



21st Century Energy Infrastructure: Policy Recommendations for Development of American CO₂ Pipeline Networks

White paper prepared by the
State CO₂-EOR Deployment Work Group

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Acknowledgements

While the final recommendations of this white paper represent the joint conclusions of state officials in the State CO₂-EOR Deployment Work Group, participating state officials want to recognize the contributions of leading private sector stakeholders and CO₂-enhanced oil recovery experts who lent their expertise and guidance to the effort. The state representatives extend their thanks to all who contributed to this white paper, and to the Hewlett Foundation for the funding that made this work possible.

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About the State CO₂-EOR Deployment Work Group

Wyoming Governor Matt Mead (R) and Montana Governor Steve Bullock (D) jointly convened the State CO₂-EOR Deployment Work Group in September 2015 as a key follow-on to the Western Governors Association resolution calling for federal incentives to accelerate the deployment of carbon capture from power plants and industrial facilities and increase the use of CO₂ in enhanced oil recovery, while safely and permanently storing the CO₂ underground in the process.

Twelve states currently participate in the Work Group: Arkansas, Colorado, Indiana, Kentucky, Mississippi, Montana, Pennsylvania, Ohio, Oklahoma, Texas, Utah and Wyoming. State participation varies by state and includes governors' staff, cabinet secretaries, utility commissioners, and agency and commission staff. Some state representatives participate at the direction of the governor; others do not. State representatives were joined by leading enhanced oil recovery, electric power, coal industry, regulatory and NGO experts.

The Work Group identified three principal roles for its work, including modeling analysis and policy identification, developing recommendations for state and federal policy makers, and supporting the implementation of those policy recommendations. The Work Group aims to foster:

- Expansion of CO₂ capture from power plants and industrial facilities;
- Buildout of pipeline infrastructure to transport that CO₂; and
- Use of CO₂ in oil production, along with its safe and permanent storage.

The Work Group released a comprehensive set of federal and state policy recommendations in December 2016 – [Putting the Puzzle Together: State & Federal Policy Drivers for Growing America's Carbon Capture & CO₂-EOR Industry](#).

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Introduction

Development of regional and national carbon dioxide (CO₂) pipeline networks, together with proposed tax credits and other financial incentives for industrial and power plant carbon capture, can support long-term production and use of America's abundant and affordable coal, oil and natural gas resources, put our nation further down the path of replacing imported oil and create high-paying jobs in energy-producing and industrial states and regions of the country, all while significantly reducing net carbon emissions.

American oil fields are poised to rapidly expand production through utilization of man-made CO₂ for enhanced oil recovery (EOR). This promise can be realized, if the oil industry can gain access to large, secure volumes of CO₂, transported via pipeline networks and purchased from industrial facilities and power plants where that CO₂ would otherwise be emitted to the atmosphere and wasted.

Nearly a half-century ago, the EOR industry got its start by capturing CO₂ at commercial scale from man-made sources, and it later began drilling for and utilizing naturally occurring geologic CO₂. The oil industry first purchased CO₂ captured through natural gas processing, then expanded to fertilizer production, coal gasification, chemical and ethanol production and, most recently, added refinery hydrogen production, coal-fired electric power generation and steel manufacturing (see Figure 1 on the next page).

However, in most cases, the costs of CO₂ capture, compression and pipeline transport remain higher than revenue received from sales of the CO₂ to the oil industry. Expanding carbon capture at industrial and power generation facilities would transform CO₂ from a liability into a resource, by driving an increase in American oil production and by storing that CO₂ safely and permanently underground in the process. In addition to federal incentives needed to deploy carbon capture equipment across industries, **a primary obstacle to scaling up this national opportunity is the lack of infrastructure: trunk pipelines are needed to link industrial and power plant CO₂ sources to oilfield customers, and they must be built at very large scale across regions to make economic sense.**

Report Outlines Federal Financial Incentives for CO₂-EOR

[Putting the Puzzle Together: State & Federal Policy Drivers for Growing America's Carbon Capture & CO₂-EOR Industry](#), a report released by the State CO₂-EOR Deployment Work Group in December 2016, provides analyses and federal and state incentive recommendations, including:

- Improving and expanding the existing section 45Q tax credit for storage of captured CO₂;
- Deploying a revenue neutral mechanism to stabilize the price paid for CO₂—and carbon capture project revenue—by removing volatility and investment risk associated with CO₂ prices linked to oil prices; and
- Offering tax-exempt private activity bonds and master limited partnership tax status to provide project financing on better terms.

Today's lack of necessary long-distance, large-volume CO₂ pipelines creates a serious transport problem for potential CO₂ suppliers and customers that stifles both energy and industrial development. This dilemma is not unlike the situation for Midwestern farmers and Western ranchers prior to the coming of the railroads, Texas natural gas producers before the development of long-distance interstate gas pipelines, the unrealized hydropower potential in the Northwest before construction of huge electric transmission lines, or the slow crawl of truck traffic before President Eisenhower spurred the buildout of an efficient interstate highway system. The federal government initially had a hand in fixing all four of these national infrastructure problems before ultimately passing the torch to industry and the states.

Importantly, no safety or technical barriers exist to large-scale CO₂ pipeline deployment. CO₂ pipelines have an excellent safety record of over 40 years of operation with no serious injuries or fatalities ever reported. Today, over 4,500 miles of pipeline transport CO₂ for EOR at wells producing 400,000 barrels of oil per day. These pipelines have operated for decades under existing policy and regulatory oversight at the local, state and federal level.

Figure 1: Past Commercial Carbon Capture Deployment Milestones

Successful commercial-scale carbon capture deployment has a long history through the capture, compression and pipeline transport of CO₂ for EOR with geologic storage, especially in the U.S. Industrial processes where large-scale carbon capture is demonstrated and in commercial operation include natural gas processing, fertilizer production, coal gasification, ethanol production, refinery hydrogen production and, most recently, coal-fired electric power generation and steel production.

1972: Val Verde gas processing plants in Texas. Several natural gas processing facilities began supplying CO₂ in West Texas through the first large-scale, long-distance CO₂ pipeline to an oilfield.

1982: Koch Nitrogen Company Enid Fertilizer plant in Oklahoma. This fertilizer production plant supplies CO₂ to oil fields in southern Oklahoma.

1986: Exxon Shute Creek Gas Processing Facility in Wyoming. This natural gas processing plant serves ExxonMobil, Chevron and Anadarko Petroleum CO₂ pipeline systems to oil fields in Wyoming and Colorado and is the largest commercial carbon capture facility in the world at 7 million MT of capacity annually.

2000: Dakota Gasification's Great Plains Synfuels Plant in North Dakota. This coal gasification plant produces synthetic natural gas, fertilizer and other byproducts and has supplied over 30 million MT of CO₂ to Cenovus and Apache-operated EOR fields in southern Saskatchewan as of 2015.

2003: Core Energy/South Chester Gas Processing Plant in Michigan. CO₂ is captured by Core Energy from natural gas processing for EOR in northern Michigan, with over 2 million MT captured to date.

2009: Chaparral/Conestoga Energy Partners' Arkalon Bioethanol plant in Kansas. The first ethanol plant to deploy carbon capture, it supplies 170,000 MT of CO₂ per year to Chaparral Energy, which uses it for EOR in Texas oil fields.

2010: Occidental Petroleum's Century Plant in Texas. The CO₂ stream from this natural gas processing facility is compressed and transported for use in the Permian Basin.

2012: Air Products Port Arthur Steam Methane Reformer Project in Texas. Two hydrogen production units at this refinery produce a million tons of CO₂ annually for use in Texas oilfields.

2012: Conestoga Energy Partners/PetroSantander Bonanza Bioethanol plant in Kansas. This ethanol plant captures and supplies approximately 100,000 MT per year of CO₂ to an EOR field in Kansas.

