PROGRAM facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Carbon Sequestration

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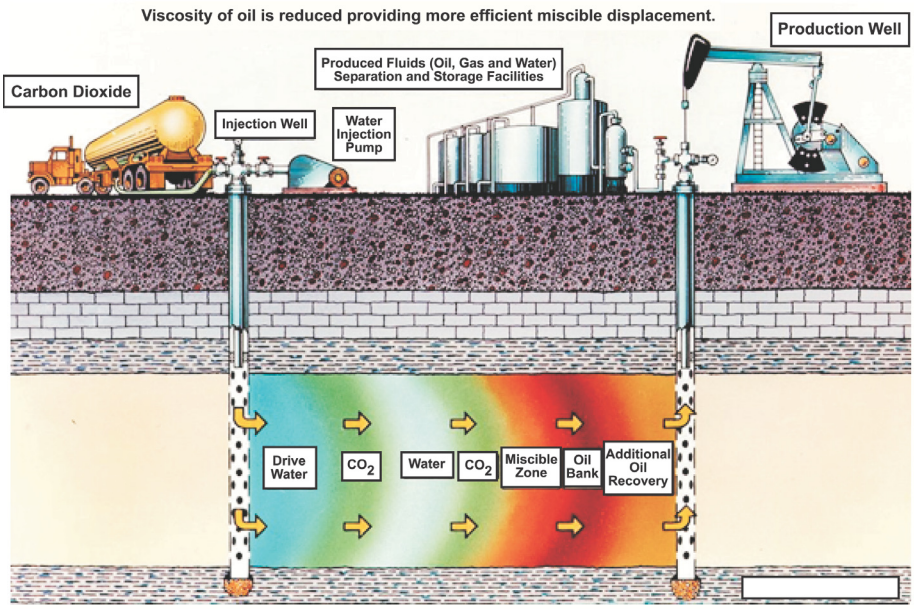
Carbon Sequestration Through Enhanced Oil Recovery

Description/Background

Enhanced Oil Recovery (EOR) refers to techniques that allow increased recovery of oil in depleted or high viscosity oil fields. In 2006, EOR projects produced a total of 650,000 barrels of oil per day (Moritis, 2006), almost 13 percent of the total U.S. production. Carbon dioxide flooding (CO_2 EOR) has the potential to not only increase the yield of depleted or high viscosity fields but also to sequester carbon dioxide that would normally be released to the atmosphere. In general terms, carbon dioxide is flooded into an oil field through a number of injection wells drilled around a producing well. Injected at a pressure equal to or above the minimum miscibility pressure (MMP), the CO_2 and oil mix together and form a liquid that more easily flows to the production well. Pumping can also be enhanced by flooding CO_2 at a pressure below the MMP, swelling the oil and reducing its viscosity.

CO_2 EOR has been used by the oil and gas industry for over 40 years, but only recently has its potential as a carbon sequestration method been realized and investigated. Currently, CO_2 EOR comprises approximately 37 percent of all EOR being performed in the United States. Maturing oil fields and rising oil prices have made this method of resource recovery increasingly attractive to industry. The United States has been a leader in developing and using technologies for CO_2 EOR by performing approximately 96 percent of worldwide CO_2 EOR. A simple schematic of the process is shown below.



Schematic of CO_2 EOR

CONTACTS

Sean I. Plasynski
Sequestration Technology Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4867
sean.plasynski@netl.doe.gov

Darin Damiani
Project Manager
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507
304-285-4638
darin.damiani@netl.doe.gov

Current CO_2 EOR Operations

Currently, over 48 million metric tons (tonnes) per year of CO_2 are used for EOR. Of this total, about 25 percent (12 million tonnes) is anthropogenic in origin i.e., produced by human activities such as oil refining or fertilizer manufacturing (Trinity 2006). The rest is extracted from naturally occurring deposits.

The CO_2 used to increase oil production is an expensive commodity, and for this reason oil companies are motivated to ensure that up to three quarters of CO_2 injected remains underground in the oil field. The amount of CO_2 sequestered is highly dependent on whether the field is blown-down following any CO_2 operations. Further research and development in this area is expected to improve the storage rate to close to 100 percent. Estimates made by the U.S. Department of Energy (DOE) show that depleted oil and gas wells in the United States and Canada have the potential to sequester over 82 billion tonnes of carbon in total (DOE 2007).

Table 1. CO_2 Utilization and Potential in EOR Projects

United States (2006)	(million tonnes/yr)
Carbon Dioxide use for EOR	48
• Naturally occurring	36
• Anthropogenic	12
Estimated CO_2 sequestered by EOR operations	9
Worldwide	
Potential CO_2 EOR sequestration	130 billion tonnes
Total CO_2 accumulated in atmosphere	**3-4 billion tonnes/yr**

Source of U.S. data: National Energy Technology Laboratory, Carbon Sequestration Atlas, 2007

Benefits

CO_2 EOR is a promising method of sequestration for a number of reasons. First, the geologic structures that originally contained the oil and natural gas should also permanently contain the injected CO_2, provided the integrity of the structures is maintained. From seismic studies, the geologic structure and physical properties of many oil and gas fields are well understood. This, combined with the vast amount of industry experience with gas-injection EOR, provides a knowledge base from which to start researching the sequestration implications of CO_2 EOR. Another benefit of CO_2 EOR for sequestration purposes is the widespread distribution of depleted and operating oil and gas fields, making it likely that an oil field is near a CO_2 source. Finally, carbon sequestration from CO_2 EOR projects can create offsets resulting in trades in the emerging greenhouse gas market. CO_2e.com has conducted a transaction between Ontario Power Generation and Bluesource. The forward purchase of 6 million tonnes of CO_2 equivalent and option for an additional 3 million tonnes of CO_2 equivalent resulted from geologic sequestration projects in Texas, Wyoming, and Mississippi, where CO_2 that would otherwise be vented by natural gas processing plants is used for enhanced oil recovery.

