CO_2 Enhanced Oil Recovery

Institute for 21st Century Energy | U.S. Chamber of Commerce

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EXECUTIVE SUMMARY

Energy, particularly the products that come from crude oil, is an every day part of our lives. From the direct use of gasoline to fuel transportation to the obvious items such as medicines, plastics, and other materials that people use daily, oil fuels our economy. Yet most Americans have little understanding of where oil originates and share a common misperception that the majority of oil imports come from the Middle East.

It surprises many people that domestic production is the largest single source of crude oil for our country! The U.S. is the third largest oil producer in the world, and its production is growing. Even more important, the U.S. is the leader in technology advancements in petroleum production.

In President Obama's 2012 State of the Union address, he challenged the country with the statement, "This country needs an all-out, all-of-the-above strategy that develops every available source of American energy." One of the tremendous resource endowments in the U.S. is its oil reserves combined with its ability to apply and advance technology for oil production. It is this combination that has resulted in the U.S. leading the world in Carbon Dioxide Enhanced Oil Recovery (CO_2 EOR).

CO_2 EOR is an important component of U.S. oil production, accounting for nearly 6% of U.S. onshore oil production, or 350,000 barrels a day.[1] This technique uses CO_2, both naturally occurring as well as a byproduct of industrial processes, to increase the production of oil from existing oil fields. While CO_2 EOR is already an important component of today's oil production, it has great potential to expand production. An analysis commissioned by the U.S. Department of Energy (DOE) projects potential oil resources recoverable with CO_2 EOR of up to 137 billion barrels, with 67 billion barrels economically recoverable at a price of $85 a barrel. This represents more than three times the current U.S. proven reserves.[2]

> "This country needs an all-out, all-of-the-above strategy that develops every available source of American energy."
>
> — President Obama

In terms of economic and energy security, this means billions of dollars of new investment in the U.S. and production potential of 4 million barrels a day of oil for 50 years from existing U.S. oil fields. The investment required would not just be in oil fields themselves, but also in power plants, pipelines, and other industries that can capture CO_2 from their industrial processes. The economic benefits will also flow to the state and federal governments, with an estimated $1.4 trillion in new government revenues. In addition to the direct benefits in the U.S., the technology used to produce this additional oil will help maintain U.S. leadership

in oil production technology, creating opportunities around the world for U.S. companies.

CO_2 EOR has direct environmental benefit. Greatly expanding CO_2 EOR will require approximately 20 billion metric tons of CO_2. While continued use of naturally occurring CO_2 is critical to current development since it represents more than 90% of the CO_2 that is available, large volumes of commercially available CO_2 captured from industrial and power plant sources have the potential to produce billions of additional barrels of trapped oil and gas.

> "The U.S. spent $330 billion on crude oil imports in 2011, representing 60% of the total U.S. trade deficit."
>
> — CRS

Captured CO_2 also has the added environmental benefit of not being released into the atmosphere. After the completion of EOR activities, the CO_2 used in oil recovery is permanently sequestered in the old oil formation. CO_2 EOR does not require extensive new land impacts because it is primarily applied to existing oil fields. This process increases the efficiency and conservation of the oil resources by producing more oil with the same land impact or "footprint". CO_2 EOR advances energy production, energy security, and environmental sustainability. It is truly a win-win-win proposition.

UNDERSTANDING OIL EXPLORATION AND PRODUCTION

Where does oil come from?

Oil is called a fossil fuel because it originated as material from plants and animals that lived millions of years ago. These plants and animals lived in an ocean environment and when they died, this carbon-based (organic) plant and animal material settled on the bottom and mixed with sand, silt, and sediment. Over thousands of years, additional layers of sentiment accumulated and turned into sedimentary rocks, such as sandstone, limestone, and shale. Pressure, temperature, and time resulted in the transformation of the deposited organic material turning into hydrocarbons, such as oil and natural gas.

The oil and natural gas that is formed in the rock exists in the pore space of the rock formations. Pore space is the open area between the solid grains of material that make up the rock. For example, when water is poured on a piece of sandstone, it is absorbed by the stone–it is flowing into the pore spaces which exist between the sand grains that make up the sandstone rock. The measure of the open space in the rock is called porosity. How well the pore spaces are interconnected determines how quickly and effectively fluids flow through the rock. The measure of this interconnectedness is called permeability.

