



U.S. DEPARTMENT OF  
**ENERGY**

# Siting and Regulating Carbon Capture, Utilization and Storage Infrastructure

## WORKSHOP REPORT

January 2017

*Prepared for:*

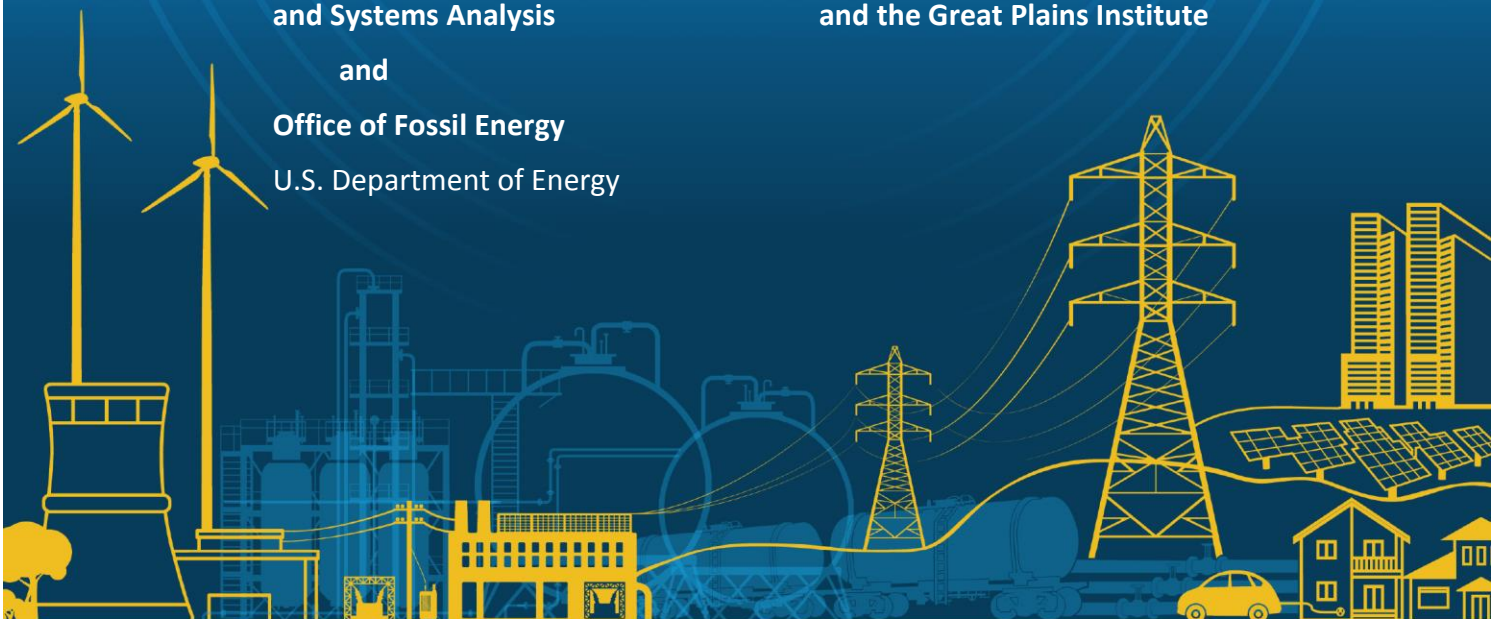
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and

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# TABLE OF CONTENTS

Table of Contents .....	3
Acronyms and Abbreviations .....	4
I. Background .....	6
II. Characterization of Existing CCUS Infrastructure and the CO <sub>2</sub> Resource Potential .....	10
Characterization of Existing CO <sub>2</sub> Pipeline Networks .....	10
Characterization of the Resource Potential: CO <sub>2</sub> Storage .....	12
1. CO <sub>2</sub> Storage Sites .....	12
2. CO <sub>2</sub> Sources .....	17
III. Projections of CCUS Pipeline Infrastructure .....	20
IV. Existing and Proposed CCUS Projects .....	21
V. Future Opportunities .....	24
VI. State Policy Environment for CCUS Infrastructure .....	25
Statutory and Regulatory Environment – Pipelines .....	25
1. Siting and Economic Regulation .....	25
Statutory and Regulatory Environment – Geologic Storage .....	27
2. Siting and Permitting .....	27
3. Property Rights .....	27
4. Long-term Management and Liability .....	28
5. State Management of EOR Resources .....	28
6. CCUS for Environmental Compliance .....	29
State Incentives .....	29
7. Tax Credits, Exemptions, Reductions, Abatements and Rate Recovery .....	29
Future Opportunities – State Level .....	30
VII. Federal Environment for CCUS Infrastructure .....	31
Federal Statutory and Regulatory Environment – Pipelines .....	31
1. Pipeline Siting and Economic Regulation .....	31
2. Pipeline Safety and Quality Standards .....	32
Federal Statutory and Regulatory Environment – Geologic Storage .....	33
3. Underground Injection .....	33
4. Greenhouse Gas Reporting Program .....	34
5. Experience with EPA Rule Compliance: UIC Program .....	34
6. Experience with EPA Rule Compliance: GHGRP .....	35
7. CO <sub>2</sub> Storage through EOR .....	35
Incentives – Federal Level .....	35
8. Existing Incentives .....	36
Future Opportunities – Federal Environment .....	38
VIII. Near-Term Investment Opportunities .....	40
Appendix A List of Workshop Participants .....	49
Appendix B Workshop Agenda .....	51

## ACRONYMS AND ABBREVIATIONS

ADM	Archer Daniels Midland	IGCC	Integrated gasification combined cycle
ANGDA	Alaska Natural Gas Development Authority	IICP	Illinois Industrial CCUS Project
ARRA	American Recovery and Reinvestment Act	INGAA	Interstate Natural Gas Association of America
BLM	Bureau of Land Management	IOGCC	Interstate Oil and Gas Compact Commission
BSCSP	Big Sky Carbon Sequestration Partnership	IPCC	Intergovernmental Panel on Climate Change
CBM	Coalbed methane	ISGS	Illinois State Geological Survey
CH <sub>4</sub>	Methane	ISO	International Standardization Organization
CO	Carbon monoxide	LCFS	Low Carbon Fuel Standard
CO <sub>2</sub>	Carbon dioxide	LSIP	Large-scale injection projects
CPP	Clean Power Plan	MGA	Midwestern Governors Association
CCS	Carbon capture and storage	MGSC	Midwest Geological Sequestration Consortium
CCUS	Carbon dioxide capture, utilization, and storage	MLA	Mineral Leasing Act
CfD	Contract-for-differences	MLP	Master Limited Partnerships
DOE	Department of Energy	MRV	Monitoring, reporting, and verification
EA	Environmental Assessment	Mt	Metric tons
EIS	Environmental Impact Statement	N <sub>2</sub>	Nitrogen
EOR	Enhanced oil recovery	NATCARB	National Carbon Sequestration Database and Geographic Information System
EPA	Environmental Protection Agency	NEPA	National Environmental Protection Act
EPSA	Office of Energy Policy and Systems Analysis	NETL	National Energy Technology Laboratory
FERC	Federal Energy Regulatory Commission	O <sub>2</sub>	Oxygen
FLPMA	Federal Land Policy and Management Act	OPS	Office of Pipeline Safety
GCCSI	Global Carbon Capture and Storage Institute	PCOR	Plains CO <sub>2</sub> Reduction Partnership
GHG	Greenhouse gas	PHMSA	Pipeline and Hazardous Materials Safety Administration
GHGRP	Greenhouse Gas Reporting Program	psi	Pounds per square inch
H <sub>2</sub>	Hydrogen	psig	Pounds per square inch gage
H <sub>2</sub> O	Water	QER	Quadrennial Energy Review
H <sub>2</sub> S	Hydrogen sulfide	PAB	Private Activity Bond
IBDP	Illinois Basin Decatur Project		
IEA	International Energy Agency		

R&D	Research and development	TCF	Trillion cubic feet
RCSP	Regional Carbon Sequestration Partnership	U.S.	United States
ROZ	Residual oil zone	UIC	Underground Injection Control
ROW	Right-of-way	USDW	Underground source of drinking water
SACROC	Scurry Area Canyon Reef Operators	ZEP	Zero Emissions Platform
SECARB	Southeast Regional Carbon Sequestration Partnership		
SRCS	Southwest Regional Carbon Sequestration Partnership		
STB	Surface Transportation Board		

## I. BACKGROUND

The United States Department of Energy's first Quadrennial Energy Review (QER) identified carbon dioxide (CO<sub>2</sub>) pipelines as "an important enabling infrastructure for reducing greenhouse gas (GHG) emissions in the future."<sup>1</sup> Carbon dioxide capture, utilization, and storage (CCUS) may involve moving CO<sub>2</sub> significant distances from power plants and other industrial sources to storage sites, including saline geologic formations and oil fields (where CO<sub>2</sub> is stored during and potentially after enhanced oil recovery (EOR) operations), as well as to entities that employ other technologies to utilize captured CO<sub>2</sub>, such as photosynthesis, chemosynthesis, or mineralization.

The regulation of CO<sub>2</sub> pipelines and other CCUS infrastructure is a joint responsibility of Federal and State governments. However, states typically play a primary role in establishing the requirements for siting, construction, and operations of CO<sub>2</sub> pipelines. The first QER found that the development of a national CO<sub>2</sub> pipeline infrastructure should "build on state experiences, including lessons learned from the effectiveness of different regulatory structures, incentives, and processes that foster interagency coordination and regular stakeholder engagement."<sup>2</sup>

The Department of Energy (DOE) sponsored a technical workshop in April 2016 in Washington, D.C., to identify and promote best practices for siting and regulating CO<sub>2</sub> infrastructure (pipelines, EOR, and other geologic CO<sub>2</sub> storage sites). The purpose of the workshop was to foster communication, coordination, and sharing of lessons learned and best practices among states and entities that are involved in siting and regulating CO<sub>2</sub> infrastructure, or that may have CO<sub>2</sub> infrastructure projects within their borders in the future.

The scope of the technical workshop also encompassed issues being addressed in the second installment of the QER, including discussions around regulation and management of CO<sub>2</sub> storage sites, which serve as critical infrastructure for entities capturing CO<sub>2</sub>.

### **Overview**

The workshop convened subject matter experts, industry and non-governmental organization representatives, and Federal and State officials with jurisdiction over energy infrastructure planning, siting, and economic development.

This report documents the workshop and highlights key themes raised by the participants.

Several workshop presentations are available on DOE's website.

The workshop will inform the second installment of the Quadrennial Energy Review: An Integrated Study of the U.S. Electricity System. These findings reflect the discussions at the workshop and do not represent consensus among the participants, and DOE did not seek consensus opinions from participants at the workshop. DOE does not necessarily agree with or support the content summarized below.

### **KEY FINDINGS & FIGURES**

1. EOR using CO<sub>2</sub> (CO<sub>2</sub>-EOR) results in geologic CO<sub>2</sub> storage. EOR operations in the United States represent a commercially demonstrated and Federally-recognized form of geologic storage that could provide a market pull for the deployment of CCUS technology.<sup>3</sup>

- EOR in the United States has created the largest CO<sub>2</sub> pipeline network in the world: 4,600 miles of CO<sub>2</sub> pipeline transports 69 million metric tons (Mt) per year of CO<sub>2</sub> to 136 EOR projects in 12 states.<sup>4</sup>
  - In 2014, CO<sub>2</sub>-EOR represented nearly 5 percent of domestic oil production (over 300,000 million barrels per day).<sup>5</sup>
  - Current CO<sub>2</sub>-EOR technologies are capable of recovering an estimated 26 to 61 billion barrels of oil in the United States.<sup>6</sup> This estimate increases to between 67 and 137 billion barrels when accounting for “next generation” EOR technology such as improved conformance control and advanced flood design.<sup>7</sup>
  - The United States will need to expand the existing CO<sub>2</sub> pipeline network to realize the full potential for domestic oil production using CO<sub>2</sub>-EOR. At an assumed CO<sub>2</sub> price of \$25 per Mt, the current pipeline network could grow at an average rate of 1,000 miles per year through 2030.<sup>8</sup>
2. Deployment of CCUS technology is critical for mitigating global climate change.
    - Under the International Energy Agency (IEA) Energy Technology Perspectives 2 Degree Scenario, CCUS would provide 12 percent of the required CO<sub>2</sub> emissions reductions by mid-century.<sup>9</sup>
    - According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, the overall cost of a global climate mitigation strategy without CCUS is higher than a strategy with CCUS in every scenario, and many models cannot limit likely warming to below 2 °C without CCUS.<sup>10</sup>
    - Decarbonization of the industrial sector will not be possible without CCUS. CCUS is also critical for reducing emissions from the power sector, both in the United States and globally.
    - CCUS is essential to maintaining global competitiveness, and presents an opportunity for global leadership that will require a local, State, and Federal commitment to investment in CCUS infrastructure and technology deployment.
  3. CCUS is capital intensive, faces policy and market uncertainties, and requires a long-term commitment, all of which present a financial burden and risk for CCUS project developers.
    - Regulatory and financial certainty is essential to securing the private investment necessary to deploy CCUS and supporting infrastructure.
    - Incentives at the Federal and State level are key drivers for CCUS development and can play a pivotal role in infrastructure buildout, particularly during periods with low oil prices.

### ***State Policy Environment for CCUS Infrastructure***

1. Leadership by states has been a key factor in the buildout of CCUS projects, CO<sub>2</sub>-EOR projects, and associated infrastructure to date.
2. States can facilitate CCUS by providing regulatory clarity, supporting infrastructure planning efforts, and providing technology and infrastructure incentives.
3. Many states have taken on a proactive role in establishing the policy, regulatory, and planning groundwork through collaborative, regional efforts, so their state is project-ready for CCUS opportunities.
4. States can streamline permitting processes by working with the Federal Government to address Federal lands impacts on the siting and development of critical pipeline infrastructure.

- For example, in Western states where Federal lands are more extensive, Wyoming’s approach to developing pipeline right-of-way (ROW) corridors could provide a model for other states looking for ways to streamline the permitting process for projects on Federal lands. The Wyoming Pipeline Authority is developing a pipeline ROW network designed to connect sources of CO<sub>2</sub> to oil fields that are suitable for EOR. The ROW would then be assigned to individual project participants, which would construct and operate CO<sub>2</sub> pipelines.

### ***Federal Policy Environment for CCUS Infrastructure***

1. Federal policy makers can create a positive regulatory and policy environment for CCUS infrastructure development, supplemented with complementary efforts by State policy-makers.
  - Federal incentives could serve as a catalyst for CCUS deployment if the incentives are structured to provide financial certainty for private investors and are sufficient in value to close the cost gap between the cost of capturing, compressing, and transporting CO<sub>2</sub> and the price of delivered CO<sub>2</sub> paid by EOR project operators.
  - However, existing Federal incentives, such as the Section 45Q Tax Credit for Carbon Dioxide Sequestration, are insufficient to fully support CCUS development.
2. There is now an accepted regulatory and permitting pathway, clarified in a 2015 Environmental Protection Agency (EPA) memo, for EOR projects to store CO<sub>2</sub>.<sup>11</sup>
3. EOR operators have the option of reporting their stored CO<sub>2</sub> under Subpart RR of the Greenhouse Gas Reporting Rule to demonstrate geologic storage for regulatory and other policy purposes.<sup>12</sup>
  - In addition, to claim the Section 45Q tax credit mentioned above, EOR operators must report under Subpart RR of the Greenhouse Gas Reporting Rule.<sup>13</sup>
  - Under Subpart RR of the GHG Reporting Program (GHGRP), EPA approved the first site-specific monitoring, reporting, and verification (MRV) plan for CO<sub>2</sub> storage through EOR that may serve as a model for other commercial EOR projects.<sup>14</sup>
4. DOE, in cooperation with Federal public land agencies, could take a convening role to promote communication, coordination, and sharing of lessons learned and best practices among states that are already involved in siting and regulating CO<sub>2</sub> pipelines, or that may have CO<sub>2</sub> pipeline projects proposed within their borders in the future.

### ***Near-term Opportunities and Challenges for CCUS***

1. Low oil prices, limited existing CO<sub>2</sub> pipeline infrastructure in many regions, and the lack of commercial deployment of CCUS technologies in some industry sectors present a barrier to additional CCUS deployment.
  - Oil prices have a substantial impact on the value of captured CO<sub>2</sub>. In a low oil price environment, the difference between the cost of capture and the market price of CO<sub>2</sub> increases. This difference can present a financial challenge for CCUS projects.
  - To date, CO<sub>2</sub> pipeline development for CCUS has generally been source-to-sink projects with no coherent strategy for investing in infrastructure buildout and optimizing the location, size, etc., of infrastructure needed to meet long-term goals.
2. There is an opportunity to use a systems approach for pipeline mapping, planning, siting, and development involving collaboration among private industry, State, and Federal Government that leads to efficient and equitable multi-user regional CO<sub>2</sub> pipeline networks.
  - The next wave of CO<sub>2</sub> pipelines will likely capture CO<sub>2</sub> from the sources with the highest-purity CO<sub>2</sub> emissions – ethanol, fertilizer plants, or geologic sources. The CO<sub>2</sub> output of



individual sources may be small, but regional pipeline networks can aggregate sources for multiple customers and uses.

