CCS

inFocus

Carbon Capture & Storage

What is Carbon Utilization?

ADDRESSING A GLOBAL ENVIRONMENTAL CHALLENGE LIKE CLIMATE CHANGE REQUIRES A BROAD-BASED STRATEGY TO ENSURE LONG-TERM SUSTAINABILITY. A KEY ELEMENT IN SUCH A STRATEGY IS CARBON DIOXIDE (CO_2) UTILIZATION—BASICALLY "RECYCLING" THE CO_2 EMITTED AND CAPTURED FROM POWER GENERATION AND INDUSTRIAL FACILITIES INTO VALUABLE PRODUCTS AND USES. THROUGH PHYSICAL, CHEMICAL, TECHNICAL AND ENHANCED BIOLOGICAL PROCESSES, CO_2 UTILIZATION CAN HAVE SIGNIFICANT ENERGY, ECONOMIC AND ENVIRONMENTAL BENEFITS, AND IS AN IMPORTANT COMPONENT IN ACHIEVING THE WIDESPREAD COMMERCIAL DEPLOYMENT OF CARBON CAPTURE AND STORAGE (CCS) TECHNOLOGY.

OVERVIEW

Fossil fuels will remain the dominant source of energy around the world through at least 2035 and perhaps longer.[1] But combustion of fossil fuels generates carbon dioxide, the largest single source of greenhouse gas (GHG) emissions.[2] Consequently, strategies to address the challenge of climate change have largely focused on developing cost-effective technologies to capture and safely and permanently store CO_2 while improving power and industrial plant efficiencies.

However, finding beneficial ways to "use" in addition to permanently storing this emitted carbon dioxide has received increased global attention as one of a portfolio of options for helping reduce human-generated CO_2. This augmentation changes CCS to Carbon Capture, Utilization and Storage (CCUS). One reason for this is that utilization has the potential to reduce CO_2 emissions by at least 3.7 gigatons per year (Gt/y),[3] equal to about 10 percent of the world's current annual emissions. Another is that it can result in value-added products that create jobs and economic benefits, and help offset the cost of implementing CCS technologies. For example, in the case of enhanced oil (EOR) and natural gas recovery (EGR), carbon dioxide

"Mainland Europe, and in particular Germany, the U.S. and Australia, are well advanced in research and development of [carbon utilization] technologies. Substantial investment has been made . . . by extending CCS (carbon capture and storage) technology, to incorporate utilization in addition to storage."

Source: "Carbon Capture and Utilization in the Green Economy, Centre for Low Carbon Futures 2050, July 2011, Executive Summary, page 1.

Did You Know?

[1] "International Energy Outlook 2011," U.S. Energy Information Administration, Sept. 2011, Highlights, page 1.

[2] "Carbon Dioxide Utilization: Electrochemical Conversion of CO_2—Opportunities and Challenges," DNV, January 20, 2011, available at: http://www.dnv.com/resources/position_papers/co2utilisation.asp.

[3] The International Energy Agency (IEA) estimates a record 30.6 gigatons of carbon dioxide were emitted into the atmosphere in 2010; see "Highest Ever Annual Carbon Emissions Leave World in Trouble," available at: http://www.the9billion.com/2011/05/29/highest-ever-annual-carbon-emissions-leave-world-in-trouble-says-iea/.

utilization not only helps produce additional quantities of otherwise unavailable energy resources, but also can provide permanent and safe geological CO_2 storage.