In nature, oil and gas flow from the original rock formation in which they were created (source rock) until it reaches a rock formation with very low permeability. Then the oil and natural gas are trapped. It is the oil and natural gas in these traps that have enabled economic development of oil and natural gas resources for the last 150 years. Just as oil and gas have been trapped beneath caprock for millennia, the injected CO_2 from the EOR process will also be trapped by the same geologic mechanism for millennia. For purposes of CO_2 EOR, this paper focuses on these types of oil reservoirs. However, new technology has enabled production from the source rock itself in the case of shale oil and gas developments over the past 10 years.

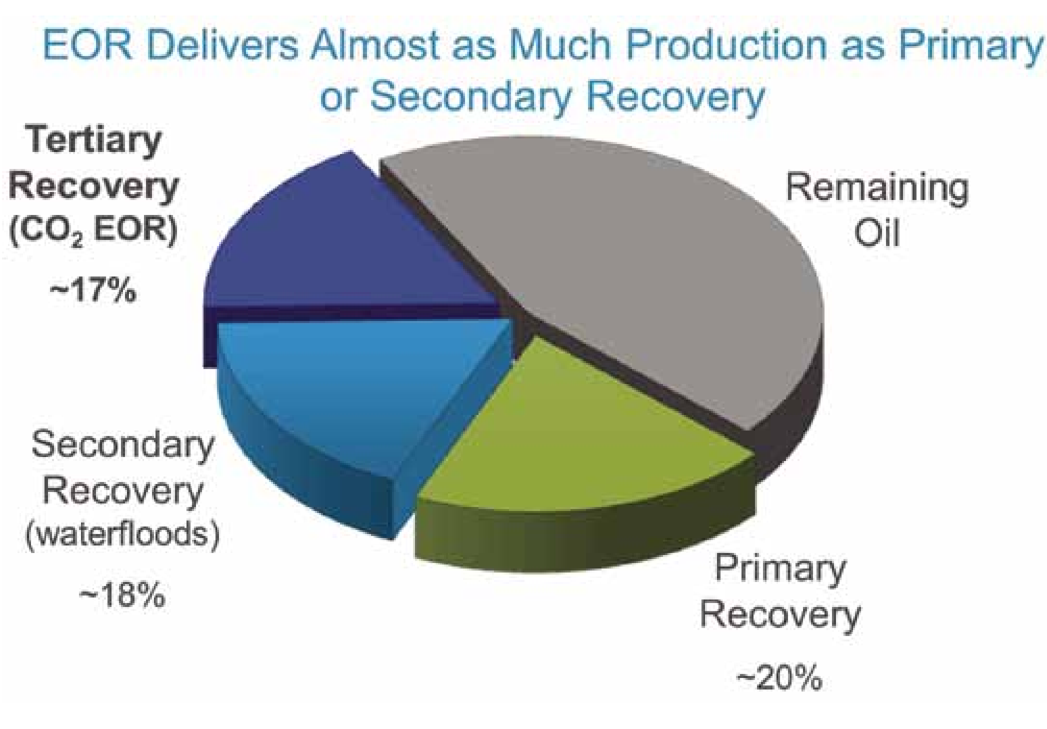
Life Cycle of an Oil Field

Oil is referred to as a nonrenewable resource. The earth takes millions of years to create a molecule of oil. Once a well starts producing oil, it is typical that the highest rate of production occurs during the first few weeks or months of production. Not only is the oil being removed from the rock formation, but the environment in the rock formation is changing as oil is produced. The pressure in the formation, in particular, is reduced as fluids are produced, causing the flow of oil to slow.

In the first phase of the oil field's productive life, called primary production, the well is produced without the addition of anything to the oil containing formation. The natural pressure from the earth is the mechanism for the oil to flow to the wellbore. Depending on the characteristics of the rock formation, primary production can result in the recovery of up to 20% of the oil originally in the rock. This means that at least 80% of the oil may remain in the rock unless additional technology is used to increase the recovery.