2013: ConocoPhillips Lost Cabin plant in Wyoming. The CO₂ stream from this natural gas processing facility is compressed and transported to the Bell Creek oil field in Montana via Denbury Resources' Greencore pipeline.

2013: Chaparral/CVR Energy Coffeyville Gasification Plant in Kansas. The CO₂ stream (approximately 850,000 MT per year) from a nitrogen fertilizer production process based on gasification of petroleum coke is captured, compressed and transported to a Chaparral-operated oil field in northeastern Oklahoma.

2014: SaskPower Boundary Dam project in Saskatchewan, Canada. SaskPower commenced operation of the first commercial-scale retrofit of an existing coal-fired power plant with carbon capture technology, selling CO₂ locally for EOR in Saskatchewan.

2016: Abu Dhabi Carbon Capture Project, United Arab Emirates. This project involves the capture of CO₂ from the Emirates Steel Factory in Abu Dhabi and its transportation to the Abu Dhabi National Oil Company (ADNOC) reservoirs for EOR.

2017: Petra Nova in Texas. Commencing commercial operation in January 2017, this project is designed to capture 1.6 million tons of CO₂ per year from an existing coal-fired power plant. At 240 MW, Petra Nova is the world's largest post-combustion carbon capture facility installed on an existing coal-fueled power plant.

Key Recommendations and Benefits

The State CO₂-EOR Deployment Work Group recommends that President Trump and Congress incorporate the development of long-distance, large-volume CO₂ pipelines as a priority component of a broader national infrastructure agenda.

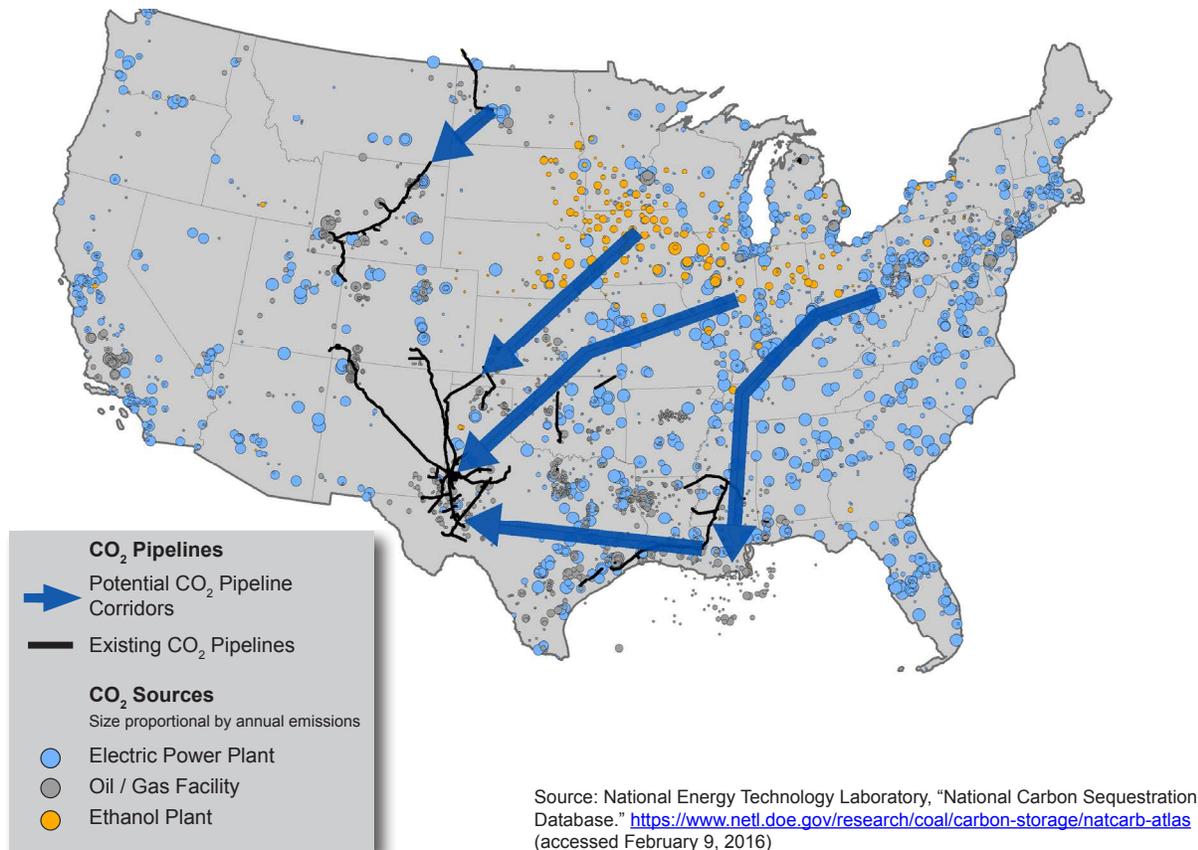
The state officials, industry leaders and other experts in the Work Group launched their work in 2015 with the development and deployment of carbon capture and CO₂ pipeline infrastructure as a top priority. Thus, Work Group members and participating states support the Administration and Congress' new focus on our nation's infrastructure, and they would welcome the opportunity to be partners in this effort.

Work Group participants also urge implementation of policies that direct the federal government to play a targeted role, supplementing private capital, in financing increased capacity for priority trunk pipelines to transport CO₂ from industrial facilities and power plants not currently served by pipeline infrastructure to oilfields for EOR.

Finally, Congress and the President should, in consultation with states, tribal governments and key stakeholders, identify and foster the development of five such priority CO₂ trunk pipelines, including support for planning, streamlined permitting, and financing. These trunk pipelines should link key industrial, fossil power-generating, and agricultural regions of the country with the potential to supply significant CO₂ to major hubs of domestic oil and gas production. A vital element in the design of the larger pipeline network is the enormous potential of the Permian Basin region and its proven CO₂ potential and vast resources of residual oil zones.¹ Each trunk pipeline for man-made CO₂ would be comparable in scale and volume to the 30-inch diameter Cortez pipeline, the world's largest CO₂ pipeline. Cortez can transport approximately 30 million tons of CO₂ annually along a 500-mile route from southern Colorado and through New Mexico to the Permian Basin of Texas.

The map below (see Figure 2) does not reflect any decisions to site, permit or build particular CO₂ pipelines by states and stakeholders participating in the Work Group, nor the federal government. Instead, **this map was prepared by the Work Group for illustrative purposes to show how just five pipeline corridors, strategically placed, could expand on existing commercial CO₂ pipeline networks to build out a national system of infrastructure with the capacity to help scale up American oil production and geologic storage of power plant and industrial carbon emissions.** With the addition over time of several connecting pipelines of modest length, this roughly horseshoe-shaped system would link the Upper and Lower Midwest in the east to the Gulf Coast and the Permian Basin of Texas and New Mexico in the south to the Rockies and Northern Plains of the U.S. and Canada in the west.

Figure 2: Potential Regional CO₂ Pipeline Corridors (Illustrative Purposes Only)



The five potential priority CO₂ trunk pipeline corridors suggested by this map are:

- **North Dakota to Montana, Wyoming and Colorado.** Moving CO₂ from coal gasification, coal and natural gas-fired power generation and ethanol production southwest into southeastern Montana, connecting the existing North Dakota-Saskatchewan and Wyoming-Colorado-Montana pipeline systems;
- **Upper Midwest to the Permian Basin.** Moving CO₂ from ethanol, fossil power generation, fertilizer production and other industries in the corn-producing heartland of the Upper Midwest into the vast potential and proven reservoirs of the Permian Basin of Texas and New Mexico;
- **Illinois Basin-Midwest to the Permian Basin.** Moving CO₂ from Midwestern ethanol production, fossil power plants and other industries to midcontinent oilfields in Oklahoma, Kansas and Arkansas and the Permian Basin;
- **Louisiana Gulf Coast to the Permian Basin.** Moving CO₂ from the cluster of refining, petrochemical and other industrial facilities in Louisiana to oilfields along the Louisiana and Texas Gulf Coast and on into the Permian Basin; and
- **Ohio River Valley-Lower Midwest to Gulf Coast.** Moving CO₂ from fossil power generation, steel production, and other industries in the industrial and manufacturing heartland of the Lower Midwest to Midwestern oilfields and down to onshore and offshore fields of the Gulf Coast of Alabama, Mississippi and Louisiana.