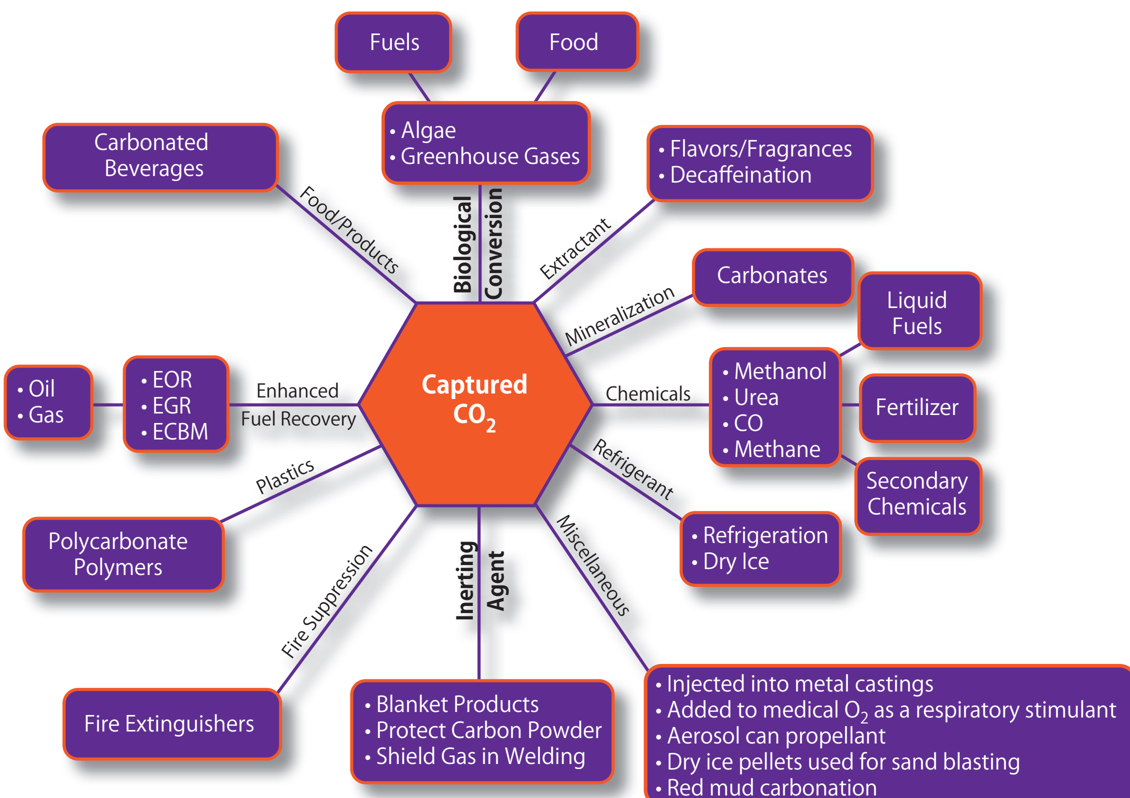
Some utilization technologies, such as EOR, are already proven and viable. Others—including converting CO_2 into fuel, cement, minerals and plastics; enhanced fixation into fast-growing biomass; and using it as a feedstock for chemicals—are at various stages of development. While permanent geologic CO_2 storage remains a central goal, a strategy of greater use of existing processes like EOR, and greater investment in those still in the research and development (R&D) phase, will help fulfill the immense potential of carbon utilization. Realizing this potential will help CCUS contribute toward a climate change solution while providing additional jobs and economic benefits for developed and developing countries alike.

Carbon Utilization Pathways

Although carbon dioxide is commonly used in the food and beverage industries, CCUS is directed toward utilization of an entirely different type—capturing CO_2 from power and industrial plants and developing beneficial uses. This achieves two goals: Reducing atmospheric carbon dioxide emissions that many scientists believe contribute to an enhanced greenhouse effect and possible climate change; and creating products, jobs and revenues that can offset a portion of the cost of capturing CO_2.