Usually, the next step in the oil field life cycle is the injection of water into the oil-bearing formation to maintain reservoir pressure, which produces oil rather than just primary production. This is called secondary recovery or water flooding. The water used for this step is largely recycling the water that is produced as part of the oil production operations. Water, typically saltwater, exists in the formation with the oil and natural gas. This water is separated and collected during production and reinjected into the oil-bearing formation to slow pressure decline. As oil fields age, they produce more water as a percentage of the total fluids recovered. The addition of secondary recovery has the potential to recover a further 15% to 20% of the original oil in place.

Even after primary and secondary recovery, a significant amount of oil still exists in the rock formation. CO_2 EOR is a type of tertiary oil recovery that can recover even more oil from these existing wells and reservoirs. In CO_2 EOR, carbon dioxide is pumped into the oil-bearing rock formation to recover even more oil. CO_2 EOR has the potential to recover an additional 15% to 20% of the original oil.



CO_2 EOR

What Is the Enhanced Oil Recovery Process?

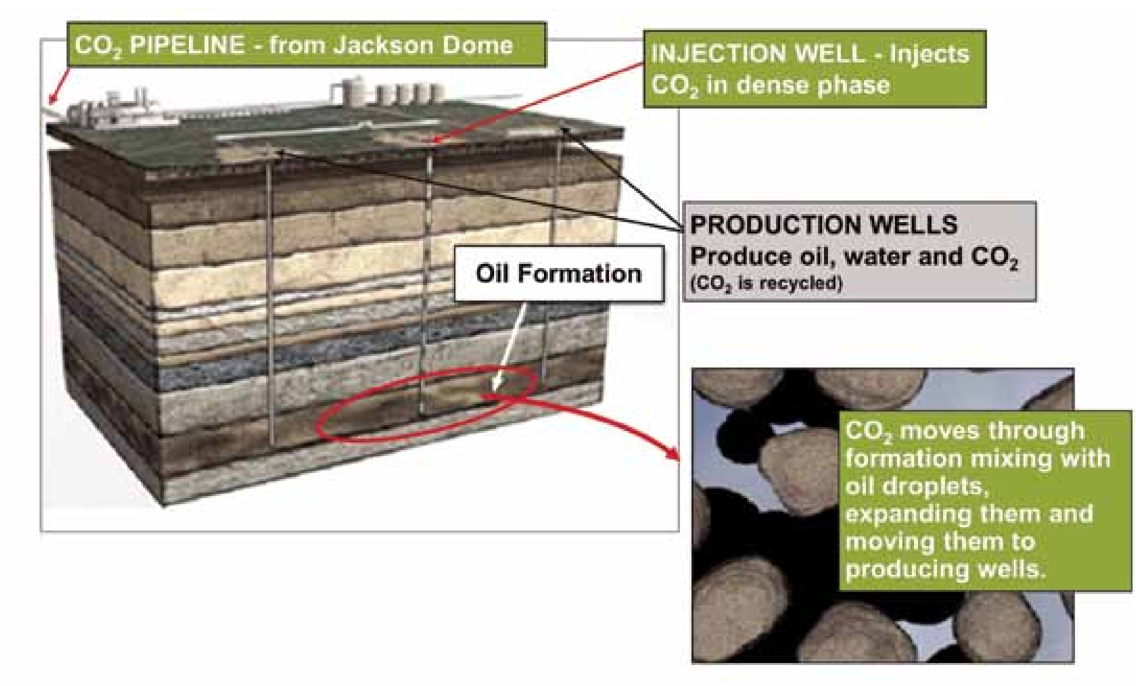
After primary and secondary (water flooding) phases of production, 65% or more of the original oil in place may remain in the rock. EOR processes change the physical characteristics of the oil to enable greater production.

The CO_2 EOR process is primarily a function of how CO_2 interacts with oil which is determined by the property of miscibility, when multiple liquids can mix together completely becoming one homogenous liquid. For example, water and vinegar are completely miscible. By contrast, water and oil are immiscible; they do not combine at any proportion. CO_2 at a supercritical pressure and temperature is completely miscible with oil; it will combine completely.