3. A Federal pipeline infrastructure planning effort should take a systems approach for addressing near-, mid-, and long-term needs. According to participants, such an effort should go further than matching CO<sub>2</sub> sources to CO<sub>2</sub> sinks, and could determine the size of pipelines that would be needed to satisfy the need for CO<sub>2</sub> infrastructure. Such an effort could determine the role that potential Federal policy could play to leverage private investment in CO<sub>2</sub> infrastructure.
  - Federal, State, and private sector coordination for pipeline planning and investment is worth exploring. DOE could facilitate this effort, in particular, by engagement with the investment community to identify innovative ways to facilitate CCUS infrastructure deployment.
  - Other industries could provide models for supporting CCUS deployment, such as the public-private support for coalbed methane (CBM) projects under Section 29 of the tax code.
  - The Administration's Fiscal Year 2017 Revenue Proposals included a refundable investment tax credit to CCUS projects and supporting transportation infrastructure, including pipelines.<sup>15</sup> If enacted, a similar investment tax credit could enable additional deployment of CO<sub>2</sub> pipelines.
4. There is significant potential for pure streams of CO<sub>2</sub> from industrial facilities (e.g., gas processing, ethanol, fertilizer, chemical, and industrial gasification plants) to become a major source of anthropogenic CO<sub>2</sub> in the near term. In turn, these near-term projects are likely to catalyze the deployment of CO<sub>2</sub> pipelines and supporting infrastructure that, over the medium-to-long term, will benefit future CCUS projects in the power sector and in other industries such as steel production.
5. Residual oil zone (ROZ) exploration and production could provide additional sites for CO<sub>2</sub> storage and provide billions of barrels of additional oil production.
6. EOR or saline reservoirs suitable for CO<sub>2</sub> storage can occur in close proximity, vertically and/or horizontally in the geologic column. This stacked scenario provides the opportunity for projects to take advantage of EOR in the short term while preparing for continued, near-by, large-volume saline storage in the long term.

### ***CO<sub>2</sub> Pipeline Safety***

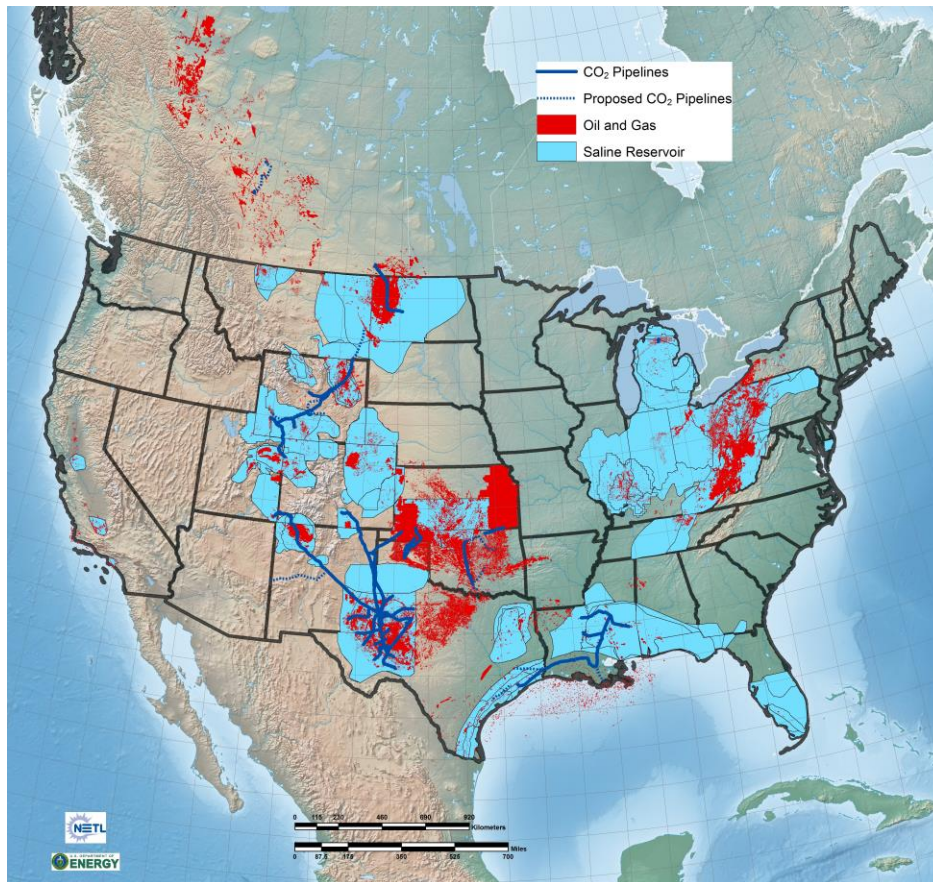
1. The existing CO<sub>2</sub> pipeline network has a strong safety record, aided in part by the fact that CO<sub>2</sub> is not combustible.
2. CO<sub>2</sub> pipeline safety standards are established by the Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA).
  - States establish the remaining regulatory framework governing CO<sub>2</sub> pipelines within their borders. These State regulations are working well, but they vary and are not present in all states that may host future CO<sub>2</sub> pipelines supporting CCUS deployment.
  - Composition standards for CO<sub>2</sub> transport have been established by pipeline operators and are designed for long-term protection of the pipelines.
3. Over half of the existing CO<sub>2</sub> pipelines were constructed more than 30 years ago. Thus far, there is an absence of research into the causes and impacts of potential pipeline leaks.
4. Existing industry standards and/or international standards under development for CO<sub>2</sub> pipelines could be helpful to states that are evaluating their pipeline safety and CO<sub>2</sub> composition standards. States and/or the Federal Government could adopt, by reference, industry quality standards for CO<sub>2</sub> composition for pipeline transportation.

## II. CHARACTERIZATION OF EXISTING CCUS INFRASTRUCTURE AND THE CO<sub>2</sub> RESOURCE POTENTIAL

### Characterization of Existing CO<sub>2</sub> Pipeline Networks

CCUS infrastructure in the United States is dominated by CO<sub>2</sub>-EOR operations. The first CO<sub>2</sub>-EOR projects, the Scurry Area Canyon Reef Operators (SACROC) and North Cross Devonian Unit in the Permian Basin in West Texas, began in 1972.<sup>16</sup> Since then, 134 additional CO<sub>2</sub>-EOR projects in 10 states have started injecting CO<sub>2</sub>.<sup>17</sup> Supplies of CO<sub>2</sub> to CO<sub>2</sub>-EOR operations in 2014 totaled about 67.8 million Mt, of which about 13.6 Mt were captured from industrial (high purity) sources and the remainder provided by natural sources.<sup>18</sup> This supply of CO<sub>2</sub> was transported from source to CO<sub>2</sub> EOR fields by a 4,600 mile pipeline network that spans 12 states.<sup>19</sup> The 4,600 mile CO<sub>2</sub> pipeline network in the United States is discontinuous and broken up into five geographic areas (Figure 1).

Figure 1: CO<sub>2</sub> pipeline network showing oil and gas fields: CO<sub>2</sub> pipeline development to date has met the needs of the EOR industry. To meet long-term climate goals, future development of pipelines will need to expand in the Northeast, Midwest, and West as well as in existing areas to connect anthropogenic sources of CO<sub>2</sub> to new or existing EOR projects and new saline storage projects. Pipeline data from Energy Velocity, saline reservoir and oil and gas field data from NATCARB. Source: NETL.



Timothy Grant, from the National Energy Technology Laboratory (NETL), kicked off the workshop presentations with an overview of the current U.S. CO<sub>2</sub> pipeline network. The largest sub-network of CO<sub>2</sub> pipelines spans about 2,470 miles across West Texas, New Mexico, and Southern Colorado.<sup>20</sup> A hub for this network in Denver City, Texas, connects the major pipelines in the Permian Basin to natural sources

of CO<sub>2</sub> at McElmo Dome and Doe Canyon in Southwestern Colorado, Sheep Mountain in South Central Colorado, and Bravo Dome in Northeastern New Mexico. This network also utilizes CO<sub>2</sub> from the Century and Val Verde natural gas processing plants in Texas.<sup>21</sup>

The next largest, though discontinuous, sub-network stretches across the Northern Rockies and plains states, from North Dakota south into North Central Colorado. In North Dakota, a dedicated 204-mile CO<sub>2</sub> pipeline connects the Dakota Gasification Plant in Beulah, North Dakota, with the Weyburn-Midale CO<sub>2</sub>-EOR field just across the border in Saskatchewan, Canada.<sup>22</sup> The remaining 806 miles of existing CO<sub>2</sub> pipelines connect multiple sources of CO<sub>2</sub> with CO<sub>2</sub>-EOR fields in Montana, Wyoming, and Colorado. Two natural gas processing plants, Shute Creek and Lost Cabin, provide the CO<sub>2</sub> for this pipeline network. The LaBarge reservoir, with 100 trillion cubic feet (TCF) of CO<sub>2</sub> reserves, is the dominant source of CO<sub>2</sub> in this region. Gas production from LaBarge is processed at the Shute Creek plant where the CO<sub>2</sub> is separated from the methane gas. A second plant, Riley Ridge, will provide similar processing of LaBarge production and is coming online soon.<sup>23</sup>

Another 414-mile, discontinuous pipeline sub-network exists in Kansas, Oklahoma, and the Panhandle area of Texas.<sup>24</sup> This network transports captured CO<sub>2</sub> from high-purity anthropogenic sources: three fertilizer plants in Coffeyville, Kansas; Enid, Oklahoma; and Borger, Texas, and an ethanol plant in Liberal, Kansas.<sup>25</sup>

In the Gulf Coast area, a 700-mile, continuous pipeline sub-network extends from Central Mississippi into Louisiana and westward along the Gulf Coast to a point south of Houston, Texas.<sup>26</sup> This pipeline network gathers CO<sub>2</sub> from a natural underground source at the Jackson Dome outside Jackson, Mississippi. Air Products's hydrogen plant in Port Arthur, Texas, sells its captured CO<sub>2</sub> to this network.

The smallest pipeline sub-network is in Northern Michigan, where an 11-mile pipeline transports CO<sub>2</sub> from a natural gas processing plant for the Antrim Shale to several nearby CO<sub>2</sub>-EOR reservoirs.

Over the history of CO<sub>2</sub>-EOR development, the pipeline build rate has averaged a little over 100 miles per year. The most recent additions to the CO<sub>2</sub> pipeline network were constructed by Denbury Resources, including the 230-mile Greencore pipeline in Wyoming and Montana in 2013, and the 314-mile Green pipeline in Louisiana and Texas in 2010.<sup>27</sup> In Texas, Denbury Resources is building two lateral pipelines totaling 99 miles from their Green pipeline for two new CO<sub>2</sub>-EOR projects.<sup>28</sup> For CO<sub>2</sub>-EOR, timing of construction of the CO<sub>2</sub> pipeline is coordinated with initiation of CO<sub>2</sub> injection operations in the oil reservoir.

Workshop participants noted that economics are the main driver of pipeline development, as the required capital expenses are significant. A presentation by Keith Tracy of Chaparral Energy noted that CO<sub>2</sub> pipelines account for 10-to-40 percent of the total capital budget of an EOR project, while the operating expenses of the pipeline are a less significant annual cost. Mr. Tracy went on to explain that 75 percent of existing CO<sub>2</sub> pipelines were developed when high oil prices drove the market for EOR and, in turn, pipeline construction. In addition, Mr. Tracy noted that the existing CO<sub>2</sub> pipeline network was facilitated by two major shifts in crude oil markets. First, during the 1980s, oil produced using EOR was subject to more favorable tax treatment in comparison to other types of oil extraction, which, in turn, created an incentive for investing in EOR and the necessary CO<sub>2</sub> pipeline infrastructure.<sup>29a</sup> Second, during the last decade, around a quarter of existing U.S. CO<sub>2</sub> pipelines were constructed in response to

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<sup>a</sup> Windfall Profits Tax of 1980 had a tax credit for incremental oil produced under enhanced methods, including CO<sub>2</sub>.

high oil prices, which made EOR production opportunities attractive. In the current low crude oil price environment, little additional CO<sub>2</sub> transportation infrastructure has been built.

CO<sub>2</sub> pipelines have a number of unique characteristics. Operating CO<sub>2</sub> pipelines at pressures ranging from 1,200 pounds per square inch gage (psig) to over 3,000 psig keeps the CO<sub>2</sub> in a liquid phase and maximizes the mass of CO<sub>2</sub> transported. Anthropogenic CO<sub>2</sub> is often acquired from sources at less than 15 psig, requiring compression to pipeline pressure. Pumps are required to maintain the pressure and to keep the CO<sub>2</sub> in a supercritical state. Water content, as well as content of non-CO<sub>2</sub> gases, must be kept to a minimum to prevent corrosion and ensure internal pipe integrity. Hydrogen sulfide (H<sub>2</sub>S) is kept to a minimum for safety reasons. The standards and regulations for the quality and safety of transporting CO<sub>2</sub> via pipelines is discussed under Federal Statutory and Regulatory Environment – Pipelines, in Section VII of this report.

## Characterization of the Resource Potential: CO<sub>2</sub> Storage

CO<sub>2</sub> pipeline planning and development depends on the success of the capture and storage projects that creates the demand for the CO<sub>2</sub> pipeline. This presents a challenge for all parties involved to balance the financial and regulatory requirements needed to develop these large-scale projects, as well as to successfully construct and operate the project. The following sections characterize the existing landscape for CCUS on each end of the pipeline: CO<sub>2</sub> storage sites and CO<sub>2</sub> sources.

### 1. CO<sub>2</sub> Storage Sites

In June 2016, DOE announced that CCUS projects supported by the Department have successfully, and safely, captured and stored more than 12.6 million Mt of CO<sub>2</sub>.<sup>30</sup> While there are several options for permanent CO<sub>2</sub> storage, including depleted oil and gas fields and CBM, saline formations and oil fields suitable for EOR are the primary targets for large-scale permanent storage.

At present, knowledge of the subsurface geologic formations between oil and gas reservoirs is limited; deep wells drilled to date were looking for hydrocarbons. The process of discovering and characterizing potential CO<sub>2</sub> saline storage sites is similar to exploration for oil and gas. While each potential saline storage reservoir encompasses unique challenges and opportunities, the long and often uncertain lead times associated with characterization and permitting can make it difficult to secure initial investment.

DOE, through NETL, has two programs to evaluate the saline storage resource potential, advance CCUS technologies, and inform the regulatory framework for geologic storage of CO<sub>2</sub>. The first DOE/NETL program is the Regional Carbon Sequestration Partnership (RCSP) Initiative, a group of seven partnerships, each encompassing a multi-state area, dedicated to evaluating CCUS technologies in their respective regions of the United States.<sup>31</sup> With the goal of facilitating the commercialization of carbon storage and utilization technologies, this multi-phase initiative includes:

- **Characterization:** Extensive characterization efforts of deep oil-, gas-, coal-, and saline-bearing formations.
- **Validation:** Small-scale (less than 500,000 Mt) storage tests aimed at confirming estimates, validating simulation models, demonstrating monitoring, verification, and accounting methods, and developing guidelines.
- **Development:** Large-scale (one million Mt or more) storage projects to demonstrate safe and effective long-term storage.<sup>32</sup>

Table 1, below, provides details on the Phase III CO<sub>2</sub> injection projects for six of the regional partnerships. Partnership details can be found in the Carbon Storage Atlas.<sup>33</sup> The Big Sky Carbon Sequestration Partnership (BSCSP) plans to inject one million Mt of naturally-sourced CO<sub>2</sub> in the Kevin Dome, located in north central Montana, between and 2022, with post-injection site care operations taking place for two years after injection.<sup>34</sup> The Illinois Basin Decatur Project (IBDP), in Decatur, Illinois, managed by the Midwest Geological Sequestration Consortium (MGSC) has injected 999,215 Mt of CO<sub>2</sub> from an Archer Daniels Midland (ADM) corn-to-ethanol plant into the Mount Simon Sandstone in the Illinois Basin between 2011 and 2014; to date, no leakage or other adverse impacts have been detected.<sup>35</sup> In Otsego County, Michigan, the Midwest Regional Carbon Sequestration Partnership (MRCSP) has successfully completed the injection of approximately 60,000 Mt of CO<sub>2</sub> into a Niagaran Pinnacle Reef reservoir in the Michigan Basin. Their CO<sub>2</sub> is sourced from a local Antrim Shale natural gas processing plant. Post-injection site care monitoring is anticipated to extend through 2018.<sup>36</sup> The Plains CO<sub>2</sub> Reduction Partnership (PCOR) has injected over 2.3 million Mt of CO<sub>2</sub> in the Muddy Formation of Belle Creek Field in the Montana portion of the Powder River Basin since injection began in 2013. This CO<sub>2</sub> is being sourced from ConocoPhillips' Lost Cabin natural gas processing plant in Fremont County, Wyoming. One partnership, the Southeast Regional Carbon Sequestration Partnership (SECARB), is conducting two separate projects: one utilizes the Paluxy Formation at the Citronelle Field site, and the other utilizes the Tuscaloosa Formation at the Cranfield Field site in southwestern Mississippi. At the Citronelle Site in southwestern Alabama, injected CO<sub>2</sub> was supplied via amine capture technology installed at Plant Barry capable of producing 100,000 to 150,000 Mt of CO<sub>2</sub> annually. Over 100,000 Mt were injected into the Paluxy Formation at the Citronelle Field site before operations ended in 2014. Injection of naturally occurring CO<sub>2</sub> from the Jackson Dome began at the Cranfield site in 2009. Between 2009 and 2014, 4.7 million Mt of CO<sub>2</sub> were injected and stored.<sup>37</sup> The final Phase III project is managed by the Southwest Regional Carbon Sequestration Partnership (SRCSP) located in the northern panhandle of Texas. Two anthropogenic sources of CO<sub>2</sub> supply this project: the Arkalon Ethanol Plant in Kansas and the Agrium Fertilizer Plant in Texas. As of July 2015, over 300,000 Mt of CO<sub>2</sub> have been stored in the Morrow Formation in the Anadarko Basin in which this project resides.<sup>38</sup>