Benefits of Building Out a National CO₂ Pipeline Infrastructure Network

Establishing a CO₂ pipeline infrastructure of this magnitude, in conjunction with targeted federal incentives for deployment of carbon capture technology, could expand the annual supply of man-made (anthropogenic) CO₂ available for EOR by 150 million tons by 2030, resulting in:

- A tripling of the U.S. EOR industry, with new domestic oil production of approximately 375 million barrels per year;
- An estimated reduction of 22 percent in current U.S. oil imports or \$30 billion in reduced annual expenditures on foreign oil; and
- A reduction of roughly four percent in U.S. stationary source CO₂ emissions from current levels.

This level of CO₂ pipeline infrastructure development has the potential to:

- Drive an estimated \$75 billion of capital investment;
- Stimulate more than \$30 billion per year in economic activity;
- Support thousands of high-paying construction, energy, mining, manufacturing, engineering and technically-skilled operations and services jobs;
- Generate additional state and federal revenues through new energy production and other economic activity; and
- Secure and expand a major competitive advantage the U.S. oil and gas industry holds in utilizing CO₂ for hydrocarbon recovery with safe and permanent geologic storage.

By providing needed common infrastructure, new CO₂ pipelines will improve the competitiveness of existing domestic manufacturing, attract new manufacturing, and help onshore and return industrial production of petrochemicals, cement, steel, and other heavy industries.

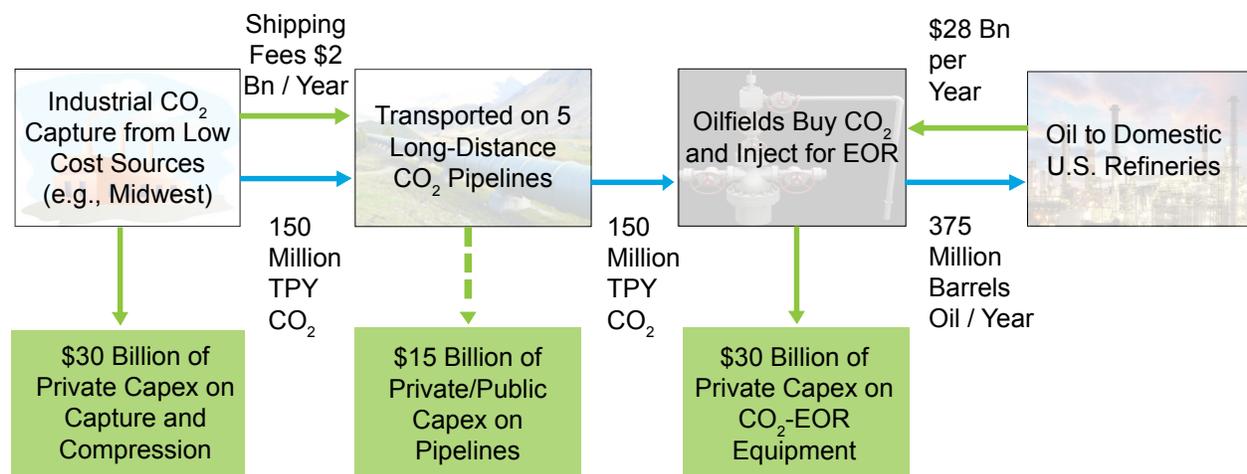
There are a number of ways the federal government could provide assistance, including:

1. Federal financial support could leverage substantially greater pipeline infrastructure capacity at a small proportion of total pipeline cost by financing the modest incremental expense of constructing increased capacity up front through, for example, the U.S. Department of Energy's (DOE) Loan Programs Office;²
2. DOE Office of Fossil Energy's Regional Industrial Carbon Capture Initiative could work with states and private sector partners to identify corridors for these pipelines that would connect industrial CO₂ sources with EOR opportunities, provide technical and financial analyses to support early private investment and commercial deployment and help address financial and other barriers to investment and deployment;

3. Governors or federal agencies could nominate these pipelines as high priority infrastructure projects for streamlined environmental review and approval, and these pipelines can use American-made equipment and materials, in accordance with President Trump’s January 24th executive orders;^{3,4}
4. These projects could be included as high priority projects in federal infrastructure legislation being developed by Congress, for example by expanding the scope of the Transportation Infrastructure Finance and Innovation Act (TIFIA) to include pipelines; and
5. Congress could enact tax incentives for carbon capture, pipeline transport and storage, such as extension and reform of the Section 45Q Tax Credit for Carbon Dioxide Sequestration and eligibility of carbon capture projects for tax-exempt Private Activity Bonds, both of which enjoy broad bipartisan support.

While the total pipeline investment for five such large projects would be approximately \$15 billion, the amount of federal support needed would be considerably smaller. The federal investment might be only the debt, or a portion of the debt. For instance, if the federal government made all the loans, and loans were 50 percent of total pipeline financing, the federal share would be \$7.5 billion. If, as described later in this document, the federal government acted as a short-term “bridge lender” to support super-sized, scale-efficient pipelines, the federal share would likely be on the order of only \$2-4 billion.

Figure 3: Economic Power of Proposed CO₂ Pipeline Investment: \$75 Billion of Investment & \$30+ Billion/Year Activity



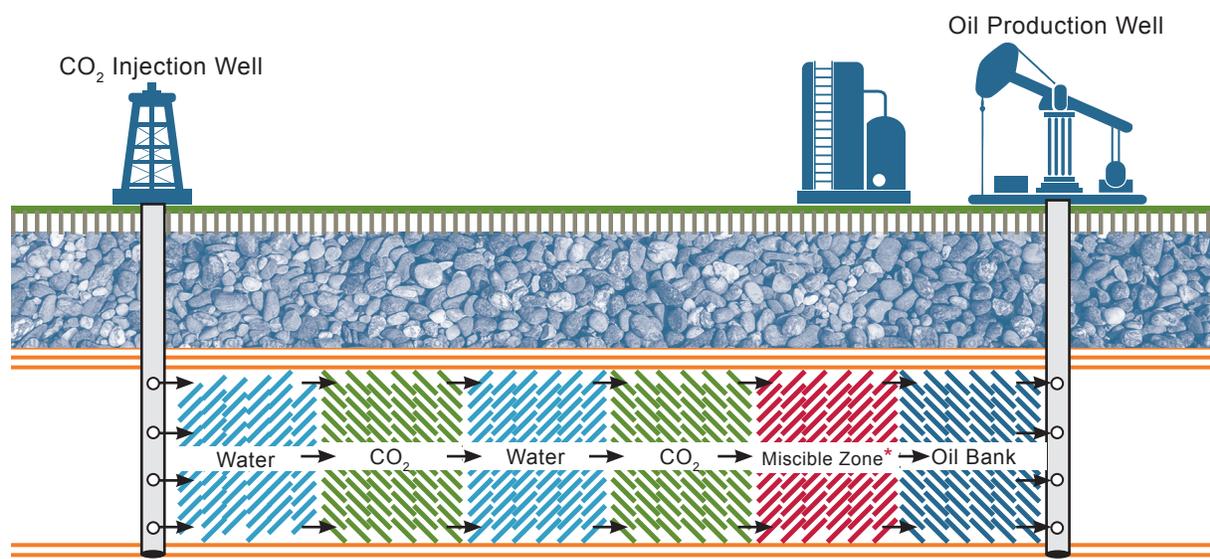
Today's CO₂ Industry – Opportunities for the Future

CO₂-EOR represents a well-understood and commercially successful technique for oil production that enables cost-effective recovery of remaining crude from mature oil fields. In the early or primary phase of traditional oil production, the extraction of oil and gas decreases the fluid pressures in a reservoir. Often, a secondary phase involving injection of water to restore reservoir pressure has followed the primary phase, enabling production of still more of the original oil in place. Eventually, waterflooding reaches a point of diminishing economic returns.⁵ Then, most of those fields are suitable for a tertiary phase of production that commonly involves CO₂ injection—referred to as “CO₂ floods”—to recover still more of the remaining oil. Suitable fields tend to be deep and at high pressures, causing CO₂ to function like a liquid that readily dissolves in the oil. Such fields also have a high degree of structural integrity, so that CO₂ floods move in a controlled, predictable fashion.