An analogous example of how this process works in oil production could be a frying pan coated in grease. When the pan is rinsed with water, some of the oil remains because oil and water are immiscible. If a solvent, such as dish soap, is applied to the pan, the solvent combines with the grease and the grease is more completely removed from the pan. In CO_2 EOR, the CO_2 combines with the oil and helps move it through the rock pore spaces, enabling greater recovery of the oil in place.

One of the first CO_2 EOR projects was initiated in 1972 in the Kelly-Snider oil field in Texas.[3] After the CO_2 EOR process was successfully demonstrated, the investment necessary to develop and transport large volumes of CO_2 to the oil fields could be put in place. The early use of CO_2 EOR was in the Permian Basin in West Texas. The CO_2 sources to support

CO_2 Recovery Process



Sources: Denbury Resources, Inc.

those developments were found in Colorado, New Mexico, and Arizona. Developing the CO_2 resources required drilling wells into geologic formations that contain CO_2, which was then transported via pipeline to the oil fields in West Texas. The increase in oil prices in the 1970s supported the development of this infrastructure.

Is CO_2 EOR Safe and Regulated?

An oil-bearing geologic formation typically has a geologic trap that has kept the oil in place for millions of years. This geologic trap contains oil and possibly natural gas and prevents it from migrating. As long as the wells that penetrate that rock formation are properly constructed, there are no pathways for the CO_2 to leak from the rock formation. Through monitoring the injection of CO_2 and all the fluids produced, the amount of CO_2 permanently sequestered in the rock is known. The combination of the natural containment of the earth and the proper construction and monitoring of the facility ensure that CO_2 will not migrate from the site.

Oil and gas development has been regulated by state governments for many decades. In fact, the U.S. Supreme Court affirmed the states' right to regulate oil and gas activities in 1900 in the *Ohio Oil Company vs. State of Indiana*. This case involved an oil company contesting Indiana's regulation of the industry through a statute enacted in 1893.[4]

Specific to CO_2 EOR, injection of any substance for the purpose of secondary or enhanced oil recovery is regulated under the Safe Drinking Water Act of 1974. All wells that serve as injection wells must be permitted for that purpose. In most cases, the state has entered into an agreement with the U.S. Environmental Protection Agency (EPA) to operate the injection well permitting program with oversight from EPA. In November 2010, EPA made a final determination that the current regulatory system was protective and opted for no additional regulation.

Example of Current and Potential EOR Production

The area of the U.S. with the longest history of CO_2 EOR is the Permian Basin in West Texas and eastern New Mexico. Currently, 56 oil fields in the Permian basin are using CO_2 EOR, collectively producing about 200,000 barrels of oil per day and account for as much as 85% of CO_2 EOR.[5] It would not be economic to continue oil production in many of these fields without CO_2 EOR.

One example of CO_2 EOR is the Denver Unit of the Wasson Field operated by Occidental Petroleum. Oil production began in the Denver unit in 1938, and oil production peaked in the mid-1940s. The operator began pressure maintenance with secondary recovery (water flooding) in 1965. CO_2 EOR began in 1983, and oil production leveled off about two years later. Through 2008, the Wassen Field's Denver Unit produced an incremental 120 million barrels of oil through CO_2 EOR.[6] The total original oil in place in the Denver Unit is estimated at 2 billion barrels.

In looking at the life cycle of the Wasson Field Denver Unit, primary recovery resulted in the production of 17.2% of the original oil in place (OOIP); secondary recovery 30.1% of the OOIP. The Denver Unit has an additional expected recovery of 19.5% through CO_2 EOR. The total of all recovery—primary, secondary, and CO_2 EOR—is expected to reach 66.8% of the original oil in place.[7]

The actual recovery factors from this project and other projects can be applied to estimate the significant opportunity of 67 billion barrels of additional economic oil to be recovered with CO_2 EOR.

