CO_2	TX	25	6	70
	White Frost	Core Energy, LLC	MI	11	6	70
	Wyoming CO_2	ExxonMobil	WY	112	20	220
Total U.S. CO_2 Pipeline Length				4,513	-	-

*Estimate

Exhibit 33 State-Level Inter- and Intrastate Pipeline Segments for the Cap40 Case

		Links									
Start	Terminus	Total Links	Direct	Feeder	Transship-ment	Averge Distance per Link (Miles)	Cost ($mm)	Total Miles	Total MMT	Total tonne-miles	Cost/mile ($k/mile)
AL	MS	1	1	-	-	173.13	61.14	173.13	17.03	2,948.06	353.13
AR	MS	1	1	-	-	165.95	58.64	165.95	3.24	537.46	353.38
AZ	CA	2	2	-	-	394.77	361.05	789.55	88.50	69,871.66	457.28
AZ	TX	2	2	-	-	467.07	326.49	934.14	53.25	49,746.93	349.51
CO	WY	1	1	-	-	378.40	132.44	378.40	35.86	13,568.64	350.01
FL	MS	1	1	-	-	232.68	127.34	232.68	45.24	10,526.83	547.26
FL	FL	4	4	-	-	98.39	140.69	393.54	20.77	8,172.34	357.51
IA	MI	1	1	-	-	407.64	222.33	407.64	29.87	12,177.48	545.40
IA	KS	2	-	2	-	165.06	218.46	330.12	74.92	24,731.64	661.75
ID	WY	3	3	-	-	402.54	422.48	1,207.61	59.71	72,104.64	349.85
IL	MI	1	1	-	-	325.33	114.01	325.33	11.06	3,598.40	350.44
IL	IL	1	1	-	-	85.10	30.56	85.10	7.05	599.53	359.09
IN	IL	3	3	-	-	190.70	244.22	572.10	27.95	15,992.99	426.88
KS	OK	1	-	-	1	204.20	216.19	204.20	206.31	42,127.37	1,058.73
LA	MS	3	3	-	-	150.62	159.96	451.87	111.66	50,455.90	353.99
MO	KS	1	-	1	-	34.09	27.55	34.09	76.26	2,599.55	808.28
MO	OK	1	-	1	-	142.62	78.44	142.62	30.23	4,310.80	550.00
MS	MS	5	2	2	1	64.01	178.82	320.07	182.60	58,443.81	558.69
MT	WY	1	1	-	-	373.16	130.62	373.16	0.27	99.63	350.04
NE	OK	2	2	-	-	354.93	320.46	709.86	16.65	11,820.78	451.45
NE	KS	2	-	2	-	164.27	180.40	328.55	55.14	18,114.94	549.07
NM	TX	2	2	-	-	330.47	231.59	660.95	15.57	10,290.55	350.39
NV	CA	1	1	-	-	311.09	109.06	311.09	12.66	3,938.62	350.58
OK	OK	1	-	-	1	81.55	45.28	81.55	30.23	2,464.87	555.30
SD	ND	1	1	-	-	318.44	111.61	318.44	5.88	1,872.02	350.50
TX	TX	21	7	12	2	168.38	2,336.15	3,535.99	908.91	3,213,881.46	660.68
UT	CA	1	1	-	-	487.69	170.41	487.69	24.24	11,819.45	349.41
UT	WY	1	1	-	-	305.59	107.15	305.59	12.27	3,748.28	350.63
WY	ND	2	2	-	-	216.68	197.14	433.35	44.82	19,422.80	454.91
WY	WY	5	5	-	-	100.01	178.70	500.06	30.96	15,481.45	357.35