Commercial CO₂-EOR was pioneered in West Texas in 1972. In the ensuing 45 years, the U.S. independent oil and gas industry turned the practice into a robust and growing industry that accounted for approximately 4 percent of domestic oil production in 2014. The first two large-scale CO₂-EOR projects in the United States (SACROC and Crossett in West Texas) remain in operation today.

Capturing, compressing and transporting CO₂ via pipeline to an oilfield transforms CO₂ from a liability into a valuable commodity with remarkable properties and potential for enhancing oil production. When injected into an existing oilfield, CO₂ lowers the viscosity of the remaining oil, reduces interfacial tension, and swells the oil, thereby allowing oil affixed to the rock and trapped in pore spaces to flow more freely and be produced through traditional means.

Figure 4: How Carbon Dioxide and Water Can Be Used to Produce Residual Oil



*Miscible Zone = Injected CO₂ encounters trapped oil → CO₂ and oil mix → Oil expands and moves towards producing well

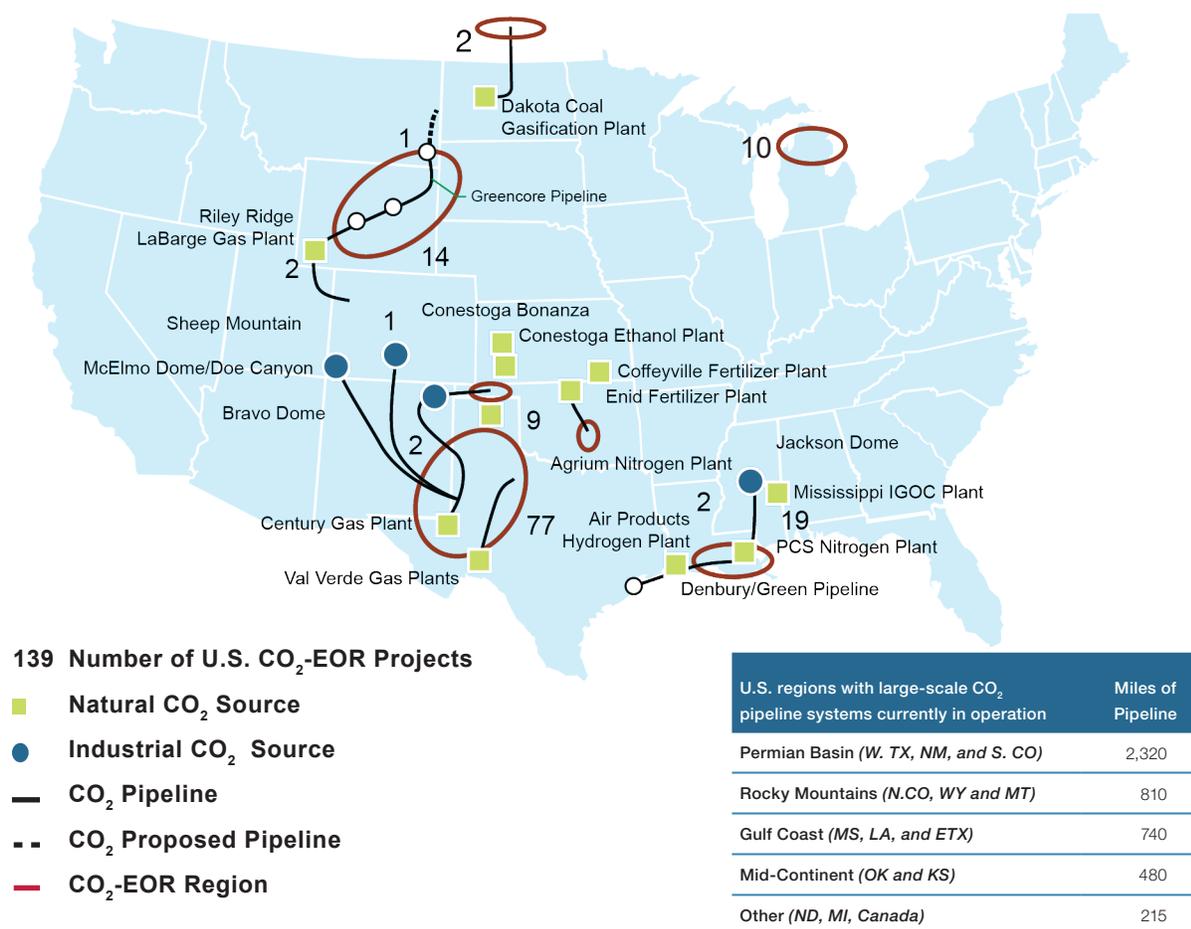
Source: National Energy Technology Laboratory, "Carbon Dioxide Enhanced Oil Recovery: Untapped Domestic Energy Supply and Long Term Carbon Storage Solution," March 2010.

A majority of injected CO₂ remains in the reservoir in the first pass; that CO₂ which does return to the surface with the produced oil is then separated, compressed, and re-injected. With standard operating procedures, this process results in only *de minimis* emissions (less than two percent) from what constitutes a closed-loop system from CO₂ source to oilfield sink.

Traditional production techniques yield one-third to one-half of the original oil in place. If oil companies could readily source ample CO₂ from pipeline networks to existing oilfields, operators would have the potential to extract a further 10-20 percent of the original oil resource. With access to CO₂, the same oilfield, with the same leases, drilling pads, extraction wells, and oil pipelines, would yield significantly more production.

However, insufficient access to CO₂ constrains long-term growth of EOR production. Two types of CO₂ supply the EOR industry, naturally occurring from geologic domes and man-made from industrial and power plant sources. The latter provides roughly one-fourth of the total volume of CO₂ purchased and injected by oilfield operators.

Figure 5: Current CO₂-EOR Operations & Infrastructure



Source: U.S. Department of Energy, "Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure," April 2015.

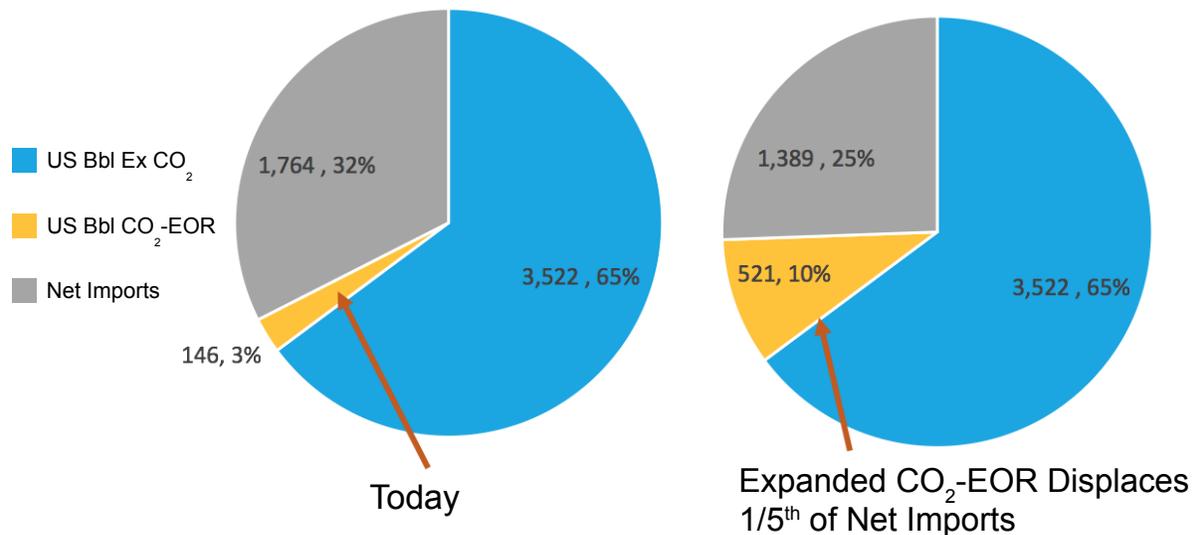
The CO₂ first used in EOR was man-made and stripped from natural gas produced from fields in Texas and later in Wyoming. Today, Exxon’s Shute Creek gas processing plant at the LaBarge gas field in Wyoming is the largest operating carbon capture facility in the world,⁶ capable of separating over seven million tons of CO₂ per year and supplying a pipeline network and EOR fields spanning much of Wyoming and extending into Colorado.