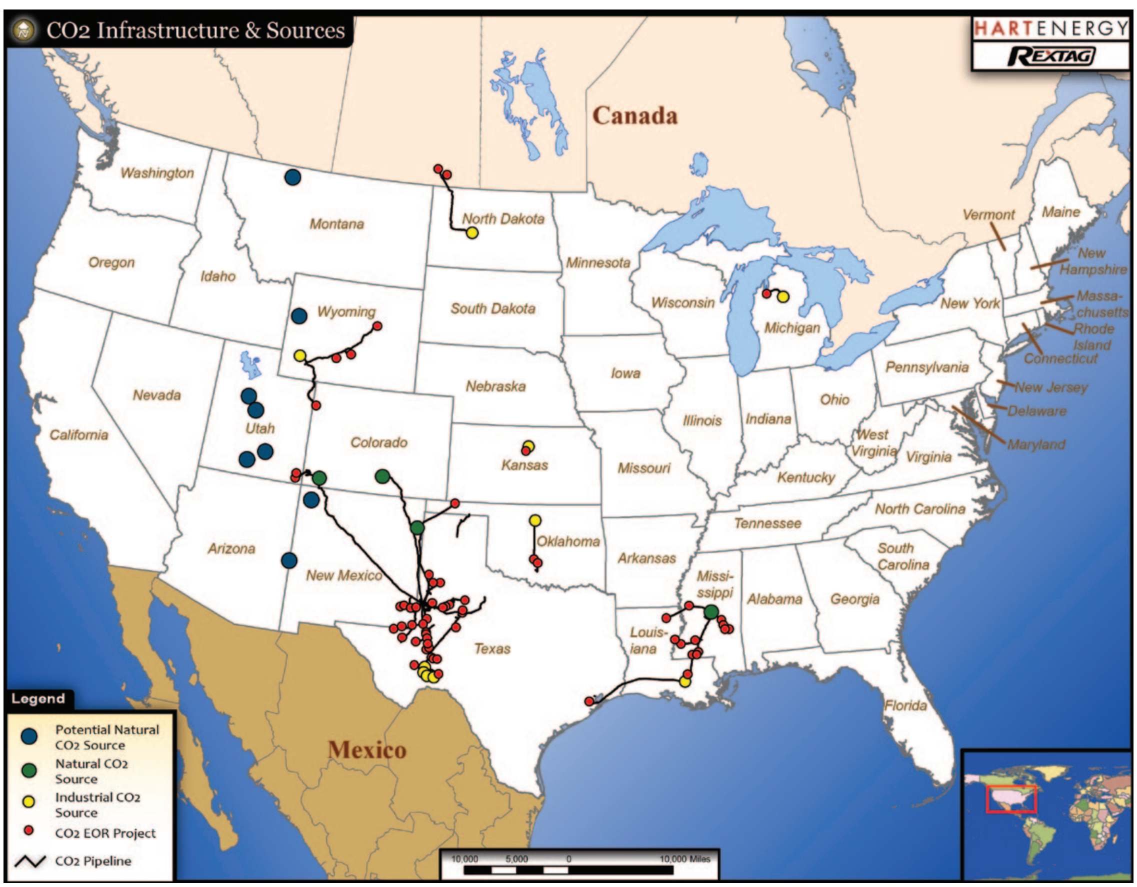
POTENTIAL FOR CO_2 EOR

Thirty states in the U.S. produce oil. Many of the historic oil-producing areas of the U.S. are potential candidates for CO_2 EOR. DOE began looking at the potential for widespread CO_2 EOR in 2006 and conducted a study of CO_2 EOR potential in 10 basins, looking at the primary oil-producing regions of the U.S.[8] This study was updated in 2011[9]. Key findings in this assessment include the following:

- Next Generation CO_2 EOR can provide 137 billion barrels of additional technically recoverable domestic oil.
- Of these 137 billion barrels, 67 billion barrels are economically recoverable at an oil price of $85 per barrel.
- Sixty-seven billion barrels of oil represent nearly 4 million barrels a day of production for 50 years, which would reduce oil imports by one third.
- Advances in technology or higher oil prices would add to these reserves.

The challenge of realizing this potential production is primarily the availability of CO_2 at prices that support economic operations. This is also one of the opportunities since CO_2 is emitted by power plants and many industrial processes. To achieve this level of production, at least 90% of the CO_2 would need to come from man-made sources, capturing CO_2 that would otherwise be released into the atmosphere.

> "Increased production from CO_2 EOR could create 375,000 jobs by 2030."
>
> — Advanced Resources International, Inc.