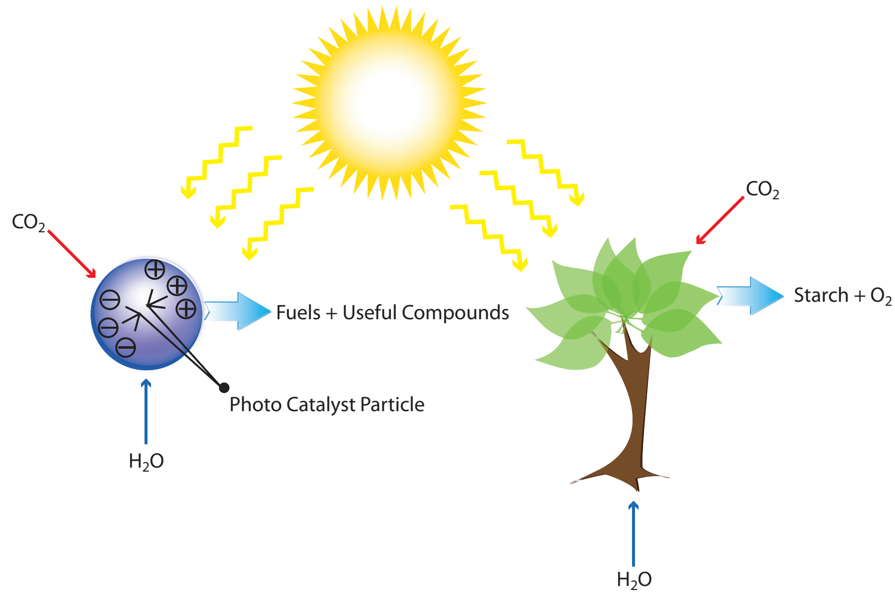
Key to this innovative approach is ensuring that additional CO_2 for each process is not produced beyond what is already being removed from or going into the atmosphere. Additionally, each potential CO_2 use has an energy requirement that needs to be determined—the CO_2 produced to create the energy for the specific utilization process must not exceed the carbon dioxide utilized.

The diagram below illustrates most of the varied and plentiful current and potential uses of CO_2. Some are small scale and result in no net CO_2 reduction; others, such as EOR, end up in significant, permanent CO_2 removal while also producing large quantities of a valuable end product (in this case, otherwise "stranded" oil resources).



Source: U.S. National Energy Technology Laboratory

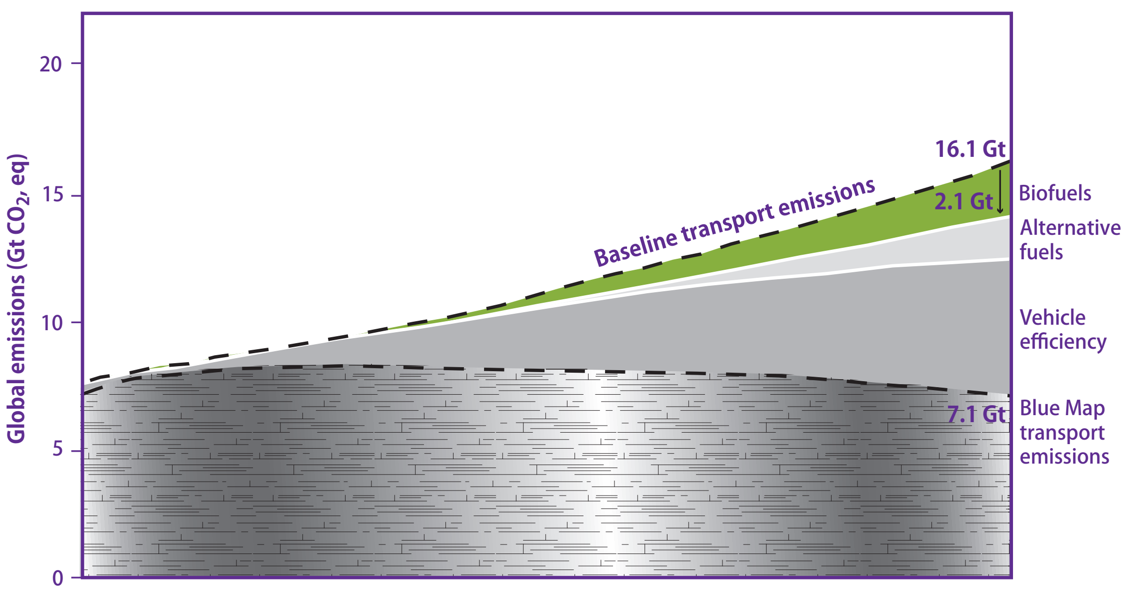
In general, CO_2 utilization falls into one of three major pathways: **converting** CO_2 into fuel; using it as a **feedstock** for chemicals; and **non-conversion** use, such as enhanced oil recovery.