Despite a long history of capturing, compressing and transporting man-made CO₂ for EOR, naturally occurring, but limited geologic CO₂ procured from underground domes now dominates the industry supply. For instance, CO₂ is transported via Kinder Morgan’s Cortez pipeline—the world’s largest—from McElmo Dome in southern Colorado across all of New Mexico, ultimately reaching the Permian Basin in Texas.

Taken together, natural and man-made CO₂ supplies about 79 million tons a year, supporting U.S. CO₂-EOR oil production of about 146 million barrels a year. **Increasing man-made CO₂ supplies by 150 million tons per year through expanded carbon capture and the buildout of five major pipeline corridors would increase annual U.S. EOR production by approximately 375 million barrels.**

Figure 6: New CO₂-EOR Reduces Oil Imports

Annual U.S. oil supply in millions of barrels/yr of crude and petroleum products. Excludes natural gas liquids, ethanol, and biodiesel. Source: U.S. Energy Information Agency 2016 Annual Energy Outlook, Table 11.

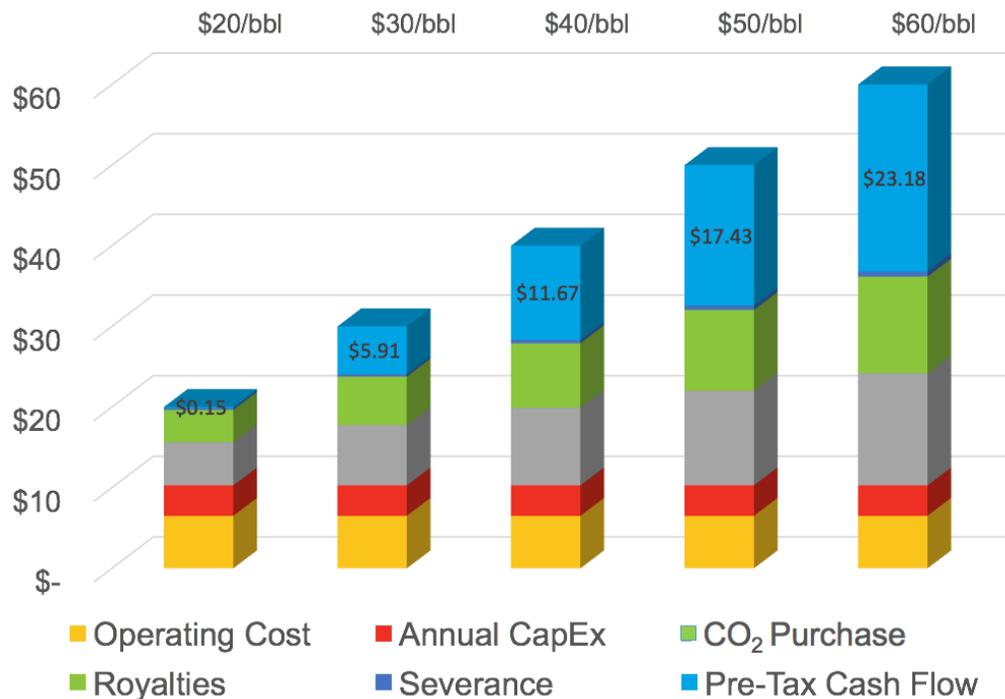


Since our nation still imports a net 1.76 billion barrels per year of foreign oil, a cost-competitive increase in U.S. domestic CO₂-EOR production of this magnitude could reduce our net imports by more than one-fifth.

CO₂-EOR can become a game changer for U.S. domestic energy production. According to 2013 analysis from the U.S. DOE's National Energy Technology Laboratory, the U.S. has the potential to produce an estimated 28 billion barrels of economically recoverable oil from conventional oil fields with today's industry best practices. Next-generation techniques have the potential to yield an estimated 81 billion barrels. For comparison, total U.S. proved reserves of oil stood at just under 40 billion barrels in 2014.

CO₂-EOR enhances our nation's energy and economic security by lessening our dependence on foreign oil, often imported from unstable and hostile areas, and reducing our trade deficit by keeping dollars currently spent on oil imports at work in the U.S. economy. Moreover, EOR operations remain relatively robust in the face of oil price declines triggered by foreign actors such as OPEC. Once the extensive infrastructure of wells, surface processing facilities, and CO₂ pipeline transport has been financed and constructed, an EOR operation is designed to operate and pay off its investors over 20 to 40 years, depending on the size of the field. An EOR operation has large initial investment costs compared to conventional onshore oil production, but very low cash costs of operation—and many of those cash costs, including royalties, severance taxes, and even CO₂ purchase costs, typically decline when oil prices fall. Thus, as shown in the chart below (Figure 7), an established EOR flood that has reached full operational levels may be able to cover day-to-day operating costs at oil prices as low as \$20 per barrel.

Figure 7. Cash Flow at Various Oil Prices for CO₂-EOR Flood



In contrast, some newer technologies such as hydraulic fracturing can be very profitable, but require consistent re-investment in order to maintain oil production volumes. In an environment where oil prices have been driven to very low levels (e.g., because of actions by OPEC or other foreign actors), that reinvestment may not occur, and domestic oil production volumes begin to fall. Even with considerable and ongoing innovation and cost reductions in hydraulic fracturing, experts peg the break-even level for drilling new wells at a considerably higher range of \$35-50 per barrel (depending on the particular site).

CO₂ Pipelines are Key to 21st Century Energy Infrastructure^{7, 8}

CO₂ from many man-made sources, especially from industrial processes with low costs of carbon capture, could readily supply oilfields with the right pipeline infrastructure in place. For example, ethanol and fertilizer plants emit CO₂ to the atmosphere that they would rather sell into a pipeline bound for an American oilfield. Even in the absence of regulatory requirements limiting CO₂ emissions, a number of industrial facilities located within reasonable proximity of oilfields have already been tapped. For example, fertilizer plants at Enid, Oklahoma, and Coffeyville, Kansas, were both close enough to oilfields to make the construction of short (~100 miles), small-diameter (~8 inch) pipelines feasible for CO₂-EOR.