Exhibit 34 State-Level Inter- and Intrastate Pipeline Segments for CP25 Case

			Links									
Start	Terminus	Terminal Region	Number of Links	Direct	Feeder	Trunk	Avg. Distance (miles)	Avg. Cost ($mm)	Total Miles	Total CO_2 (MMT)	Total tonne-miles (MMT-mi)	Avg. Cost ($000)/ Mile
Inter-state Pipelines			**60**	**24**	**20**	**16**	**251**	**199**	**15,036**	**1,960**	**29,477,059**	**624**
AL	MS	OGSM2	1	0	0	1	182	100	182	2	449	548
AR	MS	OGSM2	1	0	0	1	254	269	254	135	34,246	1,058
AR	OK	OGSM3	1	0	0	1	236	250	236	63	14,902	1,058
AZ	CA	OGSM6	2	2	0	0	395	138	790	60	47,634	175
AZ	CO	OGSM5	1	0	0	1	207	219	207	93	19,225	1,059
AZ	NM	OGSM5	1	0	1	0	95	52	95	11	1,070	554
AZ	TX	OGSM4	3	3	0	0	314	132	943	38	36,190	140
CO	NM	OGSM5	1	0	0	1	295	312	295	207	60,963	1,057
CO	WY	OGSM5	1	1	0	0	378	206	378	91	34,539	546
FL	MS	OGSM2	2	2	0	0	363	127	726	16	11,919	175
IA	KS	OGSM3	2	0	2	0	165	109	330	35	11,443	331
ID	CA	OGSM6	1	1	0	0	503	176	503	8	4,016	349
ID	ND	OGSM7	1	1	0	0	205	72	205	19	3,899	352
ID	WY	OGSM5	2	2	0	0	355	124	710	34	24,358	175
IN	KY	OGSM1	1	0	1	0	183	101	183	2	330	548
KS	OK	OGSM3	1	0	0	1	204	216	204	60	12,286	1,059
KY	TN	OGSM1	1	0	0	1	314	332	314	20	6,268	1,057
MI	IL	OGSM1	1	1	0	0	85	31	85	1	115	359
MN	ND	OGSM7	1	1	0	0	474	166	474	1	498	349
MO	KS	OGSM3	1	0	1	0	196	108	196	26	5,007	548
NC	AL	OGSM2	1	0	0	1	431	455	431	2	1,063	1,056
NM	OK	OGSM3	1	0	0	1	413	877	413	177	73,240	2,122
NM	TX	OGSM4	1	0	0	1	352	746	352	41	14,388	2,122
NV	CA	OGSM6	1	1	0	0	311	109	311	14	4,297	351
NV	ND	OGSM7	2	2	0	0	492	172	984	7	6,894	175
NV	UT	OGSM5	1	0	1	0	178	98	178	10	1,816	549
NY	PA	OGSM1	1	0	1	0	207	113	207	10	2,077	548
OH	KY	OGSM1	1	0	0	1	246	260	246	16	3,961	1,058
OK	TX	OGSM4	1	0	0	1	274	289	274	92	25,292	1,057
PA	OH	OGSM1	2	0	1	1	234	212	468	15	6,944	452
SD	WY	OGSM5	1	1	0	0	472	165	472	0	63	349
TN	KY	OGSM1	1	0	1	0	50	28	50	2	104	563
TN	MS	OGSM2	1	0	0	1	316	334	316	20	6,315	1,057
TX	AR	OGSM3	5	0	5	0	81	45	405	130	52,538	111
TX	MS	OGSM2	4	2	1	1	200	142	800	238	190,700	177
TX	OK	OGSM3	5	1	4	0	60	33	299	107	32,151	111
UT	CA	OGSM6	1	1	0	0	488	170	488	25.88	12,620	349
UT	CO	OGSM5	2	0	1	1	167	149	334	114	38,031	448
UT	WY	OGSM5	2	2	0	0	349	122	697	15	10,143	175
Intrastate Pipelines			**49**	**13**	**29**	**7**	**132**	**73**	**6,460**	**2,380**	**15,378,094**	**323**
AR	AR	OGSM3	1	0	1	0	115	63	115	68	7,786	552
AZ	AZ	OGSM5	5	0	5	0	143	78	713	93	66,114	110
FL	FL	OGSM2	1	1	0	0	71	26	71	1	90	361
MI	MI	OGSM1	2	2	0	0	207	105	413	24	10,107	253
MS	MS	OGSM2	5	3	1	1	81	37	405	406	164,507	90
NC	NC	OGSM1	1	0	1	0	223	122	223	2	550	547
OH	OH	OGSM1	1	0	1	0	70	39	70	1	89	557
OK	OK	OGSM3	2	0	0	2	92	115	184	253	46,581	625
TX	TX	OGSM2	26	7	15	4	146	92	3,806	1,449	5,512,993	24
UT	UT	OGSM5	5	0	5	0	92	51	460	83	38,098	111

Exhibit 35 Cumulative CO_2 Pipelines Construction

Pipeline Diameter	2030		2040	
	CP25	CAP40	CP25	CAP40
Pipeline Miles				
12	4,077	3,240	9,251	8,623
16	3,048	1,298	6,706	5,632
20	-	192	158	192
24	3,277	204	4,370	582
36	660	165	1,011	165
Total	11,062	5,099	21,496	15,194
Number of Pipelines				
12	16	11	33	36
16	24	5	54	32
20	-	2	1	2
24	13	1	17	3
36	3	1	4	1
Total	56	20	109	74

Exhibit 36 Total Mass of anthropogenic CO_2 Sequestered

Power Sector CO_2	2015			2030			2040		
Million metric tonnes	Ref	Cap40	CP25	Ref	Cap40	CP25	Ref	Cap40	CP25
Sequestered Power CO_2	3.48	2.89	3.48	6	92	94	6	229	171
Non Sequestered Power CO_2	2,075	2,036	1,797	2172	788	743	2193	1	190
Total Power CO_2 Emissions	2,078	2,039	1,801	2178	880	837	2199	230	361
Percent Sequestered CO_2	0.2%	0.1%	0.2%	0.3%	10.4%	11.2%	0.3%	99.6%	47.4%