Source: Hart Energy/Rextag, 2012

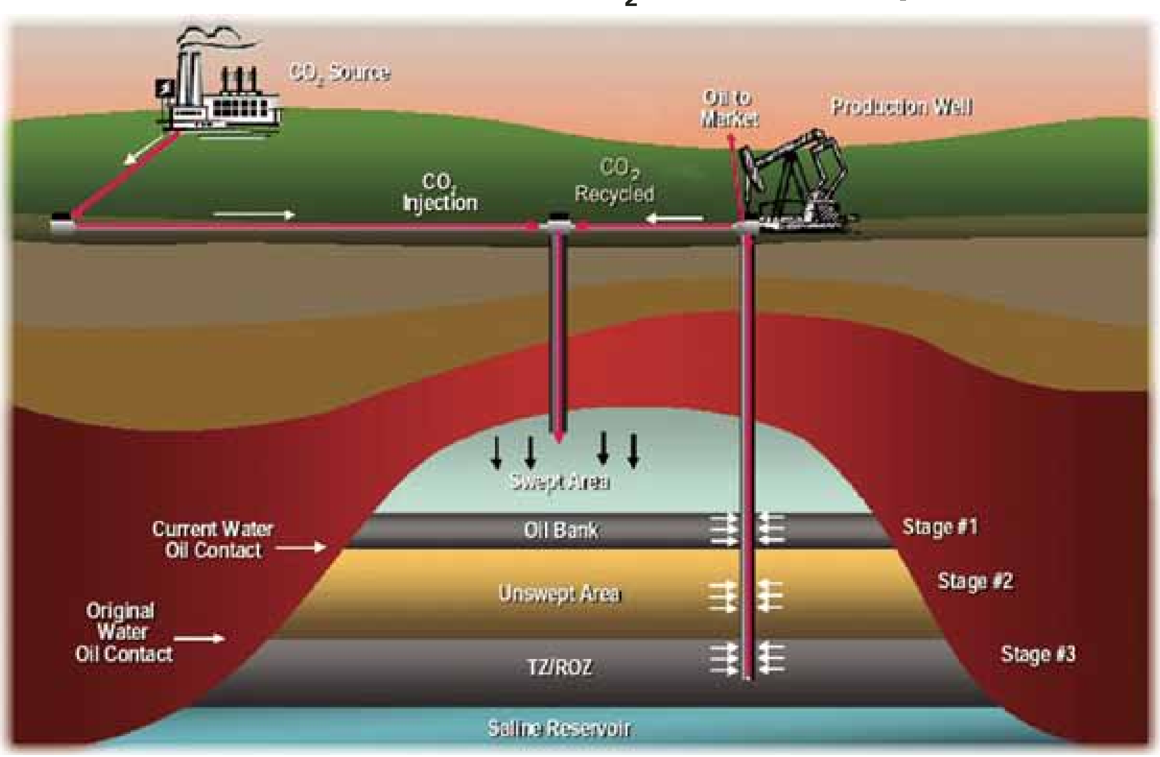
This added oil production would have great benefits to energy security for the U.S. In 2011, the U.S. imported about 60% of its crude oil, which represented about 8.9 million barrels per day. Of these total imports, 5.5 million barrels per day were from outside North America[10]. If the U.S. could achieve the 4 million barrels a day of CO_2 EOR oil production, overseas imports would be cut to just 10% of the U.S. supply. CO_2 EOR may have the greatest benefit to energy security of any option being considered.

To bring this CO_2 EOR resource to market will require huge capital investment—in the U.S. To the largest extent, this capital will be provided by the private sector. An additional 4 million barrels a day of production capacity is equivalent to one third of Saudi Arabia's production capacity. In the U.S., this is equivalent to more than a 70% increase in current oil production. This investment would include carbon capture systems at manufacturing facilities and power plants, pipelines to transport the CO_2, and significant reinvestment in the oil fields themselves. All of this will mean high-paying American jobs. The consulting firm Advanced Resources International estimates that achieving the full potential of CO_2 EOR production could create 375,000 jobs by 2030.[11]

> "Used to its full potential, CO_2 EOR could reduce overseas oil imports to just 10%."