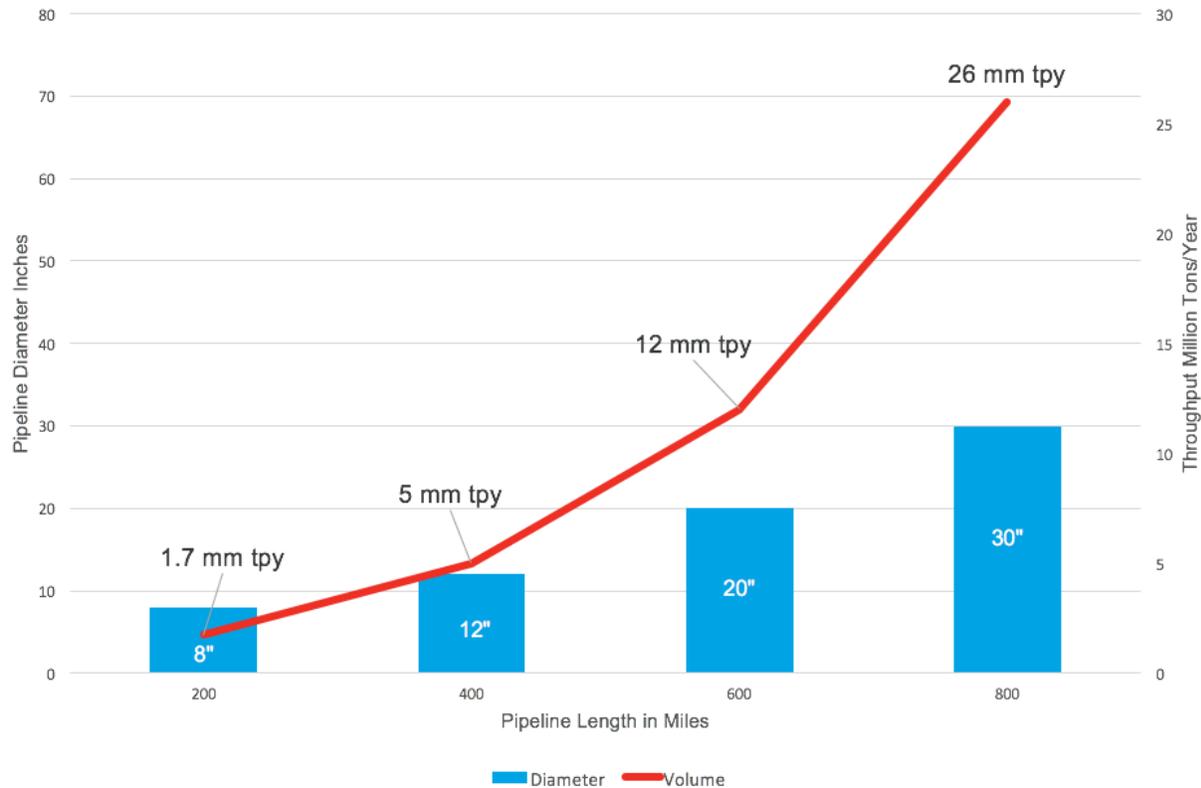
ADM (Archer Daniels Midland) captured 300,000 tons of CO₂ per year at its Decatur, Illinois, ethanol plant, and anticipates increasing capture capacity to 1.1 million tons per year—but that volume alone is not enough to make feasible the construction of a 600+ mile-long pipeline to reach large-scale EOR opportunities.⁹ Thus, the CO₂ is being injected into a saline aquifer 7,000 feet below the plant. If a company like ADM could transport the CO₂, an entirely new revenue stream would emerge—in turn supporting the entire economic value chain of farmers, fertilizer makers, seed providers, and agricultural equipment manufacturers that supply ADM with its corn. Further, the global competitors of our ethanol producers, such as Brazil, currently lack the same extra revenue opportunity.

Like natural gas pipelines, building large, high-capacity CO₂ pipelines creates economies of scale and opportunities to realize major cost savings. The reason is simple. Pipelines are categorized by diameter (typically running as small as 8 inches up to more than 30 inches). The main cost of a pipeline—the tons of steel and miles of welds needed—is based on its *circumference* (i.e. the girth of the belt of steel it takes to go around the pipe as it is formed), which increases in direct proportion to the diameter. However, the capacity of the pipeline or, in this case, the volume of CO₂ it can transport, is based upon its cross-sectional *area*, which increases exponentially with diameter. Thus, doubling the diameter of the pipeline doubles the circumference, but quadruples the cross-sectional area and, therefore, quadruples the throughput capacity of the pipeline.¹⁰

So, by spending twice as much money to build a larger pipeline, an owner can get four times as much throughput capacity. Spending four times the money garners an even greater return—16 times the capacity.¹¹ The scale economies mean that pressurized gas can be moved long distances at reasonable tariffs, but only if pipelines are built at sufficiently large diameter to drive down capital cost per unit of CO₂ throughput capacity.

In simple terms, at today's expected oil prices (using estimates from futures markets or U.S. government forecasts), CO₂ will be worth roughly \$25 per ton delivered to U.S. oilfields a decade from now. To make it worthwhile to capture and compress CO₂ at industrial and power plant sites far from those oil fields, the transport cost needs to be well under \$25. For example, if the CO₂ is worth \$25 at the oilfield, and it costs \$10 to ship, \$15 per ton remains to cover capture and compression costs and profit for an Iowa fertilizer plant or an Illinois ethanol distillery. If it costs \$25 per ton just to move the CO₂, it will not be economical for a plant owner to capture, compress and transport CO₂. Instead, that plant owner will opt to vent the CO₂, no oil company will have an opportunity to buy it, and the potential oil production, job creation and emissions reduction benefits are all lost.

Figure 8. CO₂ Pipeline Diameter and Volume to Keep Transport Tariffs at \$10/ton



Source: National Energy Technology Lab, "FE/NETL CO₂ Transport Cost Model," developed by Timothy Grant and David Morgan, 2014.

The chart above shows the pipeline size needed to drive down transport costs to \$10 per ton—the longer you build the pipe, the larger it must be to make sense economically:

- To go only 200 miles¹² (far left of chart), with a \$10 per ton tariff (transport fee), the pipeline can be eight inches in diameter and only needs to carry 1.7 million tons of CO₂ per year. (The total capital required is \$150 million, or \$750,000 per mile.)
- To go 800 miles (far right of chart), still keeping the tariff at \$10, the pipeline needs to be expanded to 30 inches in diameter, carrying 26 million tons per year. (The total capital required is \$2.4 billion, or \$3 million per mile.)

From the first example to the second example above, the pipeline cost per mile quadruples from \$750,000 per mile to \$3 million per mile, but the capacity increases a staggering 16-fold, from 1.7 million to 26 million tons of CO₂ per year. An extraordinary economy of scale is realized. However, to obtain such savings in the real commercial world, the pipeline business deal becomes very complex. The pipeline developer must assemble a larger number of CO₂ suppliers, a larger number of oilfield customers, and a much greater sum of financing (\$2.4 billion), all at once.

Rationale for Federal Involvement in CO₂ Pipeline Infrastructure Development

The potential for a major buildout of CO₂ pipeline infrastructure, together with the ramping up of industrial and power plant carbon capture, to deliver domestic energy production, jobs and environmental benefits on a truly national scale warrants a role for the federal government in supporting the financing of CO₂ pipeline infrastructure and in providing incentives for commercial carbon capture deployment.

Supersizing the capacity of the first CO₂ trunk pipelines constructed in states and regions not yet presently served by pipeline infrastructure capitalizes on the demonstrable cost-savings from economies of scale. Additionally, it will also de-risk and lower the cost of capital for tens of billions of dollars in private investment needed in carbon capture projects at industrial facilities and power plants, as well as in infrastructure required to prepare an oilfield for CO₂ injection and EOR.