Table 1: Regional Carbon Sequestration Partnerships' Development-phase Projects

	Project Name	Project Type	Geologic Basin	Expected Total Injection of CO <sub>2</sub>
<b>BSCSP</b>	Big Sky Carbon Sequestration Partnership – Kevin Dome Project	Saline	Kevin Dome	1,000,000 metric tons
<b>MGSC</b>	Midwest Geological Sequestration Consortium – Illinois Basin Decatur Project	Saline	Illinois Basin	1,000,000 metric tons
<b>MRCSP</b>	Midwest Regional Carbon Sequestration Partnership – Michigan Basin Project	EOR	Michigan Basin	1,000,000 metric tons
<b>PCOR</b>	Plains CO <sub>2</sub> Reduction Partnership – Bell Creek Field Project	EOR	Powder River Basin	1,000,000 metric tons <i>per year</i>
<b>SECARB</b>	Southeast Regional Carbon Sequestration Partnership – Citronelle Project	Saline	Interior Salt Basin, Gulf Coast Region	≤ 300,000 metric tons
<b>SECARB</b>	Southeast Regional Carbon Sequestration Partnership – Cranfield Project	Saline	Interior Salt Basin, Gulf Coast Region	> 5,000,000 metric tons
<b>SRCSP</b>	Southwest Regional Carbon Sequestration Partnership – Farnsworth Unit – Ochiltree Project	EOR	Anadarko Basin	1,000,000 metric tons

The second DOE/NETL program is the American Recovery and Reinvestment Act of 2009 (ARRA) Site Characterization Initiative. These projects provide greater insight into CO<sub>2</sub> storage resource potential as well as the different geology present throughout the United States. Capacity estimates for the evaluated storage resource potential from each of these characterization projects range from approximately 180 to 640 billion Mt.<sup>39</sup> Project data are posted to the National Carbon Sequestration Database and Geographic Information System (NATCARB), enabling users to access actual field data that provide detailed information regarding project locations, operations, and findings. Data include well borehole locations and well logs, coring and chemical sampling data, and seismic survey results.<sup>40</sup> RCSP and ARRA efforts are complemented by site characterization field projects focused on reservoirs capable of supporting CCUS technologies, and fit-for-purpose projects aimed at advancing CCUS to commercial scale.

Workshop participants noted that geology determines the location and viability of a saline storage or EOR project, and that DOE can play a role in supporting CCUS development by continuing to support projects such as those listed above. The following sections outline some of the key elements, challenges, and opportunities specific to saline and EOR storage.

*a) Saline Storage*

CO<sub>2</sub> storage resource assessment is ongoing, but the most recent DOE estimates for this storage resource potential in saline formations in the lower 48 states range from 1,710 up to 14,528 billion Mt.<sup>41</sup> While CO<sub>2</sub> storage in deep saline formations lacks the economic incentives of oil reservoirs and associated EOR operations, a saline reservoir proximal to CO<sub>2</sub> point sources may facilitate this CCUS linkage in the long term.

In North America, Cambrian-age formations have emerged as having high potential for saline storage, particularly for projects located in the Williston, Illinois, and Michigan basins. The large estimated capacity, numerous geologic seals to retain injected CO<sub>2</sub>, and lack of alternative economic use of the Cambrian Basal Sandstones in the Williston Basin or the Mount Simon in the Illinois and Michigan basins make them attractive targets for large-scale CO<sub>2</sub> storage. The Cretaceous and Tertiary sands of the Gulf Coast also present excellent saline storage potential.<sup>42</sup>

Workshop participants noted that identification and characterization of high-potential formations such as these play a pivotal role in advancement of saline storage; one participant noted that proposals to store CO<sub>2</sub> in saline formations for which data are sparse may take up to a decade to commence operations. Given the extended timelines associated with saline storage, reducing the upfront costs associated with characterization and baseline development is a major step forward.

A key component of any storage project is the assurance that CO<sub>2</sub> will not migrate to the earth's surface or contaminate drinking water. For saline storage projects, EPA's Underground Injection Control (UIC) guidelines for Class VI wells are intended to minimize that risk.<sup>43</sup> These guidelines include extensive site characterization, comprehensive monitoring, and recordkeeping and reporting throughout the project life cycle. A more detailed description of these guidelines can be found in Section VII.3: Underground Injection.

To date, two entities have received a Class VI permit for their saline storage CO<sub>2</sub> injection wells: the FutureGen Alliance for its well in Jacksonville, Illinois, and ADM's Illinois Industrial CCUS.<sup>44</sup> DOE has funded two complementary CCUS projects in which ADM is involved: IBDP led by the MGSC, and the Illinois Industrial CCUS Project (IICP) led by ADM.

Dr. Sallie Greenberg of the Illinois State Geological Survey (ISGS) presented a review of IBDP, covering the project's geologic, operational, and regulatory elements. The IBDP intended to validate sequestration efforts in the Mount Simon sandstone, a primary storage resource in the Midwest region with an estimated capacity of 11 to 150 billion Mt.<sup>45</sup> Approximately 350 million gallons of ethanol are produced annually at the ADM facility in Decatur, Illinois; at capacity, this facility also produces over one million Mt of CO<sub>2</sub> annually.<sup>46</sup> The IBDP injected approximately 330,000 Mt of CO<sub>2</sub> per year starting in November 2011. Operations ceased in November 2014, after the successful injection of 999,215 Mt. Since then, the IBDP has undertaken intensive post-injection monitoring.<sup>47</sup> Greenburg notes that while the IBDP injection well operated under a UIC Class I permit issued by the Illinois EPA, it will fulfill the U.S. EPA UIC Class VI requirements by entering a 10-year post-injection monitoring period.

The IICP intends to expand the IBDP to a commercial-scale operation, with the intention of injecting 5 million Mt over a period of 3 years.<sup>48</sup> ADM has integrated the IBDP facilities and added a second injection well approximately 3,700 feet from the IBDP injection well, which received its Class VI permit in September 2014. Two additional wells, a viewing well and a geophysical test well, have also been added to the project. ADM has also expanded its operation to include a compression facility with a capacity of 2,000 Mt of CO<sub>2</sub> per day; when integrated with the existing IBDP facility, the IICP project will reach an injection capacity of 3,000 Mt per day. Injection will occur approximately 3,700 feet from the IBDP injection well on a 200-acre, ADM-owned site adjacent to the ethanol plant.

Two other CO<sub>2</sub> saline storage injection projects are underway. In Kansas, the Kansas Geological Survey is leading a project that has filed for a Class VI permit on behalf of Berexco LLC from EPA's Region 7.<sup>49</sup> In North Central Montana, the BSCSP is working on a saline storage project at the Kevin Dome, a site of naturally occurring CO<sub>2</sub>, which is the source for this project.<sup>50</sup>

### *b) CO<sub>2</sub>-EOR*

EOR can play a vital role in deployment and advancement of CCUS technology as a proven and financially justifiable method of permanent CO<sub>2</sub> sequestration. EOR sites are ideal for CO<sub>2</sub> storage due to their proven storage capability and existing infrastructure. EOR projects are poised to benefit from existing knowledge of reservoir geology and available infrastructure, which can facilitate project planning and regulatory applications for CO<sub>2</sub> storage.

The United States is a world leader in EOR technology. The first CO<sub>2</sub> EOR projects, SACROC and North Cross Devonian Unit in the Permian Basin in West Texas, began in 1972. Since then, 134 additional CO<sub>2</sub>-EOR projects in 10 states have injected approximately 600 million Mt of CO<sub>2</sub> in EOR reservoirs in the Permian Basin, and over 850 million Mt in the United States. EOR operations now extend beyond the Permian Basin to Wyoming, Southeast New Mexico, and the Gulf Coast states (Texas, Louisiana, and Mississippi), with growth potential in Oklahoma and Michigan.<sup>51</sup> In 2014, CO<sub>2</sub>-EOR represented 3 percent of domestic oil production (about 280,000 barrels per day).<sup>52</sup> EOR offers the potential to produce 21 to 63 billion barrels of additional oil while sequestering anthropogenic CO<sub>2</sub> that would otherwise be emitted to the atmosphere.<sup>53</sup> Supplies of CO<sub>2</sub> to EOR operations in 2014 totaled about 67.8 million Mt of which about 13.6 Mt are captured from high-purity industrial sources.<sup>54</sup> Recent RCSP estimates in NATCARB suggest that oil and natural gas reservoirs are capable of storing between 186 and 232 billion Mt or up to 30 years of national CO<sub>2</sub> emissions based on recent estimates.<sup>55</sup>

As of January 2015, the Weyburn-Midale CO<sub>2</sub> Monitoring and Storage Project in Saskatchewan, Canada, was the world's largest geologic site for CO<sub>2</sub> storage. The CO<sub>2</sub> for this project is captured from the Great Plains Synfuel plant in Beulah. Of the roughly 3 million Mt of CO<sub>2</sub> captured every year, 2.4 million Mt are sent to the Weyburn EOR field, which is expected to store around 30 million Mt of CO<sub>2</sub> by the end of the project. The remainder is sent to the Midale field, which is expected to store around 10 million Mt of CO<sub>2</sub>.<sup>56</sup> Combined, these fields have stored over 25 million Mt of anthropogenic CO<sub>2</sub> and are expected to produce 220 million barrels of oil by the completion of the project.<sup>57</sup>

There is also a growing recognition of additional storage potential in ROZs, which was the focal point of a presentation by Vello Kuuskraa, from Advanced Resources International, Inc. ROZ viability is being demonstrated by several projects, including Seminole oil field operated by Hess Corporation, Wasson Denver Unit operated by Occidental Petroleum Corporation, and Goldsmith oil field operated by Kinder-Morgan, Inc. ROZ demonstration projects produced over 6,500 barrels per day within the Permian Basin in 2012.<sup>58</sup> A major constraint on development of ROZ resources is limited supply of CO<sub>2</sub>.

### *c) Stacked CO<sub>2</sub> Storage*

The Permian Basin is endowed with significant oil and natural gas resources. Here, oil and gas reservoirs occur in multiple formations, often one below another, presenting a stacked appearance. This multiple occurrence of oil and gas reservoirs and associated formation waters present a stacked appearance, providing an opportunity for "stacked storage," and the potential to centralize operations for multiple CO<sub>2</sub> storage reservoirs.<sup>59</sup> This opportunity is also present in other basins.<sup>b</sup>

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<sup>b</sup> Stacked storage could allow a single surface facility to serve multiple storage projects (e.g., both CO<sub>2</sub>-EOR and saline storage), thereby increasing the potential storage capacity and reducing the amount of infrastructure required. However, there are potential regulatory uncertainties for a stacked storage operation given that such an operation has never been attempted. The regulatory treatment for underground injection of CO<sub>2</sub> is discussed in Section VII.3 of this report.



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There are several sites that may serve as demonstrations of stacked storage, including Denbury Onshore LLC's EOR operation in Cranfield Mississippi. Approximately 5 million Mt of CO<sub>2</sub> for EOR have been injected into the Tuscaloosa Formation, an oil producing formation with underlying saline sections. As oil production begins to decline, Denbury is poised to leverage its existing infrastructure by transitioning to saline storage.<sup>60</sup>

## 2. CO<sub>2</sub> Sources

In 2010, supply of CO<sub>2</sub> for EOR was comprised of 85 percent (58 Mt/year) from natural sources, 13 percent (8.9 Mt/year) from natural gas processing plants, and 2 percent (1.1 Mt/year) from other industrial sources.<sup>61</sup>

The market for CO<sub>2</sub> is driven by economics: CO<sub>2</sub> is either pushed to the market by a price for captured CO<sub>2</sub> emissions or pulled by demand from projects that utilize CO<sub>2</sub>. The development of large natural sources of CO<sub>2</sub>, such as the McElmo and Jackson domes, established a foundation for the EOR industry. Without discovery and development of new natural resources, future EOR projects are likely to look toward additional capture from anthropogenic sources. The following sections provide an overview of natural and anthropogenic CO<sub>2</sub> sources.

### a) Natural Sources

In 2012, U.S. reserves of natural CO<sub>2</sub> totaled approximately 2.2 billion Mt, which is equivalent to 45 years of supply at current production rates; some of these resources, like those at St. Johns in Arizona, have yet to be brought on-line.<sup>62</sup> While there is potential for new discoveries or revised estimates of current reserves, utilization of these potential future CO<sub>2</sub> supplies will require expansion of current pipelines or new pipelines to connect them to EOR sites.

There are five primary sources of nearly pure naturally-occurring CO<sub>2</sub>: McElmo Dome, Doe Canyon, Bravo Dome, Sheep Mountain (which is near depletion), and Jackson Dome. McElmo Dome, Doe Canyon, Bravo Dome, and Sheep Mountain provide CO<sub>2</sub> to the Permian Basin. Jackson Dome provides CO<sub>2</sub> to the Gulf Coast EOR reservoirs in Mississippi, Louisiana, and Texas. All together these CO<sub>2</sub> reservoirs have about 1.5 billion Mt of CO<sub>2</sub> reserves.<sup>63</sup>

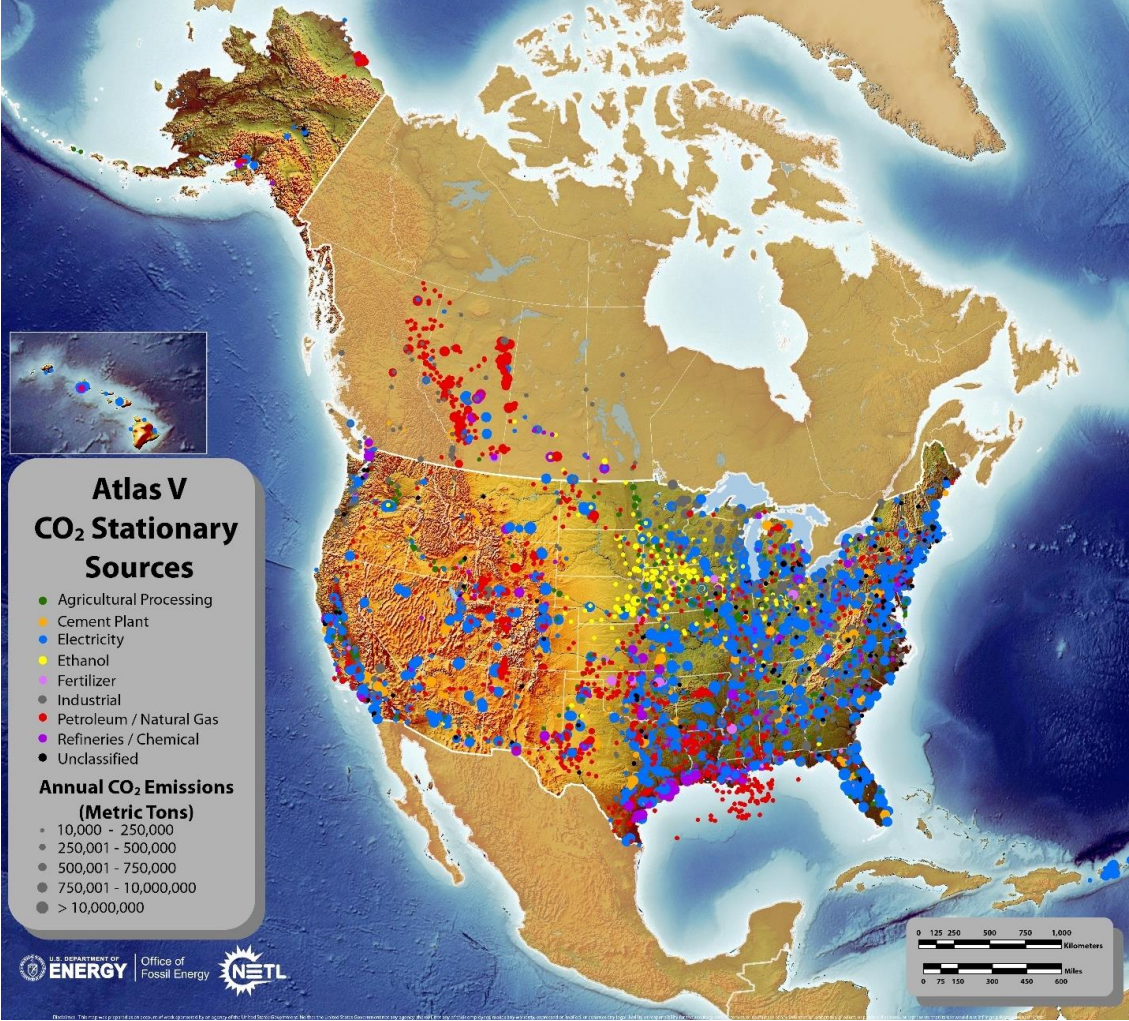
Carbon dioxide is often a constituent in natural gas reservoirs, requiring separation before the natural gas is shipped to market. LaBarge reservoir in Wyoming is the most significant example of this situation with 5.3 billion Mt of CO<sub>2</sub> reserves. Distribution of these CO<sub>2</sub> reserves to EOR reservoirs depends on gas processing plants separating the CO<sub>2</sub> from the produced natural gas. Presently, ExxonMobil's Shute Creek gas plant provides LaBarge CO<sub>2</sub> to the pipeline network in Wyoming. Denbury is building their Riley Ridge plant to process LaBarge production and provide CO<sub>2</sub> to their pipeline network in Wyoming. Denbury also has CO<sub>2</sub> from ConocoPhillips's Lost Cabin gas plant.<sup>64</sup>