A semi-conductor such as titanium oxide (TiO2) can be used as a manmade photo catalyst to convert CO_2 into fuels and other useful materials. (Source: U.S. National Energy Technology Laboratory, "High Efficiency Solar-Based Catalytic Structure for CO_2 Reforming," page 2).

Converting CO_2 into Fuel: The conversion of CO_2 into fuels results in one of the few products that can be produced on a quantity scale comparable to carbon dioxide emissions. There are several promising solutions for completing this conversion, including photo catalysts, electrochemical conversion and creating bio-renewable fuels and materials from algae. For example, research is investigating converting CO_2 into carbon monoxide (CO), which is a building block for fuels. Through the addition of other processes, the CO can be used to produce other marketable chemicals. A **photo catalyst** is a material that speeds up a chemical reaction when subjected to sufficient light energy. It can be engineered to be more efficient than photosynthesis, where current rates of sunlight conversion are less than 1–3 percent, and can be used to reform CO_2 into fuels and other useful materials. Research is also looking at the use of **micro-algae** in open ponds or **photo-bioreactors** for CO_2-to-fuel conversion.

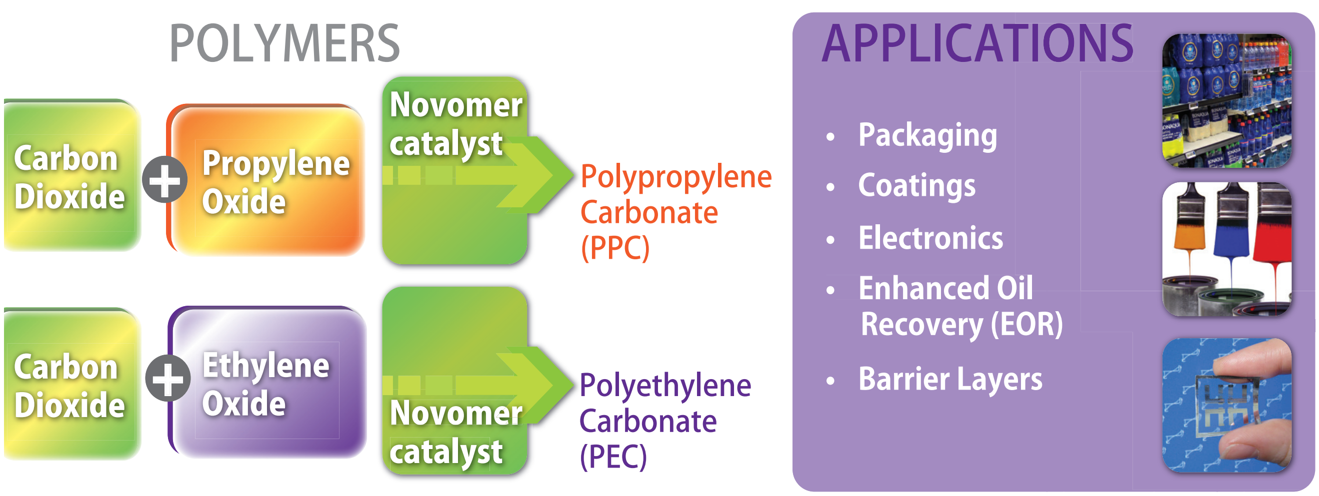
Contribution Of Biofuels To Greenhouse Gas Emissions Reduction In The Transport Sector



Note: Modal shifts (not included) could contribute an additional 1.8 Gt CO_2, eq of emission reductions. Source: International Energy Agency, "Technology Roadmap: Biofuels for Transport," page 22.