Fortunately, private sector industrial CO₂ suppliers and oil industry customers can carry *most, but not all*, of the cost of a large capacity pipeline for a few years, while the remaining CO₂ suppliers and customers are identified. To illustrate, we use numbers similar to those in the chart in Figure 8:

- A small group of shippers needing to transport CO₂ 800 miles, aggregating to only 12 million tons per year of volume, could make use of a large 30-inch diameter pipeline, instead of the smaller 20-inch line normally utilized for that volume. The 30-inch pipe can function at this smaller volume, even though it can carry much more—26 million tons per year (see the far right of pipeline bar chart above). The flexibility comes from a pipeline operator's ability to vary pressures—lower pressure for lower volumes, higher pressure for higher volumes.
- Until the rest of the suppliers and customers are recruited, the initial shippers, if unaided, would face a relatively high transport charge of \$19 per ton—a level that would normally deter prospective shippers. However, once CO₂ shippers for the full 26 million tons per year have signed on, tariffs can fall to a more commercially attractive \$10 per ton.
- However, accomplishing this favorable outcome for energy independence, jobs and the economy depends on finding an alternative to charging a prohibitive \$19 per ton for the first shippers. To keep the initial shipping fee down to a more feasible \$12 per ton, for instance, approximately \$84 million per year in cash would be required during an assumed five-year period of operation before additional CO₂ suppliers and customers are brought on board (i.e., an expenditure of \$500 million—including interest cost—would economically bridge the gap before the pipeline was filled to capacity).
- Finally, with the full complement of shippers (26 million tons per year) on board, a feasibly small repayment surcharge of \$1.50 per ton would repay that \$500 million bridge financing with interest.¹³

- Ultimately, a pipeline of this size could sell \$650 million of CO₂ per year, driving EOR production of nearly \$5 billion dollars of oil per year. More importantly the critical \$500 million bridging investment created annual savings of \$100 million per year in transportation costs.

The analysis of the Work Group suggests a critical supplementary role to private capital that the federal government is well-positioned to play. **Federal financial support could leverage substantially greater pipeline infrastructure capacity at a small proportion of total pipeline cost by financing the modest incremental expense of constructing increased capacity up front.** Federal taxpayers' infrastructure investment could then be recouped over time through minor tariff increases spread across many additional shippers added to the system as new carbon capture projects and EOR operations deploy and use the pipeline.

Under such an approach, all private sector participants—industry CO₂ suppliers, pipeline owners and EOR operators—come out financially ahead by constructing a higher-capacity pipeline with a modest federal financing component and adding shippers over time. By contrast, acting alone and building a smaller, optimized pipeline upfront would require permanently higher tariffs over the life of the project.

For its part, the federal government's incremental financing role for this CO₂ pipeline infrastructure would yield the extraordinary energy security, jobs, economic, fiscal and environmental benefits for our nation outlined at the beginning of this paper.

Additional Federal Recommendations

The State CO₂-EOR Deployment Work Group offers the following recommendations for a federal financing, siting and permitting role in CO₂ pipeline corridor development that enables construction of increased capacity upfront, potentially with options for states to supplement federal support. The Work Group urges the following:

- DOE should recognize long-distance CO₂ pipeline corridors as an “innovative” technology under the DOE Loan Program Office's funding available for Advanced Fossil Energy Projects. There has never been a long-distance (in excess of 200 miles) CO₂ pipeline constructed in the U.S. expressly to carry man-made CO₂ to oilfields, or one built with increased capacity to facilitate and accelerate future deployment of carbon capture and EOR projects.

The Canadian energy powerhouse of Alberta is pursuing just such a supersized CO₂ pipeline, the Alberta Carbon Trunk Line, in partnership with industry and in consultation with First Nations and other key stakeholders. The Carbon Trunk Line benefits from a combination of provincial and federal government financial participation.

- The US Congress should expand the mission of USDOT's Transportation Infrastructure Finance and Innovation Act (TIFIA)¹⁴ subordinated loan program to include CO₂ pipeline networks as part of its mission. This program has been used to spur innovative road and rail projects, such the Alameda Corridor Project to de-bottleneck freight movement from ports to railroads through the congestion of Los Angeles.

- Congress should authorize and direct federal agencies to play a supplementary role to private investors by financing additional capacity in strategic CO₂ trunk line projects until a sufficient customer base has been established to recoup the federal investment through tariffs.
 - In a historic example of the significant impact such a federal financing role can have, the federal government initially financed and owned the 1300 and 1500-mile oil pipelines (20 and 24-inch, respectively) from Texas to New England that eventually were privatized (sold for approximately \$1.6 billion in today's dollars) and converted to natural gas pipelines as the Texas Eastern Transmission Corporation.¹⁵ Those lines remain an important backbone of the U.S. energy system 75 years later.
 - To take another interesting example, once the federal Bonneville Power Administration had initially strung 1,000 miles of transmission lines between the Pacific Northwest and California, an enterprising group of utilities was able to piggyback on that federal investment by paying for capacity upgrades that greatly increased the lines' capacity.
- Pursuant to President Trump's January 24th executive order, Governors or heads of federal agencies should identify long-distance CO₂ pipelines as high-priority infrastructure projects for expedited environmental reviews and approvals.¹⁶
- The Administration should develop a more concerted federal policy¹⁷ and require better coordination and consultation between federal agencies and with state, tribal and local governments and stakeholders regarding pipeline corridor siting and permitting. The development and utilization of designated pipeline corridors is a highly efficient and effective way to incentivize pipeline infrastructure development. Pipeline corridors are delineated primarily by siting them adjacent to existing infrastructure and in conformance with federal agency land use and planning documents. The benefits of utilizing designated corridors include: streamlined regulatory authorization, reduced environmental impacts, and increased constructability for project proponents.
- Federal land management agencies should:
 - Actively issue themselves right-of-way (ROW) grants that they will designate and manage as pipeline corridors on lands that they own or administer.
 - Allocate resources to complete National Environmental Policy Act (NEPA) analyses, which are required for ROW grants.
 - Develop their NEPA analyses at as close to project-level scale as possible. Fine scale analyses will allow the agencies to disclose the majority of impacts associated with building pipelines within the designated corridors. These robust analyses will allow pipeline projects to proceed with a much less costly and time-consuming authorization process.
 - Foster relationships to the greatest extent allowed by law with appropriate state, tribal and local governments, as well as industry, NGOs and other stakeholders, to ensure that designated corridors encompass all reasonably

foreseeable development scenarios. To formalize these cooperative relationships, memorandums or agreements should be developed to describe the roles and responsibilities of each partner.

Conclusion

American oil fields are poised to rapidly expand production through utilization of man-made CO₂ for enhanced oil recovery. This promise can be realized if the oil industry can gain access to large, secure volumes of CO₂, transported via pipeline networks and purchased from industrial facilities and power plants where that CO₂ would otherwise be emitted to the atmosphere and wasted.

The State CO₂-EOR Deployment Work Group recommends that President Trump and Congress incorporate the development of long-distance, large-volume CO₂ pipelines as a priority component of a broader national infrastructure agenda.

In particular, Congress and the President should, in consultation with states, tribal governments and key stakeholders, identify and foster the development of five priority CO₂ trunk pipelines. This would include support for planning, streamlined permitting, and financing to transport CO₂ to oilfields for EOR from industrial facilities and power plants not currently served by pipeline infrastructure.

Development and expansion of regional and national CO₂ pipeline networks, together with proposed tax credits and other financial incentives for industrial and power plant carbon capture, can support long-term production and use of America's abundant and affordable coal, oil and natural gas resources, put our nation further down the path of replacing imported oil and create high-paying jobs in energy-producing and industrial states and regions of the country, all while significantly reducing net carbon emissions.