Producing domestic resources, rather than importing energy, will have an even greater positive impact on our economy. Our top import in terms of cost is the

Next Generation CO_2 EOR Recovery



Sources: Denbury Resources, Inc.

crude oil we import, creating the largest component to our import-export balance of payments. The U.S. spent $330 billion on crude oil imports in 2011, representing 60% of total U.S. trade deficit.[12]

In addition to benefits here in the U.S., American companies that have perfected CO_2 EOR processes domestically will have the opportunity to export that intellectual property around the world. U.S. oil and natural gas companies have historically been the technology leaders in new practices and engineering for finding and developing oil and natural gas resources. Just as U.S. companies are leading the world in shale gas and oil technology and development, they will be in a position to use their expertise and experience to apply CO_2 EOR in other countries.

ENVIRONMENTAL BENEFITS AND OPPORTUNITIES FOR USING CO_2

In terms of energy security benefits, CO_2 EOR sounds almost too good to be true, but it is even better because of its many environmental benefits. CO_2 EOR uses very little new land for production and can reduce CO_2 emissions, which would otherwise be released into the atmosphere.

While CO_2 EOR is not a substitute for new exploration if we want to realize the full benefits of producing

Sources: Denbury Resources, Inc.

domestic resources, it can substantially add to our supply through increased production from existing oil fields. The new facilities would be on land that is already developed for oil production. New pipelines that would be needed would be placed in existing pipeline corridors where practical, also minimizing land disturbance. The CO_2 capture facilities would be at the site of power plants or other industrial facilities.

The largest environmental benefit comes from the CO_2 that is captured, instead of being released into the atmosphere. The largest limitation to increasing CO_2 EOR is the availability of CO_2 in quantities and prices that make CO_2 EOR economic. DOE estimates that 20 billion tons of CO_2 will be required for production of the 67 billion barrels of economically recoverable oil. Of this, 90%, or 18 billion tons, would need to come from anthropogenic CO_2 captured from power plants or industrial sources.[13] The Natural Resources Defense Council (NRDC) has estimated that by 2030 this could require between 69 gigawatts and 109 gigawatts of new coal and natural gas-fired power generation equipped with CO_2 capture technology. This would reduce annual CO_2 emissions by 410 million to 530 million tons.[14]

The producing operations of a CO_2 EOR facility are likely to continue for years, even decades. The CO_2 is used during the oil recovery operations and then is permanently sequestered in the formation when the oil production finally stops. At completion of the oil production operations, all the facilities are dismantled and removed from the site. The wells are permanently plugged with a series of cement plugs that seal all the oil-producing and CO_2-containing formations, along with other key geologic zones in accordance with applicable regulation. This process of plugging the wells ensures that the fluids in the producing zone remain in that zone and cannot migrate to other zones.

The site is returned as nearly as possible to its original conditions. In almost all cases, the oil and gas companies lease land from landowners, most of whom are able to continue to use their land even during EOR operations. If CO_2 sequestration for long-term storage is planned for the site, then a monitoring plan is developed and implemented. Once monitoring demonstrates that CO_2 has not migrated out of the rock formation over the near term (tens of years), then there can be great certainty that no migration will occur in the long term (hundreds or thousands of years). CO_2 EOR provides a cost-effective and market-oriented means to capture CO_2 and provide long-term storage without imposing a government-mandated price on carbon.

The challenge in this process is finding cost-effective and economic technologies to capture the CO_2 from industrial and power generation sources. While technologies are available for CO_2 capture, more work is required to improve and develop new technologies that reduce capture costs (and increase operational efficiency) to enable an even greater amount of CO_2 to be economically captured. This area of research will remain an important component to realizing the full potential of CO_2 EOR. In addition, greater scientific and engineering understanding of geologic sequestration will help set longer term standards in areas such as establishing the best type and length of CO_2 long-term monitoring programs. In the U.S., we have tremendous geologic knowledge, in large part because of the hundreds of thousands of oil and gas wells drilled across the country, the more than 13,000 EOR wells, and the more than 800 million tons of CO_2 that have been injected in oil fields over four decades. From that knowledge base, the U.S. has developed the standards and regulation to safely and economically manage CO_2 EOR and long-term CO_2 storage.

ENDNOTES

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