The Potential is Immense: The International Energy Agency projects that by 2050, use of biomass-based sources for transportation fuel will grow from around 2 percent of total transport fuel today to 27 percent, or 32 exajoules (equal to 1018 joules, a derived unit of energy equal to the work required to produce one watt of power for one second).[4] The projected use of biofuels could avoid around 2.1 gigatons of CO_2 emissions per year when produced sustainably.[5] In addition to generating biomass, CO_2 can be converted via chemical and electro-chemical processes to other energy storage chemicals, such as syngas, formic acid, methane, ethylene, methanol and dimethyl ether.

Using CO_2 as a Chemical Feedstock: Utilizing renewable energy sources and water, carbon dioxide can be converted into building block chemicals and used as a source material for manufacturing commodity chemicals. CO_2 is already used in the chemical industry for synthesis of organic compounds, such as urea (nitrogen fertilizer manufacture), salicylic acid (pharmaceutical ingredient), methanol, cyclic carbonates, and poly carbonate-based plastics. This utilization consumes about 115 million tons of CO_2 annually worldwide,[6] a small amount compared to annual global carbon dioxide emissions of slightly more than 30 billion metric tons.[7] However, CO_2 recycling and conversion to chemicals is expected to increase from about 0.5 percent of carbon dioxide emissions at present to 1–2 percent of emissions in the future.[8] The potential for increasing CO_2 use as a chemical feedstock is considered significant and complementary to CCS operations. At present, pilot scale technologies can only take a slipstream from the main flue gas supply, but have the potential and economic viability to be scaled-up. Continuous flow reactor technology and the development of new active and selective catalysts will need to be developed to expand the role of this important CCUS option. CO_2 can also be converted into inorganic minerals (through electro-chemical reactions) that can be used in building materials. For example, the U.S. National Energy Technology Laboratory is investigating



CO_2 can be converted into building block chemicals and used as a source material for manufacturing commodity chemicals. For example, this diagram details Novomer's proprietary catalyst system that transforms waste carbon dioxide into high performance, low cost polymers for a variety of applications. These polymers contain up to 50 percent CO_2 by mass, in effect permanently sequestering the carbon dioxide from the environment while resulting in useful products. Source: http://www.novomer.com/?action=CO_2

[4] "Technology Roadmap, Biofuels for Transport," International Energy Agency, April 2011, Foreword, page 1.

[5] "Technology Roadmap, Biofuels for Transport," International Energy Agency, April 2011, Key Findings, page 5.

[6] "The Carbon Dioxide Capture and Conversion (CO_2CC) Program," The Catalyst Group Resources, May 2011, p. 7.