In West Texas, the Century Plant and Val Verde Plants provide separation of CO<sub>2</sub> from produced natural gas, suppling the Permian Basin pipeline network. Presently, total CO<sub>2</sub> reserves from natural gas reservoirs in Texas and Wyoming is 5.6 Gt.<sup>65</sup>

### *b) Anthropogenic Sources*

Carbon capture technologies can be applied to many sources of CO<sub>2</sub> emissions, and DOE's Quadrennial Technology Review includes several assessments relating to CCUS technologies.<sup>66</sup> There is a long history of carbon capture in the industrial sector from high purity sources. Capture from the natural gas and fertilizer industries, among others, has been operational for years, while recent efforts have focused on CCUS in other industrial sources and in the power sectors. Through RCSP characterization efforts and EPA's GHGRP, over 6,000 stationary sources of anthropogenic CO<sub>2</sub> have been documented (see Figure 2 below). Collectively, these sources emit over 3,000 million Mt per year.<sup>67</sup> Significant volumes of CO<sub>2</sub> from stationary sources can be found throughout the United States, with potential CCUS sources falling into one of two categories: energy and industry.

Figure 2: NATCARB Atlas of Stationary Sources of CO<sub>2</sub>. Anthropogenic CO<sub>2</sub> made up 20 percent of the estimated 68 million Mt of CO<sub>2</sub> transported via U.S. pipeline in 2014. Over the next few years, industrial capture is expected to increase the transport and storage needs of anthropogenic CO<sub>2</sub> by roughly 60 million Mt.



Energy sources including petroleum and natural gas systems and electricity production represented over 80 percent of emissions in 2013.<sup>68</sup> EPA GHGRP estimates for 2014 report total CO<sub>2</sub> emissions from 2,350 petroleum and natural gas facilities at 163 million Mt.<sup>69</sup> For the refinery sector, an estimated 174 million Mt were emitted from 141 facilities in 2014.<sup>70</sup>

Electricity production facilities contributed 69 percent of 2014 CO<sub>2</sub> emissions.<sup>71</sup> With 1,544 electricity facilities reporting for the 2014 GHGRP, EPA reports CO<sub>2</sub> emissions of over 2,000 million Mt for this sector.<sup>72</sup>

Industrial sources are distributed throughout the United States. Ethanol processing, such as ADM’s IBDP and IICP facility, largely occurs in the Midwest and is capable of supplying substantial volumes of nearly pure CO<sub>2</sub>. Approximately 18 million Mt of CO<sub>2</sub>, or 1 percent of 2014 stationary source emissions, are attributed to ethanol production.<sup>73</sup> The cost of capture and separation is greatly reduced due to the purity and concentration of ethanol-based CO<sub>2</sub>, since it does not require extensive separation and compression. Fertilizer production also contributes 1 percent to 2014 emissions, with several sources concentrated near potential saline and EOR storage sites.<sup>74</sup> Carbon capture at ethanol and fertilizer production facilities has already been deployed at a commercial scale.

### III. PROJECTIONS OF CCUS PIPELINE INFRASTRUCTURE

The vast majority of the CO<sub>2</sub> pipeline network is west of the Mississippi River, while most of the sources that may require capture of their CO<sub>2</sub> are east of the Mississippi River. This expansion effort will likely rely on a carbon price for support. At an assumed CO<sub>2</sub> market price of \$25/Mt, the current pipeline network could be tripled by 2030 through an average expansion rate of 1,000 miles per year.<sup>75</sup> While the network is fragmented and scattered, expansion for CCUS needs will depend on reasonable and effective legislation.

In 2014, CO<sub>2</sub>-EOR represented 3 percent of domestic oil production (about 280,000 barrels per day).<sup>76</sup> Modeling done by Office of Energy Policy and Systems Analysis (EPSA), using parameters from EIA's *Annual Energy Outlook 2014 Reference Case*, projects an increase in EOR production of 7 percent by 2030; however, there was no buildout of new pipeline due to lack of CO<sub>2</sub> capture.<sup>77</sup> This base scenario was modified by adding a carbon price of \$25 per Mt of CO<sub>2</sub>, beginning in 2015 and escalating at 5 percent annually through 2040. This scenario builds out over 21,000 miles of pipeline by 2040, with EOR contributing 16.5 percent of total domestic oil production (see Table 2 below). The report was not specific in which year pipeline construction would begin, but if it was to begin in 2020, then pipeline construction would have to average more than 1,000 miles per year to meet the modeled goal. This pipeline network would facilitate the storage of 94.1 Mt of captured CO<sub>2</sub> by 2030 and 171.7 Mt by 2040. EOR production as a percent of total domestic oil production would increase to 10.1 percent by 2030 and 16.5 percent by 2040.

Table 2: EPSA CP25 Scenario Modeling Results

	2030	2040
Pipeline Miles	11,062	21,496
CO <sub>2</sub> Stored – Mt		
Industrial	0.1	1.0
Power	94.0	170.7
EOR Oil % of Total	10.1	16.5

There are a number of planned EOR pipeline expansions. Denbury plans major pipeline developments and extensions in Wyoming, Montana, North Dakota, and Texas. One development, a new pipeline connecting the Riley Ridge Gas Plant to EOR operations in Wyoming, will be 250 miles long and cost \$500 million.<sup>78</sup> Another project will extend the Greencore Pipeline into eastern Montana to Denbury's properties along the Cedar Creek Anticline.<sup>79</sup> Two more pipeline extensions off of the Green pipeline will provide transport to EOR operations in Texas, adding 9 miles of pipeline to connect Webster Field and 90 miles of pipeline to connect Conroe Field.<sup>80</sup>

## IV. EXISTING AND PROPOSED CCUS PROJECTS

Since 2010, the Global Carbon Capture and Storage Institute (GCCSI) has tracked global activity on large-scale injection projects (LSIP). In 2015, there were 14 LSIPs, eight of which were in operation and three of which were under construction (see Table 3 below).<sup>81</sup> All of the operating projects provide CO<sub>2</sub> to EOR operations via pipeline connections. Six of the eight operational projects were financed by the oil company operators of each facility to process their oil and gas production, including separation of CO<sub>2</sub> for their own CO<sub>2</sub>-EOR operations or for sale to other operators. Two of the projects are third-party providers. Air Products has completed installation of capture equipment at their hydrogen plant in Port Arthur, Texas. About one million Mt of captured CO<sub>2</sub> per year are shipped to Denbury's Green Pipeline via a 13-mile connection. This \$430.6 million project received \$146.6 million from DOE under NETL's Industrial Carbon Capture and Storage program.<sup>82</sup> The Dakota Gasification Plant in Beulah, North Dakota also received government grants for construction.<sup>83</sup>

There are four LSIPs under construction. East of Jackson, Mississippi, Mississippi Power's Kemper County integrated gasification combined cycle (IGCC) plant is nearing completion. This 582 MW power plant will capture about 65 percent of its CO<sub>2</sub> emissions, which will be sold to Denbury Resources and Treetop Midstream Services via a 61-mile pipeline.<sup>84</sup> This project has received \$270.2 million from DOE under NETL's Clean Coal Power Initiative Program Round 2 for the development of the capture technology installed at the Kemper County Plant. South of Houston, Texas, Petra Nova is nearing completion of its 240 MWe post-capture installation at the NRG W.R. Parrish Plant in Thompsons, Texas. This project will capture 90 percent of the CO<sub>2</sub> emissions, about 1.4 million Mt per year.<sup>85</sup> The captured CO<sub>2</sub> will utilize an existing electric power line ROW for its pipeline to transport the CO<sub>2</sub> 80 miles to West Ranch Field southeast of Victoria, Texas.<sup>86</sup> This \$1 billion project will receive \$166.8 million from DOE under NETL's Clean Coal Power Initiative Program Round. In Wyoming, Denbury is near completion of their Riley Ridge gas processing plant. As mentioned earlier, this plant will process natural gas from the LaBarge reservoir and the separated CO<sub>2</sub> will be utilized by Denbury in their EOR projects in Wyoming and Montana. The lone active LSIP applied to a saline formation is the IBDP and IICP in Decatur, Illinois.<sup>87</sup> This \$207.9 million project has received \$141.4 million from DOE under NETL's Industrial Carbon Capture and Storage Program.<sup>88</sup> This project is discussed in Section II.1 under Saline Storage.

Table 3: Active CCUS Projects in the United States as of 2015 (adapted from the GCCSI database)

	Active Projects	State	Primary Industry	Year of Operation	Capture Capacity (Metric tons per year)	Transport Distance (miles)
<b>Operate</b>	Coffeyville Gasification Plant	KS	Fertilizer Production	2013	1	70
	Air Products Steam Methane Reformer EOR Project	TX	Hydrogen Production	2013	1	98
	Century Plant	TX	Natural Gas Processing	2010	8.4	>158
	Val Verde Natural Gas Plants	TX	Natural Gas Processing	1972	1.3	221
	Shute Creek Gas Processing Facility	WY	Natural Gas Processing	1986	7	Multiple Pipelines, Max of 286
	Lost Cabin Gas Plant	WY	Natural Gas Processing	2013	0.9	232
	Great Plains Synfuel Plant and Weyburn-Midale Project	ND	Synthetic Natural Gas	2000	3	204
	Enid Fertilizer CO <sub>2</sub> -EOR Project	OK	Fertilizer Production	1982	0.7	140
<b>Execute</b>	Illinois Industrial Carbon Capture and Storage Project	IL	Chemical Production	2016	1	1
	Petra Nova Carbon Capture Project	TX	Power Generation	2016	1.4	82
	Kemper County Energy Facility	MS	Power Generation	2016	3	60
<b>Define</b>	Riley Ridge Gas Plant	WY	Natural Gas Processing	2020	2.5	Not Specified

Since GCCSI began tracking LSIPs, 22 out of 36 proposed projects have been canceled for various reasons. An interesting aspect for three of these project cancellations is that Denbury Resources, Inc., conducted a comprehensive study to evaluate the feasibility of a building a CO<sub>2</sub> pipeline from southern Illinois to their existing EOR operations near the Jackson Dome in Mississippi.<sup>89</sup> From southern Illinois, Denbury anticipated gathering the captured CO<sub>2</sub> from several proposed carbon capture projects. One of the proposed sources was Leucadia Corporation's 134 MW coal gasification plant in Rockport, Indiana, a \$2.8 billion project with \$2.5 billion in loan guarantees. This project encountered problems securing eminent domain and had public opposition. The Indiana Department of Environmental Management rescinded the air-quality permit for this project at Leucadia's request.<sup>90</sup> For the second proposed source, Tenaska's 716 MW IGCC Taylorville Energy Center in Illinois, regulatory uncertainty and low natural gas prices threatened the economic viability of the \$3.5 billion project. These complications were cited as the reason for canceling the Taylorville Energy Center.<sup>91</sup> Denbury evaluated a third project in Henderson, Kentucky: Erora Group's Cash Creek IGCC plant. Erora Group eventually decided not to pursue this project.<sup>92</sup> Denbury anticipated approximately two million Mt of CO<sub>2</sub> per year to be captured and transported via a 110-mile pipeline along the Gulf Coast before connecting to the existing Free State Pipeline. Had these projects been implemented, Denbury estimated a cost of approximately \$1.0 billion to build the 500 to 700 miles of pipeline necessary to transport the captured CO<sub>2</sub>.<sup>93</sup> These projects illustrate some of the challenges of building out the CO<sub>2</sub> pipeline network and deploying CCUS technology.

## V. FUTURE OPPORTUNITIES

The following opportunities to expand CCUS infrastructure were discussed by workshop participants (note that DOE does not necessarily agree with or support the content summarized below):

- Developing a pipeline network that links multiple CO<sub>2</sub> sources and storage sites can reduce the costs of all users.
- As more CCUS projects come online, there will be growing opportunities to facilitate knowledge sharing and encourage collaboration. In doing so, there is potential to reduce timelines for project permitting and buildout.
- There is a need for additional large-scale demonstrations of CO<sub>2</sub> storage, in particular, for saline formations, to advance resource characterization efforts, reduce risks and uncertainty, and provide a better understanding of costs.
- ROZ exploration and production could provide additional sites for significant CO<sub>2</sub> storage and provide billions of barrels of oil.<sup>94</sup>
- Stacked storage presents an opportunity for projects to take advantage of EOR revenue streams in the short-term while preparing for continued, large-volume saline storage in the long-term.
- Development of industrial sources, including power plant CCUS, and using the CO<sub>2</sub> captured from these projects for EOR could facilitate the production of an additional 21 to 63 billion barrels of oil, providing storage of 10 to 20 billion Mt of CO<sub>2</sub>.<sup>95</sup> With 1 to 3 barrels of oil produced per Mt of CO<sub>2</sub>, oil prices below \$40 per barrel make efficiency and cost reduction a top priority for current capture operations. The gap between the market price for CO<sub>2</sub> and the cost to add capture to new anthropogenic sources of CO<sub>2</sub> presents a barrier to taking advantage of EOR potential within the United States.



## VI. STATE POLICY ENVIRONMENT FOR CCUS INFRASTRUCTURE

Workshop participants highlighted the significant role of states in facilitating CCUS infrastructure. States have provided financial incentives, established CO<sub>2</sub> storage regulations, developed expertise in CO<sub>2</sub> injection and pipeline buildout over the last three decades, and crafted innovative approaches to infrastructure planning.

### Statutory and Regulatory Environment – Pipelines

#### 1. Siting and Economic Regulation

States play the lead role in economic regulation of CO<sub>2</sub> pipelines and in regulating pipeline siting on non-Federal lands. The vast majority of existing State laws and experience with regulating CO<sub>2</sub> pipelines is based on pipelines built to transport CO<sub>2</sub> for the purpose of EOR. While some have suggested a potential need for additional Federal involvement in CO<sub>2</sub> pipeline regulation, several participants in the workshop commented that the current State-led approach works well for pipeline development. One participant suggested, however, that an enhanced Federal role could be helpful in some Western states where significant ownership of Federal land can introduce additional complexity to the pipeline planning and permitting process.

State laws shape where pipelines are sited and how developers acquire ROWs. In order to build a pipeline, developers must meet any State requirements for siting approval and acquire ROWs along the pipeline pathway from landowners in the form of purchased easements. In cases where a landowner does not want to sell an easement, pipeline developers may exercise eminent domain, in states where it is allowed, to acquire the property. Various states allow eminent domain in certain circumstances to enable acquisition of property by the government or government-defined parties for public use (e.g., a CO<sub>2</sub> pipeline). States that allow the exercise of eminent domain for CO<sub>2</sub> pipelines often do so only if such pipelines have common carrier status. Common carrier status usually includes requirements that the pipeline is available for public use and can be accessed and/or used by other parties, and allows the state to become involved with setting tariffs. Aside from the common carrier status, public notice is also a requirement that operators may have when they file for State approval to build or modify the pipeline.

Workshop participants discussed eminent domain and noted that some states are unlikely to provide eminent domain authority due to political opposition. Workshop participants also noted that these same states appear to be successful at building pipelines (e.g., Oklahoma) without eminent domain authority. Even in states that provide eminent domain authority, its controversial nature means that it is generally used as a last resort. Most pipeline operators would prefer to secure their pipeline ROW through negotiations with the landowners.<sup>96</sup> Mike Smith of the Interstate Oil and Gas Compact Commission (IOGCC) presented at the workshop and observed that much of the buildout of the existing CCUS infrastructure was done without eminent domain and with private contracts.