Endnotes

1. Identifying and developing technology for enabling small producers to pursue the residual oil zone (ROZ) fairways in the Permian Basin San Andres. Final Report <http://www.netl.doe.gov/file%20library/research/oil-gas/10123-17-final-report.pdf>
2. In order to be eligible for LPO financing, a project must use fossil energy; avoid or store greenhouse gas emissions; be innovative; and provide a reasonable prospect of repaying the federal loan.
3. "...it is the policy of the executive branch to streamline and expedite, in a manner consistent with law, environmental reviews and approvals for all infrastructure projects, especially projects that are a high priority for the Nation, such as improving the U.S. electric grid and telecommunications systems and repairing and upgrading critical port facilities, airports, pipelines, bridges, and highways...upon request by the Governor of a State, or the head of any executive department or agency (agency), or on his or her own initiative, the Chairman of the White House Council on Environmental Quality (CEQ) shall, within 30 days after a request is made, decide whether an infrastructure project qualifies as a "high priority" infrastructure project...the Chairman of the CEQ shall coordinate with the head of the relevant agency to establish, in a manner consistent with law, expedited procedures and deadlines for completion of environmental reviews and approvals for such projects..." <https://www.whitehouse.gov/the-press-office/2017/01/24/executive-order-expediting-environmental-reviews-and-approvals-high>.
4. "The Secretary of Commerce, in consultation with all relevant executive departments and agencies, shall develop a plan under which all new pipelines, as well as retrofitted, repaired, or expanded pipelines, inside the borders of the United States, including portions of pipelines, use materials and equipment produced in the United States, to the maximum extent possible and to the extent permitted by law. The Secretary shall submit the plan to the President within 180 days of the date of this memorandum..." <https://www.whitehouse.gov/the-press-office/2017/01/24/presidential-memorandum-regarding-construction-american-pipelines>.
5. Some operators go directly to CO₂, where it is readily available and skip the waterflooding phase.
6. Information on the Shute Creek facility can be found at: <https://www.globalccsinstitute.com/projects/large-scale-ccs-projects>
7. "CO₂ EOR: A Model for Significant Carbon Reductions," L. Steven Melzer and C. Michael Ming, Paper Presented at the Symposium on the Role of EOR in Accelerating the Deployment of CCS, July 23, 2010, Massachusetts Institute of Technology. <https://rfflibrary.wordpress.com/2011/05/25/role-of-enhanced-oil-recovery-in-accelerating-the-deployment-of-carbon-capture-and-sequestration/>

8. A Policy, Legal, and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for the Transport and Storage of Carbon Dioxide, Interstate Oil and Gas Compact Commission, December 31, 2011. <http://groundwork.iogcc.ok.gov/node/987>
9. Decatur to North Burbank Field (Chaparral) is about 600 miles. To Permian hubs (Denver City) is approximately 900 miles.
10. The surface area of a pipe (cylinder) = length x circumference = length x (2 x π x radius). The volume of a pipe (cylinder) = length x cross-sectional area = length x (π x radius²).

Steel needed vs. volume of a one-foot long pipe					
Diameter	Radius = D/2	Area of steel plate needed to form the pipe = 12 inches x Circumference	Area vs. 2 inch diameter pipe	Volume of gas contained inside the pipe = 12 inches x Area	Volume vs. 2 inch diameter pipe
2 inch	1 inch	12 x 2 x 3.14 x 1 = 75.3 sq-in	1x	12 x π x 1 ² = 37.7 cubic-in	1x
4 inch	2 inch	12 x 2 x 3.14 x 2 = 150.8 sq-in	2x	12 x π x 2 ² = 150.8 cubic-in	4x
8 inch	4 inch	12 x 2 x 3.14 x 4 = 301.4 sq-in	4x	12 x π x 4 ² = 603.2 cubic-in	16x
16 inch	8 inch	12 x 2 x 3.14 x 16 = 602.8 sq-in	8x	12 x π x 8 ² = 2,411 cubic-in	64x

11. The main cost that has to be recovered through transportation tariff rates charged to pipeline shippers is the annual financing charge based upon the original capital cost.
12. Note that in the chart we assume the pipeline climbs 4 feet per mile, since industrial sources in the Midwest (for example) are located at low elevations (for example, 1,000) feet, whereas much of the oil production region lies at altitudes 3,000 to 4,000 feet higher.
13. The repayment surcharge is relatively small because it is spread over the full 26 million ton per year customer base and extended over the full life of the pipeline.

14. The TIFIA program was modeled on the Alameda Corridor \$400 million loan, though it is not clear that the actual loan was technically a TIFIA loan at the time. (Source: <https://www.gpo.gov/fdsys/pkg/CHRG-107hhrq77859/html/CHRG-107hhrq77859.htm>)

TIFIA Eligibility - <https://www.transportation.gov/buildamerica/programs-services/tifia/eligibility>

Any type of project that is eligible for Federal assistance through existing surface transportation programs (highway projects and transit capital projects) is eligible for the TIFIA credit program, including intelligent transportation systems (ITS). In addition, the following types of projects are eligible: international bridges and tunnels; intercity passenger bus and rail facilities and vehicles; publicly owned freight rail facilities; private facilities providing public benefit for highway users; intermodal freight transfer facilities; projects that provide access to such facilities; service improvements on or adjacent to the National Highway System; and projects located within the boundary of a port terminal under certain conditions.

An eligible project must be included in the applicable State Transportation Improvement Program. Major requirements include a capital cost of at least \$50 million (or 33.3 percent of a state's annual apportionment of Federal aid funds, whichever is less) or \$15 million in the case of ITS. TIFIA credit assistance is limited to a maximum of 33 percent of the total eligible project costs. Senior debt must be rated investment grade. The project also must be supported in whole or in part from user charges or other non-Federal dedicated funding sources and be included in the state's transportation plan. Applicable Federal requirements include, but are not limited to Titles 23 and 49 of the U.S. Code, NEPA, Buy America provisions, and the Civil Rights and Uniform Relocation Acts.

Qualified projects are evaluated by the Secretary against eight statutory criteria, including among others, impact on the environment, significance to the national transportation system, and the extent to which they generate economic benefits, leverage private capital and promote innovative technologies.

15. Big Inch definition on Wikipedia: https://en.wikipedia.org/wiki/Big_Inch
The Big Inch and Little Big Inch, collectively known as the Inch pipelines, are petroleum pipelines extending from Texas to New Jersey, built between 1942 and 1944 as emergency war measures in the U.S. Before World War II, petroleum products were transported from the oil fields of Texas to the northeastern states by oil tanker. After the United States entered the war on January 1, 1942, this vital link was attacked by German submarines in the Operation Paukenschlag, threatening both the oil supplies to the northeast and its onward transshipment to Great Britain. The Secretary of the Interior, Harold Ickes, championed the pipeline project as a way of transporting petroleum by the more secure interior route.

The pipelines were government financed and owned, but were built and operated by the War Emergency Pipelines company, a non-profit corporation backed by a consortium of the largest American oil companies. It was the longest, biggest and heaviest project of its type then undertaken; the Big and Little Big Inch pipelines were 1,254 and 1,475 miles (2018 and 2,374 kilometers) long, respectively, with

35 pumping stations along their routes. The project required 16,000 people and 725,000 short tons of materials. It was praised as an example of private-public sector cooperation and featured extensively in U.S. government propaganda.

After the end of the war, there were extended arguments over how the pipelines should be used. In 1947, the Texas East Transmission Corporation purchased the pipelines for \$143,127,000, the largest post-war disposal of war-surplus property. The corporation converted them to transport natural gas, transforming the energy market in the northeast. The Little Big Inch was returned to carry oil in 1957. The pipelines are owned by Spectra Energy Partners and Enterprise Products and remain in use.

16. "...it is the policy of the executive branch to streamline and expedite, in a manner consistent with law, environmental reviews and approvals for all infrastructure projects, especially projects that are a high priority for the Nation, such as improving the U.S. electric grid and telecommunications systems and repairing and upgrading critical port facilities, airports, pipelines, bridges, and highways...upon request by the Governor of a State, or the head of any executive department or agency (agency), or on his or her own initiative, the Chairman of the White House Council on Environmental Quality (CEQ) shall, within 30 days after a request is made, decide whether an infrastructure project qualifies as a "high priority" infrastructure project...the Chairman of the CEQ shall coordinate with the head of the relevant agency to establish, in a manner consistent with law, expedited procedures and deadlines for completion of environmental reviews and approvals for such projects. <https://www.whitehouse.gov/the-press-office/2017/01/24/executive-order-expediting-environmental-reviews-and-approvals-high>.
17. USDOE, A Review of the CO₂ Pipeline Infrastructure in the U.S., DOE/NETL-2014/1681, April 21, 2015.