Industries Activities

CO_2 is specifically processed for most of the 82 projects utilizing CO_2 for EOR (Moritis, 2006). The CO_2 for these projects is mined from naturally occurring, high-pressure deposits that occur close enough to oil fields to make transmission economically feasible. The following table lists DOE-sponsored projects that utilize anthropogenic CO_2 for EOR and additionally promote GHG reduction, since this CO_2 would otherwise be vented to the atmosphere.

Table 1. Examples of DOE- Sponsored CO_2 Sequestration Projects in the U.S. Involving EOR

EOR Field	CO_2 Source	Geological Stratum	Injection Start Date	Cumulative CO_2 Injection	Description
Zama Field, Alberta, Canada	Natural Gas Processing Plant	Pinnacle Reef, Middle Devonian Keg River	December 2006	230,000 tons	The Zama oil field validation test being conducted in Alberta, Canada, is evaluating the potential for geologic sequestration of CO_2 in an acid gas stream that also includes high concentrations of hydrogen sulfide (H_2S) for the concurrent purposes of CO_2 sequestration, H_2S disposal, and EOR. The acid gas is generated as a by-product during the processing of raw natural gas being extracted from the field.
Williston Basin	Pulverized Coal Power Plant	Devonian Duperow or Mississippian Madison Group	2011	500,000 tons/year	The Williston Basin demonstration test will evaluate the potential for geological sequestration of CO_2 in a deep carbonate reservoir for the dual purpose of CO_2 sequestration and EOR. Characterization studies indicate that the oil fields of the Williston Basin may have over 1 billion tons of CO_2 storage capacity. Additionally, the volume of incremental oil that could be produced from Williston Basin oil fields has been estimated to be approximately 1 billion barrels.
Louden Field, Illinois	Refinery or Ethanol Plant	Mississippian Weiler Sandstone	March 2007	43 tons	The Louden field test, an enhanced oil recovery "huff-n-puff" project, is designed to inject (huff) CO_2 into a producing well for 3-5 days, allow the gas to soak for approximately one week, then place the well back on production and measure the amount of petroleum fluids produced (puff).
Louden Field, Illinois	Refinery or Ethanol Plant	Mississippian Weiler Sandstone	February 2008	2,500 tons	The well conversion EOR field test does not require the drilling of any new wells because available well(s) will be converted to handle CO_2 injection and the pattern and spacing of existing wells is adequate to test EOR processes in the reservoir. Well conversion represents a potential near-term, low-cost opportunity to implement EOR.
Snyder, Permian Basin, Texas	McElmo Dome	Strawn- and Canyon-age carbonate reefs	Second Quarter 2008	700,000 tons	This test will include a post-audit modeling analysis of injected CO_2 for EOR over the last 30 years at the SACROC Unit in the Permian Basin of Texas, in addition to intense monitoring analyses of ongoing CO_2 injection at SACROC.
Aneth Oil Field, Bluff, Utah	McElmo Dome	Paradox Formation, Pennsylvanian Desert Creek	Second Quarter 2007	300,000 tons	The primary research objective of this EOR-sequestration test is to evaluate and maximize the efficacy of CO_2 subsurface monitoring technologies, and to improve the ability to track the fate of injected CO2 and to calculate ultimate storage capacity.
Weyburn, Saskatchewan	Dakota Gasification Plant	The Midale Beds of the Mississippian Charles Formation,	September 2000	33 million tons	The Weyburn program is organized around five technical themes: geological integrity, wellbore integrity, storage monitoring methods, risk assessment and storage mechanisms, and data validation and management. The technical objectives are to determine the long-term storage risks and monitoring requirements to mitigate such risks.

Source: National Energy Technology Laboratory

Conclusions

CO_2 EOR is a promising technology to safely store CO_2 underground so that it cannot contribute to climate change. While this technology has been implemented by the oil industry since 1972, further research is needed to ensure that the stored CO_2 remains isolated from the atmosphere and the biosphere on the order of thousands of years and that the storage process remains as safe and economically viable as possible.

DOE's Carbon Sequestration Program is currently addressing the following challenges:

- Improving understanding of oil reservoir characteristics relative to CO_2 fate and transport
- Reducing the costs of capturing, processing, and transporting anthropogenic CO_2, particularly from power generation facilities
- Further developing technologies to monitor and verify CO_2 storage, and
- Developing CO_2 emissions trading protocols.

For more information about how the research program is specifically addressing CO_2 EOR, visit the National Energy Technology Laboratory's Carbon Sequestration Reference Shelf at http://www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html.

Bibliography

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ADDRESS

National Energy Technology Laboratory
1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

2175 University Avenue South
Suite 201
Fairbanks, AK 99709
907-452-2559

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

One West Third Street,
Suite 1400
Tulsa, OK 74103-3519
918-699-2000

CUSTOMER SERVICE

1-800-553-7681

WEBSITE

www.netl.doe.gov