Some states willing to allow eminent domain have declared CO<sub>2</sub> pipelines to be in the public interest in order to enable its use. For example, the Illinois legislature passed the Carbon Dioxide Transportation and Sequestration Act (220 ILCS 75) that declared CO<sub>2</sub> pipelines are in the public interest and provided the legal framework for certification of CO<sub>2</sub> pipelines for construction.<sup>97</sup> See Table 4 below for different examples of the application of eminent domain.

Table 4: Eminent domain provisions

State	Eminent Domain Provisions
Mississippi	Limited to CO <sub>2</sub> pipelines in connection with enhanced recovery of hydrocarbons (e.g., EOR). <sup>98</sup>
Louisiana	Expropriation of property can be approved by the Commissioner of Conservation conditioned on approval of an EOR project which may be located in another state. <sup>99</sup>
Texas	A common carrier may exercise a State-granted power of eminent domain and the ability of the pipeline operator to exercise this power is not limited for purpose; it can be utilized for EOR or for transportation to a geologic storage site. <sup>100</sup>

In terms of economic regulation, CO<sub>2</sub> pipelines are commonly built on a contractual basis between relevant parties and rates for CO<sub>2</sub> transportation are negotiated between them. If a dispute arose between parties, states would have authority to hear complaints for intrastate pipelines. For interstate pipelines, it is not clear who would have authority to hear complaints, but some have suggested the Federal Surface Transportation Board (STB) has the potential to play that role under the current framework.<sup>101</sup>

States have also established authorities and mechanisms to assist and promote pipeline development that result in streamlined siting processes and project finance tools. Examples include

- Wyoming Pipeline Corridor Initiative.* This initiative is developing “a proposed pipeline ROW network designed to connect sources of CO<sub>2</sub> to existing oil fields that are suitable for EOR, via CO<sub>2</sub> flooding.”<sup>102</sup> At the workshop, Matt Fry from Wyoming Governor Mead’s office presented on the Wyoming Pipeline Corridor Initiative and described how it will address many of the challenges to developing pipelines on Federal lands in Wyoming, which cover much of the state. Through this initiative, the state identified pipeline corridors and is in the process of completing a significant portion of the planning in the corridors so that, when operators are ready to build a pipeline, it takes much less time and lowers costs. From the state’s perspective, this process will facilitate commercial deployment of important infrastructure in the state while doing so in an environmentally sound manner. Several workshop participants suggested that this initiative could be a model for other states that have significant Federal lands.
- North Dakota Pipeline Authority.* North Dakota’s Pipeline Authority may “participate in a pipeline project through financing, planning, development, acquisition, leasing, rental, joint ownership, or other arrangements.”<sup>103</sup> While North Dakota has one operating CO<sub>2</sub> pipeline, the Authority reported in 2015 that it remains active in the Plains CO<sub>2</sub> Reduction Partnership and “continues to work with interested parties on the development of new carbon dioxide pipelines for capture and sequestration, as well as enhanced oil recovery operations.”<sup>104</sup>

**Safety regulation.** For intrastate pipelines, the Federal Government sets the requirements, but states may be the administrator for pipeline inspection and enforcement if the state statutes meet or exceed Federal safety requirements. For interstate pipelines, the Federal Government may designate states as interstate agents for the purpose of pipeline inspection. A detailed breakdown of Federal and State

authority on pipeline safety is discussed under Federal Statutory and Regulatory Environment – Pipelines, in Section VII of this report.

## Statutory and Regulatory Environment – Geologic Storage

State statutory and regulatory frameworks play a major role in siting and permitting CO<sub>2</sub> storage sites, including for CO<sub>2</sub> that is stored through EOR. States that meet minimum Federal requirements and are authorized by EPA also play a role in managing CO<sub>2</sub> storage sites.

### 2. Siting and Permitting

Many states have experience with and developed siting and permitting authorities and regulations for CO<sub>2</sub> injection and storage that often stem from CO<sub>2</sub>-EOR operations. Over the last decade, EPA developed and promulgated rules (discussed in more detail in Section VII: Federal Environment for CCUS Infrastructure of this report) that provide the minimum requirements for CO<sub>2</sub> injection, storage, and management in both saline formations and oil and gas fields. States that meet or exceed Federal rules may apply for primacy, which means that they have primary enforcement authority and can oversee the regulatory program in their state.<sup>105</sup> Many states have primacy to regulate CO<sub>2</sub> injection and storage for oil and gas projects where the primary purpose is hydrocarbon recovery. While there are no states with primacy for projects where the primary purpose of CO<sub>2</sub> injection is geologic storage of CO<sub>2</sub> (called a 'Class VI permit,' discussed in Section VII of this report), North Dakota submitted an application for primacy for Class VI permits in 2013. Following North Dakota's application submission, EPA provided public notice and opportunity for public comment on the action.<sup>106</sup> This action is currently pending approval.<sup>107</sup>

Some participants also noted that each state and geologic storage formation is unique, so a one-size-fits all approach does not make sense for regulating CO<sub>2</sub> storage sites. Subsurface geology is variable. Oil and gas reservoirs occur in various lithologies and sizes, from giant fields to a shallow one-well reservoir. The same is true for saline storage.

### 3. Property Rights

State law governs property rights, including which property rights must be acquired for siting CO<sub>2</sub> storage projects, either in a saline formation or through EOR. Because numerous interests could be involved in the surface, pore space, and mineral rights associated with the injection, operation, and management of a geologic storage site, participants stressed that it is important for states to have clear statutes in this area. There has been much discussion over who owns the pore space where CO<sub>2</sub> will be stored. States that have begun to analyze and clarify this issue have commonly designated the surface owner as the owner of the pore space (e.g., North Dakota<sup>108</sup>).<sup>109</sup> Statutes may also be developed to clarify how CCUS projects might interact with existing mineral rights (e.g., in Texas).<sup>110</sup> While oil and gas leases provide a legal framework for this interaction during incidental storage of CO<sub>2</sub> through EOR, additional legal issues may arise when the primary purpose of a project transitions from EOR to CO<sub>2</sub> storage.<sup>111</sup>

Some states have looked to the oil and gas practice of unitization, whereby a percentage of property owners aggregate their rights into one unit.<sup>112</sup> Unitization can be voluntary or, depending on the state, compulsory once a certain percentage – usually 60 to 80 percent – of owners have agreed to unitize. With 60 years of experience and case law on unitization in the oil and gas industry, all major oil and gas producing states have passed laws in support of compulsory unitization for oil and gas projects, with the exception of Texas.<sup>113</sup> Montana, North Dakota, and Wyoming are all examples of states that have passed legislation to enable unitization of pore space rights for CO<sub>2</sub> storage.<sup>114</sup> A workshop participant noted

that a benefit of unitization is that it has the potential to result in more efficient development of resources because all ownership is aggregated and a resource is operated and managed as a single unit.

#### 4. Long-term Management and Liability

Another issue tied to property ownership and site management over time is long-term liability. Liability in this context refers to legal responsibility for environmental and/or human health impacts of a geologic storage project. Many states have studied and taken action to clarify who would be legally responsible and liable for a geologic storage site in the long-term (i.e., in the post-injection period).<sup>115</sup> Due to the long-term nature of geologic storage, some have recommended that the public sector provide a mechanism for site management and liability using different funding tools that would keep the responsible party financially solvent. Depending on the state, the responsible party might be the operator, the state, or a third-party. Workshop participants commented that the Federal Government is not likely to play a major role in long-term liability, even though that is not without precedent in other industries. A 2011 report by the Federal Interagency Task Force on Carbon Capture and Storage discussed several potential approaches to long-term liability, including post-closure transfer to the Federal Government with contingencies. The Task Force report declared that open Federal indemnification was not an option under consideration.<sup>116</sup>

At the workshop, participants noted that states have played a leadership role in addressing the liability issue and that there are several models available for other states to draw upon. One of the most commonly cited options for states is a trust fund, whereby money would be collected into a fund over time and, in most cases, administered by the state.

Conceptually, a trust fund could be established to provide financial support for the long-term management and monitoring of a geologic storage site. In 2007, the IOGCC studied this issue and provided model statutory language for states to establish such a trust fund.<sup>117</sup> States including Kansas, Louisiana, Montana, North Dakota, Texas, and Wyoming have passed legislation to establish funding mechanisms to support long-term site management and monitoring.<sup>118</sup> For example, Kansas bills H.B. 2419 and H.B. 2418 provide for limited liability, require financial responsibility requirements to be met by the CO<sub>2</sub> storage site owner for operation and site closure, and establish a CO<sub>2</sub> well and underground storage fund that covers various steps in the operation and management of a CO<sub>2</sub> storage site including permitting, emergencies, long-term remediation, and enforcement. H.B. 2418 provided limits to liability for the state in cases of damages that result from CO<sub>2</sub> leakage or discharge.

Another option for management and long-term stewardship of a geologic storage site is to create a publically regulated geologic storage utility. This concept was introduced by the Clean Air Task Force and discussed in detail as part of the Midwestern Governors Association's (MGA) Carbon Capture and Storage (CCS) Task Force.<sup>119</sup> A geologic storage utility could provide basin-wide management of storage resources and, according to a discussion paper prepared for the MGA, would be "responsible for reliably receiving and distributing CO<sub>2</sub> to geologic storage sites, which it would also manage in perpetuity."<sup>120</sup>

#### 5. State Management of EOR Resources

One issue raised by workshop participants is the need to keep declining oil fields alive (i.e., unplugged and not abandoned) so they remain available in the future when CCUS becomes feasible at that particular site. This was characterized as a constant struggle, and it was pointed out that many wells have been permanently plugged. Once plugged, it becomes very difficult and expensive to resume production from the well. Existing wells are a likely pathway to future EOR, and viable wells are critical to maintaining the EOR resource and preserving carbon storage opportunities.

Participants urged states to keep these properties open and to protect these resources for future use, while maintaining a balance with other priorities such as landowner rights and addressing other environmental issues associated with oil and gas development. One participant commented that you can eliminate the need to abandon and plug a well (while still maintaining the mechanical integrity of the well), if you notify a State regulator that you intend to use it for CO<sub>2</sub> injection.

## 6. CCUS for Environmental Compliance

States have implemented different approaches for reducing the carbon emission profile of large point sources, especially large electric generating units. In addition, CCUS is an important source of clean electricity in the United States, which the Clean Power Plan (CPP) recognizes, and states have many opportunities to incorporate CCUS into their compliance plans.

Two states have passed portfolio standards, which require a certain percentage of power generation to come from specific sources, including renewables and CCUS. In Utah, utilities must use CCS or renewables to generate 20 percent of their electricity starting in 2025, and in Illinois, utilities must capture at least 50 percent of their CO<sub>2</sub> emissions and limit other regulated pollutants. The Illinois law also requires state retail suppliers to purchase up to five percent of their electricity from clean coal sources.<sup>121</sup>

Another option is a performance standard, which requires compliance with specific environmental performance, often during a specified time period. For example, California has an emission performance standard of 1,100 pounds per megawatt-hour CO<sub>2</sub> for a baseload generation facility, along with regulatory requirements for CCS projects.<sup>122</sup> California also has a Low Carbon Fuel Standard (LCFS) with requirements for the lifecycle carbon intensity of fuels. Oil produced through EOR, and ethanol facilities that capture and store their CO<sub>2</sub> emissions, could be used to comply with the LCFS if the carbon intensity of their fuel meets the required score.<sup>123</sup>

## State Incentives

States have provided leadership to spur CCUS development through various incentive mechanisms. State incentives can provide complementary financial support to CCUS projects in combination with Federal incentives and other support to drive deployment. Workshop participants stressed that state incentives have played a significant role where CCUS projects have been developed. For example, Patrick Sullivan of the Mississippi Energy Institute described in his workshop presentation how effective state incentives have been in the developing the CO<sub>2</sub>-EOR industry in that state, with CO<sub>2</sub>-EOR accounting for half of the oil production in Mississippi.<sup>124</sup> In another presentation, Dan Lloyd of the Montana Governor's Office of Economic Development discussed how that state is working to lay the groundwork for CCUS projects through a set of incentives, including property tax abatement for CO<sub>2</sub> pipelines and incentives for CCS equipment.

There are several potential tools for states to incentivize projects, described in the next section.

## 7. Tax Credits, Exemptions, Reductions, Abatements and Rate Recovery

States have targeted incentives to support deployment of CCUS infrastructure, including tax credits, exemptions, reductions, and abatements and rate recovery. These incentives are commonly applied at the State level to equipment, property associated with CCUS infrastructure, CO<sub>2</sub> used in EOR, utilities, and businesses. Here are some examples:

- **Property tax exemption.** Kansas H.B. 2419 provides a property tax exemption on carbon capture, sequestration, or utilization property for five years after construction or installation.<sup>125</sup>

- **Reduced income tax.** Mississippi H.B. 1459 provides for a reduced income tax rate of 1.5 percent for qualified businesses that sell CO<sub>2</sub> for EOR or storage.<sup>126</sup>
- **Severance tax reduction.** New Mexico (Section 7-29 New Mexico Statutes Annotated) provides a rate of 1.875 percent of taxable value for oil produced with CO<sub>2</sub> in qualified enhanced recovery projects, under specified pricing circumstances.<sup>127</sup>
- **Sales tax reduction on equipment used for CCS.** Montana applies a reduced tax rate of 50 percent for the first 15 years for equipment placed in service after January 1, 2014, used for geologic sequestration of CO<sub>2</sub>.<sup>128</sup>
- **Rate recovery.** Virginia S.B. 1416 and H.B. 3068 provide for utilities to recover an enhanced rate of return for investment in specific project types, including carbon capture facilities.<sup>129</sup>

## Future Opportunities – State Level

States that have an interest in cultivating a CCUS industry can help make their state attractive to CCUS projects through a combined statutory and regulatory foundation for siting, permitting, and managing projects; developing innovative approaches to planning and financing projects; and establishing incentives that can complement any potential Federal level incentives.

For example, a group of 14 oil and gas-producing states, co-convened by Governor Matt Mead (R-WY) and Governor Steve Bullock (D-MT), recently recommended that states optimize a suite of taxes common in most oil and gas-producing states in order to provide incentives for both carbon capture projects and EOR operations. Analysis undertaken for the State CO<sub>2</sub>-EOR Deployment Work Group found that optimizing four types of traditional taxes—sales tax on carbon capture equipment, property taxes on a carbon capture facility, sales tax on equipment need for oilfield CO<sub>2</sub>-EOR operations, and oil and gas production and severance taxes—can have a beneficial impact on CCUS project economics equivalent to roughly an \$8 per barrel increase in the price of crude oil. The Work Group noted that this impact is significant, especially when compared to the value of existing federal incentives.<sup>130</sup>

Participants encouraged states to learn from and draw on the many examples of other states and to consider multi-state collaboration where it would be beneficial. Some specific future opportunities at the State level that were discussed at the workshop include:

- Be proactive at the State level and do the policy, regulatory, and planning groundwork so that states are project-ready when the opportunity to pursue CCUS presents itself.
- Initiate collaborative, regional efforts among states to advance CCUS infrastructure.
- Improve the planning process and streamline the permitting process, especially in the context of states working with the Federal Government to address impacts to Federal lands in the siting and development of critical pipeline infrastructure.
- Wyoming’s approach to developing pipeline ROW corridors across the patchwork of Federal lands managed by different agencies, which could provide a model for other states with significant Federal lands that are looking for ways to reduce the timeframe for projects going through the Federal planning process.

## VII. FEDERAL ENVIRONMENT FOR CCUS INFRASTRUCTURE

### Federal Statutory and Regulatory Environment – Pipelines

#### 1. Pipeline Siting and Economic Regulation

Rulings to date by both the Federal Energy Regulatory Commission (FERC) per the Natural Gas Act and the STB per the Interstate Commerce Act indicate that they generally have no jurisdiction over rates and siting of inter- or intra-state CO<sub>2</sub> pipelines.<sup>131</sup> While a report by the Government Accountability Office indicated that the STB does in fact have jurisdiction over CO<sub>2</sub> pipelines, the STB did not weigh in on the matter.<sup>132</sup> A 2008 Congressional Research Service analysis of Federal jurisdiction clarified that while neither FERC nor the STB has indicated they have jurisdiction, it is possible for agencies to change their interpretation of existing law.<sup>133</sup> As mentioned in the state section, the STB may have jurisdiction to hear complaints related to the economic regulation of interstate CO<sub>2</sub> pipelines, but no cases have been brought to the STB.

Should a CO<sub>2</sub> pipeline developer seek to cross Federal lands, the Bureau of Land Management (BLM) can grant a ROW under the Mineral Leasing Act (MLA) of 1920 or the Federal Land Policy and Management Act (FLPMA). A ROW granted under the MLA imposes a common carrier status on the pipeline.<sup>134</sup> If the ROW is granted under the MLA then common carrier status is attached to the pipeline, as was the case for the Exxon pipeline connecting its LaBarge production to its Shute Creek gas processing plant.<sup>135</sup> A pipeline crossing Federal lands also triggers the National Environmental Protection Act (NEPA), which requires that either an Environmental Impact Statement (EIS) or and Environmental Assessment (EA) must be conducted. NEPA is also triggered for CCUS projects that use Federal funding. The determination to require an EIS, or the less intensive EA, depends on specific criteria that enable the EPA to evaluate the potential level of impact a project may have.<sup>136</sup>

Workshop participants discussed the current State and Federal balance of jurisdiction over CO<sub>2</sub> pipelines and opined that there is no need for additional Federal involvement in economic regulation. Some experts have raised the possibility of an increased Federal role if the pipeline network substantially increased.<sup>137</sup> A workshop participant commented that, for states with significant Federal lands additional Federal authority and engagement could be helpful in dealing with the challenges presented by various Federal regulations and permitting schedules. The Wyoming example cited under the state section discusses one approach by a state to address these challenges.