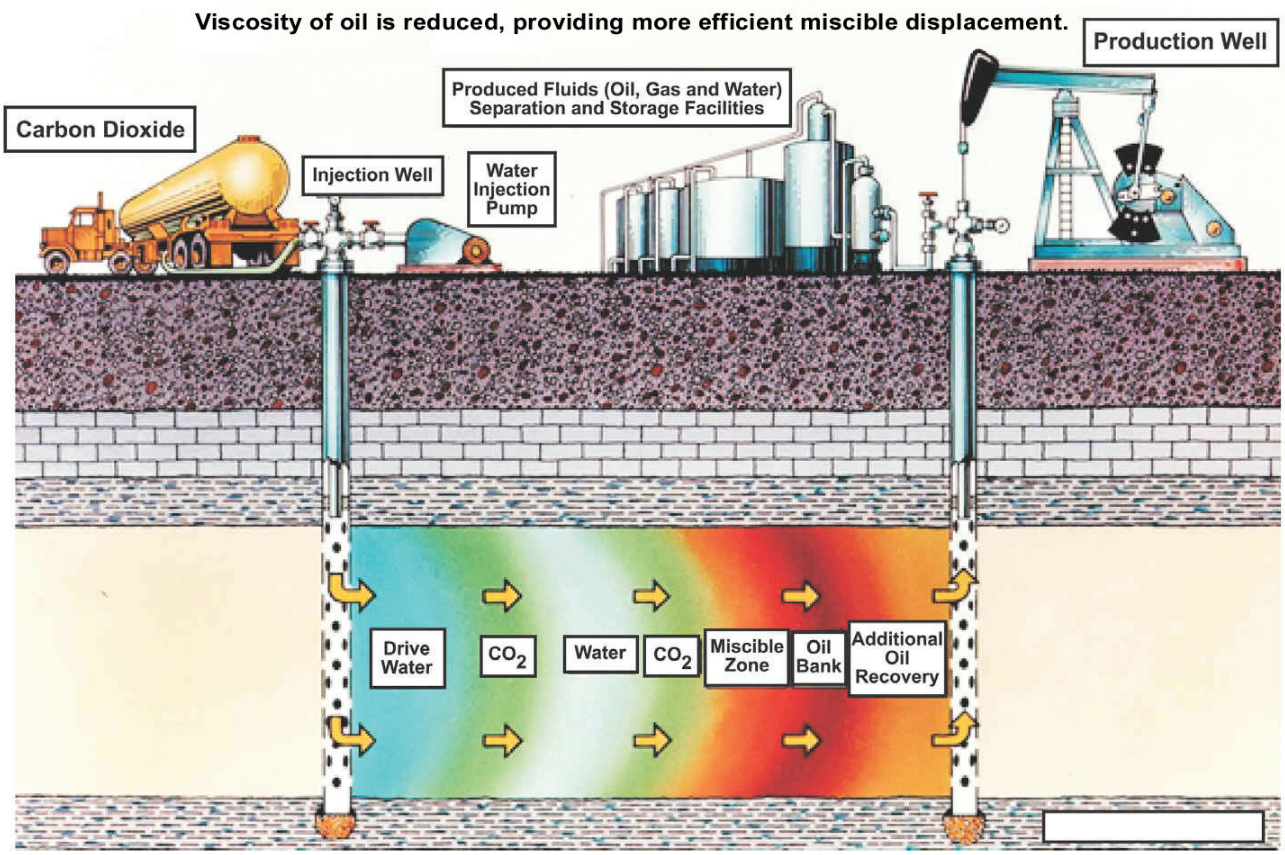
[7] "International Energy Outlook 2011," U.S. Energy Information Administration, September 2011, page 139.

[8] "The Carbon Dioxide Capture and Conversion (CO_2CC) Program," The Catalyst Group Resources, May 2011, p. 7.

efficient ways to integrate CO_2 in the production of Portland cement and other products. Initial estimates suggest that even if 10 percent of the world's building materials were to be replaced by such a source, consumption of 1.6 gigatons annually of CO_2 would result.[9]

Non-Conversion CO_2 Use: Enhanced oil recovery with carbon dioxide injection is a well established technology (see inFocus: Is Geologic CO_2 Storage Safe? and inFocus: Underground CO_2 Storage: A Reality?). In the United States, which accounts for 94 percent of worldwide CO_2/EOR production, CO_2 has been safely and permanently injected underground for commercial enhanced oil recovery operations for decades; about 63 million metric tons of mostly naturally produced carbon dioxide are injected annually for this purpose.[10] Three large-scale projects—Sleipner in Norway, Weyburn in Canada and In Salah in Algeria—have been injecting and successfully storing 1 million to 3 million metric tons of CO_2 annually for several years. In addition, the Cranfield project in the United States has injected more than 3 million metric tons of CO_2 into permanent storage in a depleted oil field over the past two years. These projects have allowed scientists to acquire the data needed to validate the capacity and potential impact of geologic CCS.