Exhibit 37 Sequestered Anthropogenic CO_2 Captured at Industrial vs. Power Sector Sources

Sequestered Anthropogenic CO_2	2015			2030			2040		
Million metric tonnes	Ref	Cap40	CP25	Ref	Cap40	CP25	Ref	Cap40	CP25
Industrial	0.4	0.7	0.4	31.6	0.1	0.1	46.7	8.2	1.0
Power Sector	3.5	2.9	3.5	6.3	91.9	94.0	6.2	228.6	170.7
Total	3.8	3.6	3.8	37.9	92.0	94.1	52.9	236.8	171.7
Percent Power Sector CO_2	90.6%[11]	80.5%	90.6%	16.7%	99.9%	99.9%	11.8%	96.5%	99.4%

Exhibit 38 Electric Capacity with Carbon Sequestration

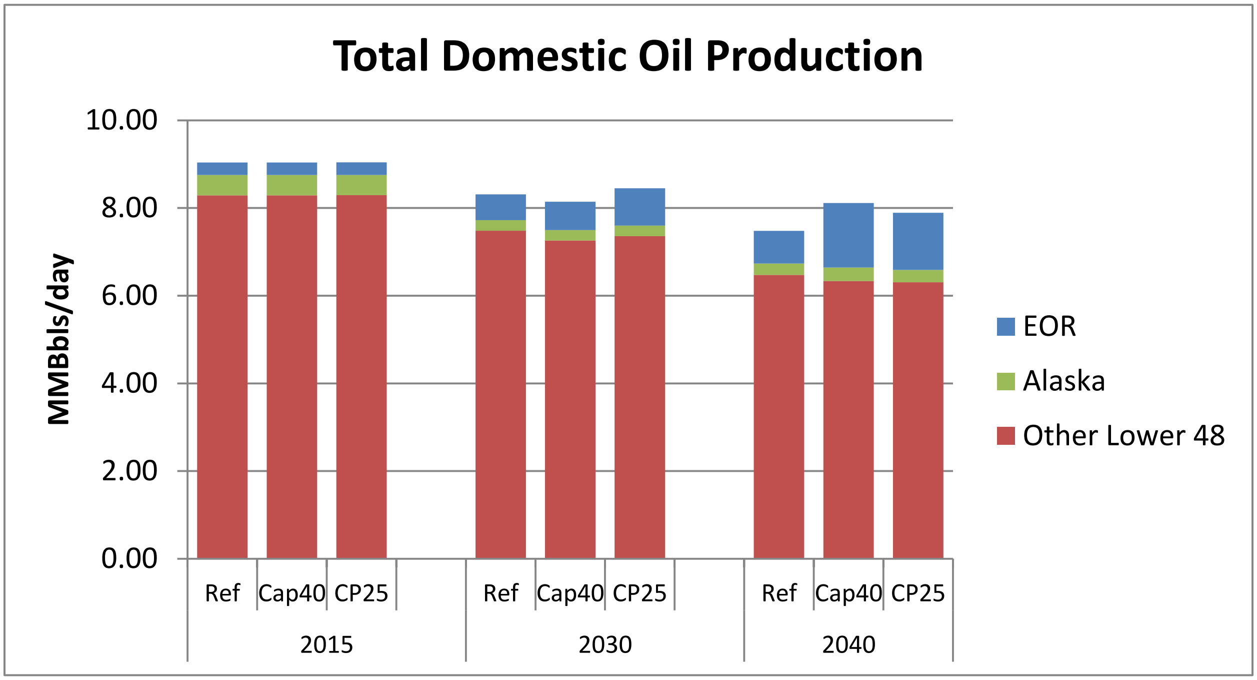
GW	2015	2030	2040
Reference	0.6	1.0	1.0
Cap40	0.6	35.6	101.8
CP25	0.6	32.3	80.9

Exhibit 39 U.S. Oil Production (MMBbls/day) Associated with CO_2-EOR, in 2015, 2030, and 2040 (table)

U.S. oil production	2015			2030			2040		
	Ref	Cap40	CP25	Ref	Cap40	CP25	Ref	Cap40	CP25
EOR	0.29	0.29	0.29	0.59	0.64	0.85	0.74	1.47	1.30
Other Lower 48	8.29	8.29	8.29	7.48	7.26	7.36	6.47	6.34	6.31
Alaska	0.46	0.46	0.46	0.24	0.24	0.24	0.26	0.31	0.28
Total	9.04	9.04	9.04	8.31	8.14	8.45	7.48	8.12	7.89
EOR percentage of Total	**3.2%**	**3.2%**	**3.2%**	**7.1%**	**7.9%**	**10.1%**	**9.9%**	**18.2%**	**16.5%**

[11] The reference model assumes a demo plant is currently in operation, and the CO2 is from that plant.

Exhibit 40 U.S. oil production (MMBbls/day) associated with CO_2-EOR, in 2015, 2030, and 2040 (graph)



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