Alternative regulatory models were discussed in an IOGCC report regarding possible Federal involvement:<sup>138</sup>

- **Oil Pipeline Model:** Pipelines are common carriers under the Interstate Commerce Act. Operators will be required to apportion capacity in their pipeline. FERC has authority over rates and access. FERC does not have siting or eminent domain authority, which remains with the state.
- **Natural Gas Pipeline Model:** Here, a Federal agency will have siting authority with the ability to grant eminent domain. They will also have tariff responsibilities and open access will be required.
- **Federal/State Cooperative Model:** A Federal agency would have authority to provide needed siting authority, including eminent domain, should a pipeline operator be refused these at the State level. Other aspects of pipeline regulation would be exercised at either the State or Federal level. Use of eminent domain from a Federal agency can bring along Federal oversight of tariffs and aspects of operations.

## 2. Pipeline Safety and Quality Standards

Interstate pipeline safety is regulated by PHMSA, within the Department of Transportation, under the Hazardous Liquid Pipeline Safety Act of 1979.<sup>139</sup> While CO<sub>2</sub> is not considered a hazardous liquid by PHMSA, liquid pipeline safety standards are applied because CO<sub>2</sub> is transported as a dense phase liquid (pipeline pressure above 1,275 pounds per square inch (psi)). The Federal Government has exclusive authority over pipeline safety regulation, but the Office of Pipeline Safety (OPS) under PHMSA may authorize states to become interstate pipeline agents for the purpose of pipeline inspection (see Table 5 for a list of authorized states).<sup>140</sup> The OPS remains responsible for enforcement of pipeline safety regulation in all cases.<sup>141</sup>

One participant at the workshop noted that CO<sub>2</sub> pipelines have a strong safety record, with no fatalities reported to PHMSA.<sup>142</sup> It is also useful in the safety context to note that CO<sub>2</sub> is neither flammable nor explosive.

Table 5: States that have authorization to act as interstate agents, as of 2015

Arizona	New York	Washington
Minnesota	Virginia	

For intrastate pipelines, the Federal Government develops the rules and regulations for pipeline safety and states may apply for annual certification to have inspection and enforcement responsibilities.<sup>143</sup> To receive certification, states must meet several requirements, including adoption of regulatory safety standards that are as stringent as Federal standards (see Table 6 for a list of authorized states).<sup>144 145</sup>

Table 6: States with intrastate authority, as of 2015

Alabama	Maryland	Texas
Arizona	Minnesota	Virginia
California (Fire Marshal)	New York	Washington
Indiana	New Mexico	West Virginia
Louisiana	Oklahoma	

Standards for the composition of transported CO<sub>2</sub> do not fall under the authority of states or the Federal Government. For the current CO<sub>2</sub> pipeline network, the pipeline industry has established composition standards. As described in a presentation by CO<sub>2</sub>-EOR expert L. Stephen Melzer, the composition standard types are separated into three categories:<sup>146</sup>

- Type I Special, Single Use Pipelines (Case-by-case Specifications for Carried Fluid Composition)
- Type II The North American Network, i.e., Multiple Source and User Lines (Strict Specified CO<sub>2</sub> Composition)
- Type III Hybrid Lines (Relaxed but Controlled CO<sub>2</sub> Composition)



Among the three types, Type II is most common. It requires CO<sub>2</sub> content greater than 95 percent and limits H<sub>2</sub>S, oxygen (O<sub>2</sub>), and water (H<sub>2</sub>O) content. Type III standards allow higher H<sub>2</sub>S content, but this standard is only applied to one pipeline at the moment, a dedicated pipeline between the Dakota Gasification Plant in Beulah, North Dakota, and the Weyburn-Midale EOR formation in Saskatchewan, Canada. Type I standards are not in use at this time.<sup>147</sup> Current sources meeting Type II standards are either natural gas processing plants or high-purity ethanol or fertilizer plants. Coal combustion can introduce a range of impurities depending on the source of the coal, requiring treatment of the CO<sub>2</sub> prior to releasing it to the pipeline.<sup>148</sup>

At the workshop, participants noted that industry has developed and applied CO<sub>2</sub> composition and quality standards because the integrity of pipelines and the successful end-use application of the CO<sub>2</sub> depends on such standards. Examples of negative consequences from contaminants in a CO<sub>2</sub> stream include corrosion (H<sub>2</sub>O, O<sub>2</sub>) of pipelines and, in an EOR project, a reduction in the effectiveness of CO<sub>2</sub> in producing oil (methane (CH<sub>4</sub>), nitrogen (N<sub>2</sub>), O<sub>2</sub>, carbon monoxide (CO), hydrogen (H<sub>2</sub>)).

Participants at the workshop noted that industry finds the current industry-established standards acceptable and effective. From the industry perspective, the current standards allow for flexible application for each circumstance and they cautioned against a one-size-fits-all approach.

One participant from a State agency commented that it would be helpful for states to learn more about the industry standards and consider whether any additional action (e.g., at the State or Federal level) is necessary. The same participant asked if industry might be open to states evaluating and potentially adopting the industry standard. An industry participant suggested that greater information sharing on this topic would be helpful and that states and/or the Federal Government could review the existing standards and adopt them by reference.

At the international level, there is an effort by the International Standardization Organization (ISO), an independent, international non-governmental organization, to develop CO<sub>2</sub> composition standards, and other CCUS-related standards.<sup>149</sup> According to a workshop participant involved in the effort, the ISO has a working group focused on CO<sub>2</sub> pipelines that has developed draft standards that were developed, in part, by looking at the ISO standards for other pipeline types. Another suggested resource is to find out what insurance companies require for CO<sub>2</sub> composition.

## Federal Statutory and Regulatory Environment – Geologic Storage

### 3. Underground Injection

The permitting of CO<sub>2</sub> injection is governed by rules promulgated by EPA under the Safe Drinking Water Act, and applied through the EPA's UIC program. The UIC Program has different categories of well classes that are based on "the type and depth of the injection activity, and the potential for that injection activity to result in endangerment" of underground sources of drinking water (USDWs).<sup>150</sup>

The well classes are as follows:

- Class I industrial and municipal waste disposal wells
- Class II oil and gas related injection wells
- Class III solution mining wells
- Class IV shallow hazardous and radioactive waste injection wells
- Class V wells that inject non-hazardous fluids into or above underground sources of drinking water
- Class VI geologic sequestration wells

In the context of CCUS projects, operators can apply to inject CO<sub>2</sub> in either:

- Class II, for projects that inject CO<sub>2</sub> primarily for EOR operations, including EOR projects that store CO<sub>2</sub> as an incidental part of operations; or
- Class VI, for projects that inject CO<sub>2</sub> for the purpose of storage.

Class VI rules are much more extensive and require a higher level of investment to achieve compliance than for a Class II well, since projects operating under a Class VI permit present a greater potential risk to USDWs. Operations under Class VI utilize a full reservoir and involve higher injection pressure (90 percent of fracture gradient), while Class II operations utilize a depleted reservoir and injection is limited to 80 percent of the fracture gradient and maintain general reservoir pressure equilibrium.

Class II permits, like Class VI permits, are designed to protect USDWs. Most states have primacy over Class II permit administration, and the use of area permits, rather than individual well permits, reduce redundancy. For owners/operators, this is a significant advantage over Class VI wells, which require a separate permit application for each well.

#### 4. Greenhouse Gas Reporting Program

In 2008, the EPA established the GHGRP that aims to provide policymakers with accurate and timely information on GHG emissions, including assessment of CCUS in mitigating GHG emissions.<sup>151</sup> This program has three different reporting categories that apply to CCUS projects:

- Subpart PP: Applies to suppliers of CO<sub>2</sub> used in a geologic sequestration project.
- Subpart UU: Applies to projects that inject CO<sub>2</sub> for the purpose of EOR or other purposes and requires basic reporting on the source and volume of CO<sub>2</sub> injected.
- Subpart RR: Applies to projects that geologically sequester CO<sub>2</sub> and requires such projects to submit to an MRV plan subject to EPA approval. EOR projects operating with a Class II permit that intend to track and verify (e.g., for the purpose of seeking a tax credit for storing CO<sub>2</sub>) the amount of CO<sub>2</sub> sequestered as an incidental part of their operations can opt-in to Subpart RR.<sup>152</sup> While reporting under Subpart RR is voluntary for Class II projects, any project permitted under Class VI must report under Subpart RR.

#### 5. Experience with EPA Rule Compliance: UIC Program

To date, only two entities have received a Class VI permit for their saline storage CO<sub>2</sub> injection wells:

- The FutureGen Alliance was awarded four Class VI permits, one for each of the injection well laterals to be located near Jacksonville, Illinois, in August 2014 (applied for in March 2013).<sup>153</sup>
- The Illinois ADM project was awarded a Class VI for their Illinois Industrial CCUS project well in September 2014 (applied for in December 2011).<sup>154</sup> ADM was also awarded a Class VI permit in September 2014 for their IBDP (applied for in July 2011).<sup>155</sup>

As mentioned in Section II.1 of this report, the Kansas Geological Survey is leading a project that has filed for a Class VI permit on behalf of Berexco LLC from EPA's Region 7.<sup>156 157</sup>

Before Class VI rules were finalized, projects that were in a pilot or research phase operated under a Class I permit (as was the case for the ADM IBDP) or a Class V permit (as was the case for SECARB's Citronelle Project). As discussed in Section II.1 of this report, there have been numerous CO<sub>2</sub> injection projects across the United States to assess the resource and develop tools and practices for site management.

At the workshop, Dr. Sallie Greenberg, of ISGS, discussed lessons learned from the ADM projects. As a DOE RCSP site, the ISGS project was intended to help inform other projects and develop technology, infrastructure, and regulations.<sup>158</sup> This included evaluation of different monitoring techniques to help improve the application of the EPA UIC regulations with real-world experience.<sup>159</sup> One insight from this research indicated that a more adaptive approach, including performance-based criteria, would be a helpful way to structure the monitoring framework. Another workshop participant commented that the EPA is integrating such knowledge and improved scientific understanding into best management practices and a series of implementation and guidance documents for geologic storage.

## 6. Experience with EPA Rule Compliance: GHGRP

While numerous projects have successfully reported under the GHGRP to date, the first commercial EOR project, operated by Occidental Petroleum recently had its MRV plan under Subpart RR approved by the EPA.<sup>160</sup> EPA's Joe Goffman called the approval "an important milestone for secure carbon dioxide storage" and stated that it shows that the GHGRP "provides value to companies, as well as to EPA and the public, to help track how much carbon dioxide is being stored and provide confidence that the carbon dioxide remains securely underground over time."<sup>161</sup>

At the workshop, Al Collins of Occidental Petroleum described their approach to developing the MRV plan, noting that they began with the premise that a well operated and managed CO<sub>2</sub> flood would provide the necessary data for compliance. To comply with Subpart RR, Occidental Petroleum built upon the injection monitoring and control system already in place for EOR operations. As stated in the Occidental Petroleum MRV plan:

Because CO<sub>2</sub> is an expensive injectant, the study [of the subsurface] includes a thorough analysis of the capability of the reservoir to maintain fluids within the targeted subsurface intervals, including an analysis of formation parting pressures and the ability of the reservoir strata to assimilate the injected CO<sub>2</sub>.<sup>162</sup>

Tim Dixon of IEA recently stated in an IEA GHG publication that Occidental's MRV plan "sets important precedents for the level of information and detail" required under Subpart RR.<sup>163</sup> For policymakers, this MRV plan can provide information about how geologic storage occurs and can be monitored in an EOR project.

## 7. CO<sub>2</sub> Storage through EOR

EPA clarified in a 2015 memorandum that CO<sub>2</sub> can be stored through EOR. Workshop participants agreed that CO<sub>2</sub> is stored through the EOR process, with several commenting that this needs to be better communicated to stakeholders.<sup>164</sup> The Occidental Petroleum project described above provides an example of how CO<sub>2</sub> can be stored through EOR operations under the existing regulatory framework, using a combination of Class II injection wells and a MRV plan established under Subpart RR of the GHG reporting program.

## Incentives – Federal Level

The current CO<sub>2</sub> pipeline network was developed to ship a commodity with a known price for delivery, for both naturally occurring CO<sub>2</sub> and CO<sub>2</sub> captured from anthropogenic sources. Realizing deep decarbonization goals will require CO<sub>2</sub> capture from a wide range of sources and from locations at varying distances from CO<sub>2</sub> sinks. Depending on the CO<sub>2</sub> source, there are varying levels of cost for cleaning up the captured CO<sub>2</sub> and compressing the CO<sub>2</sub> to the required pressure for pipeline transportation.

While Federal funding has enabled some saline storage projects in the United States, workshop participants noted that the main driver for CCUS infrastructure in the near-to-midterm will be EOR projects for economic reasons. A key challenge to driving these projects is that the cost of CO<sub>2</sub> capture is higher than the price that companies are willing to pay for the commodity. Bridging this cost gap will require Federal and/or State incentives.

One illustration of this challenge discussed at the workshop is the case of an existing Denbury pipeline that extends along the Gulf Coast refinery row and delivers CO<sub>2</sub> to EOR operations. Despite the close proximity of this pipeline to a number of high-purity (and lower capture cost) industrial CO<sub>2</sub> sources, the economics still do not support capturing and delivering the CO<sub>2</sub>. Conversely, pipelines that have been built were able to make the economic case on each end of the pipeline (e.g., Chaparral's Coffeyville project).<sup>165</sup>

For this reason, incentive policy has focused in large part on lowering the cost of the capture technology and lowering the cost of CO<sub>2</sub> storage, rather than on pipelines per se. While there are some existing Federal incentives for CCUS, including the 45Q tax credit for carbon sequestration, it is widely accepted that they are insufficient to address the cost gap, primarily due to the cost of capture.<sup>166</sup> Recent analysis estimates the cost of capture for fossil energy power plants (both the largest sources of CO<sub>2</sub> and the most expensive), from coal and natural gas combined cycle, at between \$56 and \$71 per metric ton respectively.<sup>167</sup> Pairing the cost of capture with analysis that estimates EOR operators would pay \$33 per metric ton (assuming a \$70 per barrel oil price), the cost gap ranges from \$23-38 per metric ton. Oil prices below \$70 per barrel would result in a corresponding, increased cost gap.<sup>168</sup> The current 45Q tax credit, as available, would close the gap by an additional \$10.<sup>169</sup> However, incentives that are available do not provide the financial certainty needed to attract capital for projects. This was a key point emphasized by several participants at the workshop.

## 8. Existing Incentives

- **Tax credits.** Investment tax credits under Section 48A of the tax code provide credits for qualified power sector projects and tax credits under section 48B provide credits for industrial gasification projects.<sup>170 171</sup> Section 45Q of the Internal Revenue Code provides production tax credits for carbon storage through EOR and non-EOR applications (\$10 and \$20 per ton of CO<sub>2</sub>, respectively). Reforming and expanding 45Q has been a priority for a diverse group of interests (additional discussion below).<sup>172</sup>
- **Federal loan guarantees.** Loan guarantees were provided in the Energy Policy Act of 2005 for several advanced energy technologies, including CCS; loan guarantees help to lower the financial risk of projects in an effort to attract private investment.<sup>173</sup> However, no CCS project has successfully utilized the program to date.
- **Matching grants.** Competitively awarded matching grants were established for advanced coal projects, including those that use CCS, and require a 50 percent match from the private sector.

<sup>174</sup>

In the case of tax credits and grants, most of the available incentives and funds have been used and, given the timeframe and cost to develop CCUS projects, these programs have already effectively expired and are unlikely to incent additional projects.

### Proposed Incentives:

- **Master Limited Partnerships (MLP)** are Federal tax structures that provide favorable treatment as partnerships for Federal tax purposes, but are allowed to raise funds by issuing and trading equity shares similar to a public corporation, thus reducing the costs of financing projects. The opportunity to utilize the tax structure of these particular partnerships would be advantageous

to CO<sub>2</sub> pipelines for CCUS, but the challenge is that MLPs are applicable to qualifying income from depleting resources such as natural gas, oil, and naturally occurring CO<sub>2</sub>. Enactment of the Energy Improvement and Extension Act of 2008 expanded the definition of qualifying income to include industrial sources of CO<sub>2</sub>. Future CCUS projects have been also included in the proposed Master Limited Partnerships Parity Act of 2015-2016.<sup>175</sup> The Act would extend the publicly traded partnership ownership structure of MLPs to renewable energy and CCUS.

- **Private Activity Bonds (PABs)** are tax-exempt bonds that are similar to municipal bonds and can lower the cost of capital for a project by making debt available on more favorable terms. In the 1970s and 1980s, Congress authorized PABs for clean air projects and the PAB mechanism was used to fund improvements at coal-fired power plants.<sup>176</sup> In 1986 the PAB authorization for power plants was eliminated. NRG Energy, Inc. was able to use the PAB model to finance part of its Petra Nova CCUS demonstration (\$140M) because the project was in a hurricane disaster zone, which made the power plant exclusion null. The PAB financing model has also been supported by advocates of CCUS incentives as a low cost way to help finance purchase of equipment that could bring in a new investor pool.
- **Carbon Dioxide Investment and Sequestration Tax Credits** are refundable tax credits proposed for Congress to enact as described in the QER, and are part of the Administration's FY2017 budget proposal. The investment tax credit would provide up to \$2 billion for carbon capture and storage property. The refundable sequestration tax credit would be a 20-year, indexed credit providing \$50 per ton of CO<sub>2</sub> stored (non-EOR projects) and \$10 per ton of CO<sub>2</sub> stored (used in EOR projects or other beneficial reuse).<sup>177</sup>
- **Section 45Q Tax Credit for Carbon Dioxide Sequestration**, described above, is currently the focus of a stakeholder coalition that aims to reform the credit. In his workshop presentation, Patrick Falwell of Green Strategies pointed out that the tax credit, as currently written, is ineffective. It is capped at 75 million Mt and fails to provide any certainty for investors, because no one knows how long it will be available to projects. In addition, the credit value of \$10 per ton of CO<sub>2</sub> captured and stored is insufficient to leverage private investment in CCUS projects, even lower cost industrial projects, let alone more expensive post-combustion CO<sub>2</sub> capture at power plants. Proposed reforms to 45Q would create financial certainty for investors, and enable developers of carbon capture projects to utilize the tax credit more effectively through different business models and tax partnerships:
  - In the U.S. House of Representatives, a bill to extend, amend and expand the current 45Q credit (H.R. 4622, the Carbon Capture Act) would raise the credit value to \$30 for both EOR and saline storage, remove the existing cap (making the credit permanent), lower the qualifying threshold for eligibility for power plants and industrial facilities to 150,000 tons of CO<sub>2</sub>, and allow transferability of the credit to the entity that uses and/or stores the CO<sub>2</sub>.<sup>178</sup> and
  - In the U.S. Senate, S. 3179 (the Carbon Capture Utilization and Storage Act) would increase the credit value to \$35 per Mt for EOR storage and \$50 per Mt for saline storage, expand eligibility to include other forms of CO<sub>2</sub> utilization beyond EOR, extend the credit to provide new carbon capture projects seven years to commence construction enable projects to claim the credit for 12 years once placed in service, would lower the threshold of eligibility for new facilities to 100,000 tons of CO<sub>2</sub>; and provide enhanced transferability of the credit to allow for multiple business models.<sup>179</sup>

In addition, the National Coal Council submitted recommendations to Energy Secretary Ernest Moniz, in response to his request, on how to advance CCUS.<sup>180</sup> Some of the recommendations focused on Federal incentives sufficient to reach 5-10 gigawatts of CCUS demonstration projects by 2025 including feed-in tariffs, tax credits, loan guarantees, and price stabilization contracts or “contract-for-differences” (CfD).<sup>181</sup> The Council also stressed the importance of evaluating incentives and coordinating them in order to ensure that they actually lead to technology deployment.<sup>182</sup>

There was discussion at the workshop about CCUS incentives in response to the presentations:

- **Price stabilization.** The Federal Government could create a price stabilization or CfD program that contractually establishes a target oil price for a CCUS project based on official forecasts. This would reduce investment risk and, therefore, the cost of capital by creating a floor for the sales price of CO<sub>2</sub> to address the challenge of oil price volatility in CO<sub>2</sub> contracts. However, if the target oil price were exceeded, the CCUS project would reimburse the Treasury, preventing a situation of windfall profits being earned at taxpayer expense and creating the potential for an incentive program that is revenue neutral for the Federal government. Participants noted that the Senate energy bill had been amended to authorize DOE to study the potential costs and benefits of a potential CfD program and report back to Congress.<sup>183</sup>
- **Review and build on successful incentives in other industries.** Participants suggested a review of incentives in other industries that have led to successful technology deployment. One example highlighted by participants was the Section 29 tax credit that was the catalyst for the CBM industry. The credit, established under the Windfall Profit Act of 1980, helped establish the industry and jumpstarted projects that led to technology advancement and improved project economics.<sup>184</sup> The tax credit was limited to 15 years and was coupled with a significant research and development (R&D) program and additional support from the quasi-government funded Gas Research Institute. Participants commented that Section 29 is one of the most successful examples of tax credits paired with investment in technology. Another attractive component of Section 29 was its transferability, which allowed producers to attract capital.
- **Targeted incentives for pipelines.** Participants suggested that Federal incentives for CO<sub>2</sub> pipelines could be impactful and that DOE could look at ways it could assist the development and buildout of pipeline infrastructure.

## Future Opportunities – Federal Environment

Workshop participants noted that the Federal Government has the opportunity to drive CCUS infrastructure deployment through a combination of significant, targeted incentives and through a clear and predictable regulatory structure that supports timely infrastructure deployment. Note that DOE does not necessarily agree with or support the content summarized below. Specific Federal opportunities discussed at the workshop include:

- Increase Federal incentives, such as a reformed 45Q tax credit, that could be a catalyst for CCUS infrastructure development if structured in a way that provides certainty and are sufficient to close the cost gap between the cost of capturing, compressing, and transporting CO<sub>2</sub> and the price of delivered CO<sub>2</sub>.
- Identify areas where the Federal Government can reduce the time it takes to plan and develop CCUS infrastructure, including ways to streamline the Federal permitting process and create more certainty around schedules.

- Refer to existing industry standards and/or international standards under development for CO<sub>2</sub> pipelines that could be helpful to states or others looking at pipeline safety and CO<sub>2</sub> composition standards. In addition, states and/or the Federal Government could adopt, by reference, industry quality standards for CO<sub>2</sub> composition for pipeline transportation.
- Provide models from other industries for supporting technology deployment, such as the public-private support under Section 29 of the tax code.
- Move forward on State approvals for Class VI primacy through work between the Federal Government and states, including identification of how to accelerate the approval process where possible.

## VIII. NEAR-TERM INVESTMENT OPPORTUNITIES

### *Drivers of CCUS Deployment to Date*

Workshop participants described the historic development of CCUS-related infrastructure in the United States, and noted that infrastructure that was built for EOR was primarily driven by high oil prices and demand for CO<sub>2</sub> used in EOR production. When CO<sub>2</sub> pipelines were first being built in the 1980s, conventional oil production was taxed at a higher rate than EOR, providing an economic incentive for the development of the EOR and CCUS industry. Subsequently, in the late 2000s, historically high global oil prices again drove demand for new and varied sources of oil such as EOR. Workshop participants stressed the importance of these economic drivers for CCUS infrastructure buildout.

Building facilities and infrastructure for CO<sub>2</sub> capture, transportation through pipelines, and site injection, operation, and management incurs capital costs. A workshop participant estimated that pipeline construction accounts for approximately 10 percent to 30 percent of the total project capital costs, which require investment and execution by companies at least two years before CO<sub>2</sub> injection and EOR production can even begin. Thus, significant buildout of CO<sub>2</sub> pipeline infrastructure requires at least medium-term oil price certainty and a viable project business model for private companies to invest the early capital necessary to enable CO<sub>2</sub> transportation and injection.

Currently, there are numerous potential high-purity sources of CO<sub>2</sub> throughout the United States that are ready to supply CO<sub>2</sub> as soon as there are nearby pipelines capable of delivering their output to injection, storage, and utilization sites. These sources, including ethanol refineries and fertilizer plants can provide what are currently considered as some of the purest streams of CO<sub>2</sub>.<sup>185</sup> While an individual ethanol plant may produce a smaller amount of CO<sub>2</sub> than sources such as a power plant, there are many ethanol plants distributed throughout the Midwest and elsewhere whose combined output can be substantial. Therefore, the next group of CO<sub>2</sub> pipelines in the United States will likely be built as a network that enables aggregation from these clean sources, and distributes CO<sub>2</sub> to EOR and other storage sites. An aggregated and distributed supply works well for EOR operators and the market for CO<sub>2</sub>, which operates by choosing the most cost efficient CO<sub>2</sub> from any source.

### *Current CO<sub>2</sub> Pipeline Network Business Models*

A number of private businesses already own and operate CO<sub>2</sub> pipelines in the United States (see Table 7 below). There is a mixture of business models among CO<sub>2</sub> pipeline operators and EOR operators where some operators are involved in both EOR and pipeline operations, some are involved in just EOR or pipeline operations, some are involved for their own use, or some are involved for CO<sub>2</sub> sales to third parties.



Table 7: CO<sub>2</sub> pipeline operators listed by length of pipeline system they operate (EOR operators and daily production) <sup>186 187 188</sup>

Owner/Operator	CO <sub>2</sub> Pipeline Length		EOR Produced (Barrels Per Day)
	Miles	Kilometer	
Kinder Morgan	1,010	1,625	55,875
Denbury	933	1,500	34,900
Oxy Permian	709	1,140	107,180
Chaparral Energy	297	524	2,983
ExxonMobil	262	420	16,000
Dakota Gasification	204	328	
Chevron	201	323	32,477
Anadarko	158	254	14,050
Merit	146	235	16,841
Petrosource	146	235	
SandRidge	123	198	
Trinity CO2	113	182	
TransPetco	110	177	
Devon	85	137	2,700
Hess	50	80	21,000
Whiting	26	42	7,800
Apache	15	24	11,470
Core Energy, LLC	11	18	365
Penn West Petroleum, Ltd	8	13	
XTO	7	11	4,350
Breitbart Energy			7,070
ConocoPhillips			6,650
Trinity			1,930
Energen Resources			1,626
Fasken			1,255
Resolute Natural Resources			1,200
Great Western Drilling			170
Orla Petco			128
Stanberry Oil			102
Total	4,614	7,466	348,122

### *Existing Business Models for Development and Ownership*

These examples provide a glimpse into possible development scenarios for expanding the CO<sub>2</sub> pipeline network.

A few of these companies are described here to illustrate the variation in business models.

- **Denbury Resources.** Denbury Resources operates an EOR-focused business model with its pipeline subsidiaries owning 701 miles of CO<sub>2</sub> pipeline in Gulf Coast states. This network ties the Jackson Dome area with naturally occurring CO<sub>2</sub> to multiple EOR projects in Mississippi, Louisiana, and Texas. Air Products of Port Arthur, Texas, is capturing CO<sub>2</sub> from their plant and selling it to Denbury's Green pipeline for their Hastings Field EOR south of Houston.<sup>189</sup> There are numerous industrial plants along the Gulf Coast route of the Green pipeline providing potential future sources of captured CO<sub>2</sub>. Denbury's pipeline subsidiary also owns another 232 miles in Wyoming and Montana. This Greencore pipeline connects ConocoPhillips's Lost Cabin Gas Plant in Wyoming, from whom Denbury purchases CO<sub>2</sub>, with Denbury's Bell Creek Field in Montana. Denbury also has an interest in the LaBarge reservoir in Southwestern Wyoming. This reservoir is rich with CO<sub>2</sub> and Denbury is completing a gas plant at Riley Ridge to process this gas and separate the CO<sub>2</sub>. The company plans to build a pipeline connecting this source of CO<sub>2</sub> with current and future projects, including reservoirs acquired along the Cedar Creek Anticline in Montana.<sup>190</sup>
- **Kinder Morgan.** Kinder Morgan is the largest energy infrastructure company in North America with ownership or an interest in 84,000 miles of pipeline for various resources, and active CO<sub>2</sub> and EOR projects.<sup>191</sup> The company controls the naturally occurring CO<sub>2</sub> at McElmo Dome and Doe Canyon in Southwestern Colorado. A 502-mile dedicated Cortez pipeline transports this CO<sub>2</sub> to the Denver City hub in Denver, Texas. From here this CO<sub>2</sub> is distributed to EOR operations in the Permian Basin. Kinder Morgan has 468 miles of open access CO<sub>2</sub> pipeline in the Permian Basin providing for third-party sales.<sup>192</sup> It also has several of its own CO<sub>2</sub>-EOR projects, the largest of which is SACROC, the oldest EOR field where operations began in 1972. Kinder Morgan recently completed a project to increase CO<sub>2</sub> production from its McElmo Dome and Doe Canyon reservoirs as well as an expansion of the Cortez pipeline to meet increasing demand for CO<sub>2</sub> from Permian Basin projects,<sup>193</sup> including their own EOR projects.
- **Chaparral Energy.** Chaparral Energy controls about 297 miles of CO<sub>2</sub> pipelines in Kansas, Oklahoma, and the panhandle area of Texas. These are both dedicated intrastate and interstate pipelines. A unique feature is that Chaparral Energy secures its supply of CO<sub>2</sub> from anthropogenic sources. These sources include the Koch Nitrogen plant in Enid, Oklahoma, the Agrium fertilizer plant in Borger, Texas, the Arkalon ethanol plant in Liberal, Kansas, and the CVR Energy fertilizer plant in Coffeyville, Kansas. Chaparral Energy installed the capture equipment at the CVR Partners fertilizer plant and built the 68-mile pipeline connection to their North Burbank Unit in Oklahoma. In Western Kansas, the company utilized an existing nitrogen pipeline for CO<sub>2</sub>.<sup>194</sup>
- **Core Energy.** Core Energy operates a small pipeline network in Northern Michigan. This 11-mile pipeline transports CO<sub>2</sub> from an Antrim Shale natural gas processing plant to several local Niagaran Pinnacle Reef CO<sub>2</sub> EOR reservoir projects.<sup>195</sup>

Within the Permian Basin, twelve EOR projects managed by seven different operators receive their CO<sub>2</sub> from third-party pipeline operators.<sup>196</sup> Four pipeline operators in the Permian Basin without any EOR projects of their own control 492 miles of pipeline.<sup>197</sup>

Each CO<sub>2</sub> pipeline will be planned, built, and operated under a set of guidelines, regulatory requirements and business models depending on its location, route, size, and ownership. The IOGCC described four potential business models for CO<sub>2</sub> pipelines under different scenarios.<sup>198</sup> These models are designed around configurations of access the pipeline: intrastate dedicated or open access, and interstate dedicated or open access. In Table 8 below, information on these four basic business models is provided.

Table 8: CO<sub>2</sub> pipeline business models as presented by the IOGCC

	Dedicated	Open Access
Intrastate	Mostly single operator Sometimes multiple owners Mostly without eminent domain State & local siting approval Fed approval IF cross Fed lands Deliver own CO <sub>2</sub> (private) Deliver 3 <sup>rd</sup> party CO <sub>2</sub> (contract carrier): Limited access Negotiated rates, not subject to economic regulations	Provide transport to multiple users Owner may also sell CO <sub>2</sub> to end user May use eminent domain but: Subject to economic regulations Required 3 <sup>rd</sup> party access Common Carrier status Many pipelines built without eminent domain
Interstate	Built without use of eminent domain State & local siting approval Limited access Negotiated rates No Fed approval involved	Requires some Fed (BLM) lands: FLPMA MLA If state public utility commission involved: Common Carrier status imposed Regulation of rates

While the business models outlined in Table 8 may include interaction and collaboration between private companies and State or Federal Government, these models are often operated primarily by private interests. The IOGCC report also presents a fifth business model, the **Government/Public Option**, which describes increased involvement by State governments in planning, building and operating pipelines. The report provides examples from three states: Alaska, Wyoming, and North Dakota.<sup>199</sup>

- Alaska. The Alaska Natural Gas Development Authority (ANGDA) was created to develop the state’s natural gas resources. ANGDA has the authority to design, construct, and operate pipelines and other facilities associated with delivering natural gas to market, including purchasing natural gas.
- Wyoming. Wyoming created the Wyoming Pipeline Authority as a corporation of the state. Its purpose is to develop inter- and intrastate pipeline infrastructure that facilitates the state’s natural resource development. In 2012, the State legislature provided two million dollars to “implement a permitting process to further a carbon dioxide pipeline network across Federal lands in Wyoming.”<sup>200</sup>

- North Dakota. The North Dakota Pipeline Authority was created in 2007 with similar rights and obligations for energy related pipelines, including for CO<sub>2</sub>, as those legislated organizations in Alaska and Wyoming.<sup>201</sup>

In terms of which parties own each part of a CO<sub>2</sub> pipeline network, four ownership models were discussed by ICF International in a report for the Interstate Natural Gas Association of America (INGAA) Foundation on *Carbon Sequestration & Storage: Developing a Transportation Infrastructure*.<sup>202</sup> The **On-site Sequestration Model** is a simple integrated model where the CO<sub>2</sub> source owns the storage site, the connecting pipeline and the CO<sub>2</sub> itself.

When multiple parties are involved, the **Project Ownership Model** has several variations. Separate ownership could apply to each link of the CCUS chain, source, transport, and storage. Otherwise, two of the three links may be under single ownership, or finally all three may fall under the ownership of a single entity. Most often the CO<sub>2</sub> source is separate and contracts with a combination of parties for transportation and storage. These projects can be simple with one source contracting a single storage site and connection pipeline, but can also involve multiple entities for each link of the CCUS chain. CO<sub>2</sub> ownership may or may not change hands depending on the project structure.

For the **Municipal Solid Waste Model** the source transfers ownership of the CO<sub>2</sub> at the plant gate to the transport-storage provider under contract to the source. The Public Utility model (aka Government Ownership) represents an independent business that collects and stores the captured CO<sub>2</sub>.

A **Public Utility or Government Ownership Model** is also an idea that was discussed by stakeholders the MGA, as mentioned in the previous section on State regulation.<sup>203</sup> This model includes providing for basin-wide management of CO<sub>2</sub> storage. Basin-wide management can assure that multiple CO<sub>2</sub> storage projects will not interfere with each other or that any particular CO<sub>2</sub> storage project will not interfere with other natural resource extraction projects, i.e., oil and gas production. This model can also provide for long-term stewardship following CO<sub>2</sub> storage site closure.

Other countries have worked to find solutions to development and deployment challenges for CCUS infrastructure. In Australia, the CarbonNet project is working towards the development of a large-scale, multi-user CCUS network for the Gippsland region in the State of Victoria.<sup>204</sup> The Gippsland basin has significant oil and gas production and demonstrable storage potential, both onshore and offshore. The GCCSI report on CarbonNet provides several structures for the development of a CCUS hub.<sup>205</sup> The GCCSI report also expands the CCUS value chain from *source – transportation – storage* to *source – capture – transportation – injection – storage*. Further subdividing the CCUS value chain suggests that more businesses may get involved in the CCUS industry. A source-led project may have either a regulatory obligation to include CCUS as demonstrated by Chevron’s Gorgon project or a CCUS funding incentive to adopt this technology.<sup>206</sup>

Public-private CCUS projects can be fully integrated where the government works with a single entity across the whole CCUS value chain, or segmented where the government works with multiple entities. Financial support can also be applied to specific segments of the value chain, for example by funding the front end engineering design study or through revenue support during the operational phase of the storage project. The scale and geographic location of the CarbonNet project in the Gippsland Basin is analogous to placing a similar network in the U.S. Gulf Coast region, in the mid-continent area utilizing the Illinois Basin, or in the northern plains utilizing the Williston and Powder River basins.

In the European Union, a study done by the Zero Emissions Platform (ZEP) describes three business models for transport and storage deployment.<sup>207</sup> A contractor to the State model “is suitable before an established policy incentive mechanism exists and when market failure requires tailored state intervention.”<sup>208</sup> The contractor here has some level of investment in that portion of the project for which they have some responsibility. An enabled market “is a hybrid model comprising state intervention in some parts of the market and managed completion in other parts.”<sup>209</sup> The market-maker here manages the development of primary CCUS infrastructure and ensures corresponding storage is available. Finally, the liberalized market is one “in which private companies involved in the CCUS chain develop and manage pipeline, hubs and storage sites without specific state direction.”<sup>210</sup> This is analogous to the development of the current CO<sub>2</sub> pipeline network in the United States.

## Laying the Groundwork for Investment in CCUS Infrastructure

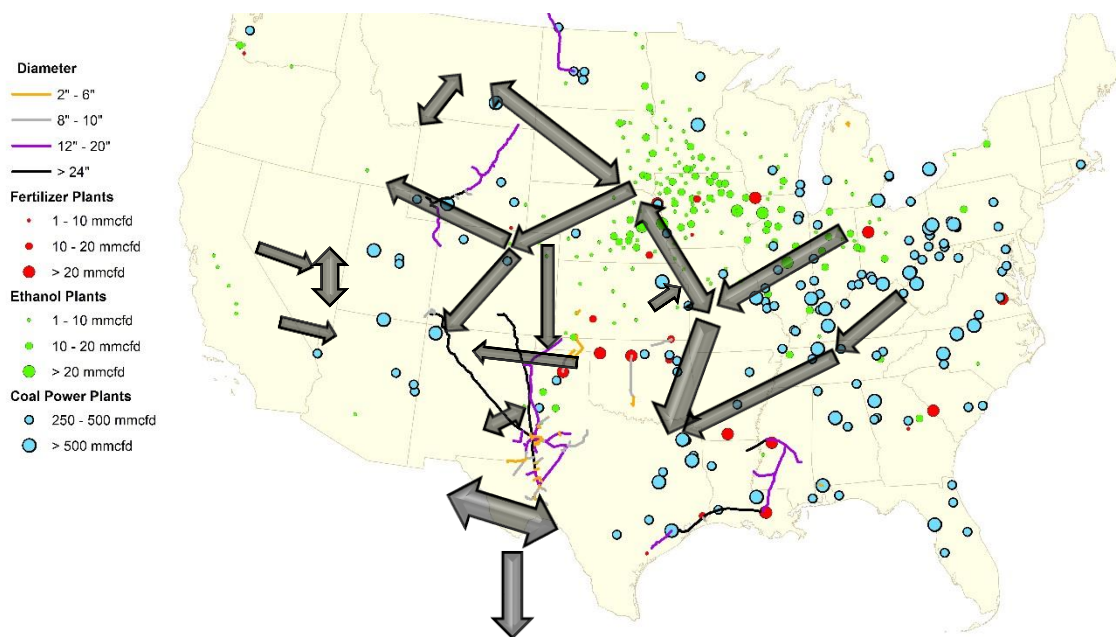
As stated above, the historical buildout of CO<sub>2</sub> pipeline infrastructure was largely driven by the windfall profit tax on EOR projects in the 1980s, and in later years by high oil prices. Workshop participants suggested that going forward, the industry faces the challenges of poor project economics due to low oil prices (for EOR storage) and insufficient incentives (for non-EOR geologic storage). But while barriers exist for the buildout of CO<sub>2</sub> and EOR infrastructure, many in the industry believe that this presents the opportunity for private and public collaboration on devising a framework for planning efficient and regional pipeline networks. For example, participants discussed the need to evaluate opportunities for building a network of pipelines that could aggregate and deliver CO<sub>2</sub> from high-purity sources such as ethanol facilities to EOR projects and other geologic storage sites.

For example, a report published by the Clinton Climate Initiative on CO<sub>2</sub>-EOR potential in the Midwest estimated there to be a potential for 2 billion barrels of oil production from EOR dispersed throughout the region in Michigan, Illinois, Indiana, Kansas, and Ohio.<sup>211</sup> To supply the 1 billion Mt of CO<sub>2</sub> necessary to realize this potential for energy production and economic growth, regional pipeline infrastructure would be needed.<sup>212</sup> Regional pipeline networks could enable the aggregation of dispersed anthropogenic sources of CO<sub>2</sub> and connect this supply to meet the demand at potential EOR sites around the United States. Near term collaboration on establishing State and Federal regulatory guidelines, mapping hubs and potential pipeline routes, and determining the most effective financial incentives could result in having a framework in place for the most efficient and beneficial investments in CO<sub>2</sub> pipeline infrastructure when oil prices start to recover.

**Strategic Infrastructure Planning.** Mapping out potential locations for pipeline hubs and routes is a key component to planning a regional and, ultimately, a national pipeline network. DOE and others have already identified the major sources of CO<sub>2</sub>, including anthropogenic sources whose volumes are tracked in EPA’s GHG reporting data. The most recent *Carbon Utilization and Storage Atlas* compiled by DOE’s RCSP identified at least 2,400 billion Mt of U.S. CO<sub>2</sub> storage resource.<sup>213</sup> Building on the knowledge already compiled by DOE to strategically map CO<sub>2</sub> sources and utilization sites will help identify the low-hanging fruit that can act as a catalyst for future infrastructure buildout. Areas that contain the greatest CO<sub>2</sub> capture opportunities in the vicinity of utilization sites could provide critical mass for the development of pipeline network hubs. These hubs could, in turn, guide the identification of regional and national corridors for CO<sub>2</sub> transportation.

Many companies have already begun the initial stages of identifying CO<sub>2</sub> sources and sinks, and mapping potential pipeline network concepts. At the workshop, Chaparral Energy presented an early concept of what such a map might look like (see Figure 3 below) and helped spark conversation on how to collaborate on infrastructure research and planning.

Figure 3: Possible Future CO<sub>2</sub> Pipeline Corridors as presented by Chaparral Energy. Used with permission from Chaparral Energy 2016



**Partnership Opportunities.** A regional CO<sub>2</sub> pipeline network will require collaboration between private companies, the investment community, State agencies, Federal regulators, and other interested stakeholders. Planning for this infrastructure can identify areas for future investment. Workshop participants noted that there is an opportunity for DOE to act as a facilitator, utilizing its existing resources such as the Carbon Sequestration Atlas, and engaging State regulators to devise a framework that meets stakeholder needs and enables efficient and equitable buildout of CO<sub>2</sub> pipeline infrastructure.

The regional nature of early infrastructure buildout also presents the opportunity for regional partnerships between states, private companies, and the Federal Government. Multi-state collaborations can develop studies on pipeline hubs and corridors in their regions, and provide a platform for coordination meetings and pre-planning. Where enough demand and supply of CO<sub>2</sub> exists in a particular area, entities that operate and govern in that area can collaborate on studies to determine hub locations and the type of pipeline networks that would best serve their area.

States such as Wyoming have established agencies like the Wyoming Pipeline Authority with coordinating and bonding authority that facilitates timely and efficient planning and approval of infrastructure projects. As mentioned previously in this report, the Wyoming Pipeline Authority could serve as a model for other states or regions to establish regulatory and bonding authority to coordinate CO<sub>2</sub> pipeline infrastructure. Engaging the Federal Government in the planning process can also help identify sites where permitting time requirements and costs could be minimized.

There are also opportunities for private collaborations to access and develop ROZs, which are also discussed in the resource potential section of this publication. Operators could work together to build pipelines with large capacities to serve multiple parties, operate flexibly at different pressure levels, and enable growth in production and transportation.

One challenge of the regional approach is the actual practical construction of pipelines in each corridor. Large-scale analyses are often difficult to fully execute, and issues can arise at ground-level construction or with local stakeholders. One participant noted that the issues and settlements arising from the energy corridors spanning the entire Western region of the United States can serve as a lesson here.

**Providing Incentives for Efficient Pipeline Networks.** As outlined above, EOR operators and pipeline developers face significant economic barriers to infrastructure development, especially in the face of low oil prices. Industrial sources of CO<sub>2</sub> have generally higher costs than naturally occurring sources of CO<sub>2</sub>, and without incentives, a price gap may persist between capture costs and the value of CO<sub>2</sub> for EOR.<sup>214</sup> Tax policies and other efforts that provide incentives can improve project economics and enable private companies to collaborate with states and the Federal Government on buildout of CO<sub>2</sub> pipelines. State and Federal tax policies and incentives could be implemented at various points of the planning, building, and operating timeline to maximize the industry's ability to capture and store CO<sub>2</sub>.

The technical design and planning of pipelines is one area that could benefit from incentives. An individual pipeline's capacity is generally designed for the needs of a particular project. This could lead to pipelines with insufficient capacity to support expansion or changes in project scope, or allow for additional, nearby projects to benefit from the transportation provided. One concept discussed during the workshop was to construct pipelines larger than needed for an individual project in order to lay the foundation for a pipeline network that could accommodate larger future quantities of captured CO<sub>2</sub>. Modest increases in the diameter of a pipeline can result in large increases in CO<sub>2</sub> transportation capacity, which would allow projects to deliver additional CO<sub>2</sub> to more storage sites over time. Research conducted at Los Alamos National Laboratory and with the SimCCUS model has shown that regional CO<sub>2</sub> pipeline networks will require greater capacity pipelines than are currently being built for individual projects, and that building pipelines with greater capacity may be more economically efficient in the long run.<sup>215</sup>

Participants noted that while increasing the diameter of a pipeline would require more construction material, such as steel, doing so would generally be a modest portion of total project costs. Individual project developers are typically hesitant to build above the needs of their own projects, and are often unable to do so due to financing constraints, so this could represent a strategic point of opportunity where incentives have the potential to transform small, individual pipeline projects into large capacity networks that can serve multiple CO<sub>2</sub> sources and sinks and a larger networked system over time.

Participants opined that financial support could also be applied to focus development in areas that show greatest potential for CO<sub>2</sub> storage, such as stacked formations that combine EOR and saline reservoirs in the same location, thus utilizing the same infrastructure. Participants also stated that government support could provide incentives for developing pipelines that serve stacked formations and help offset the costs of planning and development at sites that would provide storage or production benefits to multiple parties.

### **Future Opportunities**

As discussed in this section, there are many opportunities in the future for attracting investment in CCUS infrastructure at the State and Federal level and across public and private sectors. Some of the key future opportunities discussed at the workshop, summarized below, include

- Engage the investment community to identify creative ways to facilitate CCUS infrastructure buildout.
- Federal, State, and private sector coordination for pipeline planning and investment is worth exploring. DOE could help facilitate this with mapping and convening. A Federal pipeline infrastructure planning effort should take a systems approach for addressing near-, mid-, and long-term needs. Not just source-sink matching, but looking at what size of pipelines might be needed (e.g., an assessment could help determine where it would make sense to overbuild capacity initially) and what role Federal policy and support can play in leveraging private investment.
- There is significant potential for pure streams of CO<sub>2</sub> from industrial facilities (e.g., natural gas processing, ethanol, fertilizer, chemical, and industrial gasification plants) to become a major source of anthropogenic CO<sub>2</sub> in the near-term as carbon capture is scaled up over the medium to long term in the power sector and in other industries such as steel production where capture technologies are only now beginning to be deployed commercially.



## APPENDIX A

### LIST OF WORKSHOP PARTICIPANTS

Name	Organization
Joshua Arnold	Department of Transportation
Mary Rose Bayer	Environmental Protection Agency
Anthony Bitonti	United States Energy Association
James Bradbury	Department of Energy
Sean Brennan	Geological Survey
Jeff Brown	Summit Power
Jennifer Christensen	Great Plains Institute
Al Collins	Occidental Petroleum
Brad Crabtree	Great Plains Institute
Colin Cunliff	Department of Energy
Darin Damiani	Department of Energy – Fossil Energy
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Laura Demetrian	National Energy Technology Laboratory
Victor Der	Global Carbon Capture and Storage Institute
Patrick Falwell	Green Strategies
Sarah Forbes	Department of Energy
Matthew Fry	Wyoming Office of the Governor
Michael Godec	Advanced Resources International
Tim Grant	National Energy Technology Laboratory
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Judi Greenwald	Department of Energy
John Harju	Energy and Environmental Research Center
Rob Hurless	University of Wyoming
Jack Jacobson	Hogan Lovells
Chacko John	Louisiana Geological Survey
Andrew Kambour	National Governors Association
Daniel Keiser	Occidental Petroleum
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Jordan Kislear	Department of Energy
Bruce Kobelski	Environmental Protection Agency
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Amishi Kumar	United States Energy Association
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Stephen Lee	Louisiana Department of Natural Resources
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Sasha Mackler	Summit Power
Bob Mannes	Core Energy
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Doug McCourt	Department of Energy
Patrick McDonnell	Pennsylvania Department of Environmental Protection
Dana McFarlane	Great Plains Institute
David Mohler	Department of Energy
John Monger	Environmental Protection Agency
David Morgan	National Energy Technology Laboratory
Deepika Nagabhusan	Clean Air Task Force

Name	Organization
Erica Pionke	Bureau of Land Management
William Polen	United States Energy Association
David Rosner	Department of Energy
Michael Smith	Interstate Oil & Gas Compact Commission
Patrick Sullivan	Mississippi Energy Institute
Sharon Tucker	Tucker Associates
Keith Tracy	Chaparral CO <sub>2</sub> LLC
Peter Warwick	Geological Survey
Barry Worthington	United States Energy Association

## APPENDIX B

### WORKSHOP AGENDA

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8:30 a.m. – 9:00 a.m.	Welcome, Building Orientation, and Introductions
9:00 a.m. – 10:30 a.m.	<b>Session 1:</b> Characterization of Existing CCS Infrastructure, Policy Landscape
10:30 a.m. – 10:45 a.m.	Break
10:45 a.m. – 12:00 p.m.	<b>Session 2:</b> Investment Opportunities
12:00 p.m. – 1:00 p.m.	Lunch
1:00 p.m. – 2:20 p.m.	<b>Session 3:</b> Pipeline Panel Discussion – Common Practices for CO <sub>2</sub> Pipeline Siting and Permitting: Lessons Learned
2:20 p.m. – 2:40 p.m.	Break
2:40 p.m. – 4:00 p.m.	<b>Session 4:</b> Storage Panel Discussion – Common Practices for CO <sub>2</sub> Storage, Siting and Permitting: Lessons Learned
4:00 p.m. – 5:00 p.m.	<b>Session 5:</b> Future Opportunities and Concluding Remarks

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