HOW CO_2/EOR WORKS



Cross-section illustrating how carbon dioxide and water can be used to flush residual oil from a subsurface rock formation between wells. Source: "Carbon Dioxide Enhanced Oil Recovery," U.S. Department of Energy, National Energy Technology Laboratory, March 2010, page 5.

[9] "Carbon Dioxide Utilization: Electrochemical Conversion of CO_2 – Opportunities and Challenges," DNV, January 20, 2011, page 5, available at: http://www.dnv.com/resources/position_papers/co2utilisation.asp.

[10] "The Role of Underground CO_2 Accumulations in the Emergence of CO_2 Enhanced Oil Recovery," U.S. Department of Energy, National Energy Technology Laboratory, June 2011, Executive Summary, page 1.

Enhanced Oil Recovery—the U.S. Experience

- Accounts for 94 percent of global CO_2/EOR production.
- A nearly 40-year record of safe and environmentally secure operation.
- According to the American Petroleum Institute, the U.S. oil and gas industry operates over 13,000 CO_2/EOR wells, 3,500 miles of high pressure CO_2 pipelines, and has injected a total of more than 600 million tons of CO_2.
- Approximately 63 million metric tons of CO_2 injected annually for EOR.
- About 5 percent of U.S. annual crude oil production—281,000 barrels per day – comes from CO_2 injection.
- Economic recovery of 62 billion barrels of crude oil possible with existing EOR (more with accelerated EOR); would sequester 20 billion metric tons of CO_2, 90 percent of which would come from coal-based power and industrial plants.
- Potential recovery of 137 billion barrels with advanced EOR technology.

Source: U.S. Department of Energy

At present, CO_2/EOR is the only commercially viable technology for CCS and has the potential to be greatly expanded, enhancing efforts to reduce CO_2 emissions while enabling additional hydrocarbon recovery from mature fields, and encouraging additional job creation and economic activity. The logical source to obtain large quantities of CO_2 for expanding CO_2/EOR worldwide would be from power plants and industrial facilities, making this utilization method an important component of strategies to mitigate human-generated GHG emissions. In the United States alone, where 5 percent of annual crude production already comes from CO_2 injection,[11] it is estimated an additional 67 billion barrels at a minimum could be recovered with accelerated enhanced oil recovery.[12] Similarly, a study by Durham University of the net worth of the United Kingdom's North Sea oil fields indicated they could yield an additional 3 billion barrels over the next 20 years.[13] An estimate made for Norway indicates EOR can increase ultimate oil production by 300 million cubic meters (m3), or about 10 percent of production to date plus the remaining reserves.[14] Reflecting the importance of CO_2/EOR, the International Energy Agency (IEA) sponsors an implementing agreement on enhanced oil recovery. This group meets once a year to hold a two-day symposium and one-day workshop to foster bilateral conversations from the perspectives of various nations as well as encourage international research on EOR projects. According to IEA, CO_2/EOR can enhance oil production substantially, with additional recovery amounting to 5 to 20 percent of the total quantity of original oil in place, thus increasing total recovery for an average field by as much as 50 percent.[15] IEA notes that estimates of the cumulative global storage capacity potential varies from a few gigatons of CO_2 to several hundred gigatons, but in

[11] "Annual Energy Outlook 2010," U.S. Energy Information Administration.

[12] "Improving Domestic Energy Security and Lowering CO_2 Emissions with Next Generation CO_2-Enhanced Oil Recovery, U.S. Department of Energy, National Energy Technology Laboratory, 2011, page 4.

[13] "North Sea Oil Recovery Using Carbon Dioxide is Possible, but Time is Running Out, Expert Says," Yahoo Science Wordpress, January 13, 2011.

[14] "CO_2 Capture and Storage: A Key Carbon Abatement Option," International Energy Agency, 2008, page 92.

[15] Ibid.

a study matching carbon dioxide sources and sinks, 420 early opportunities for CO_2/EOR projects were identified, "where capture sources and depleted oil fields were within 100 km (kilometers) of each other and EOR could start relatively soon. Assuming approximately one million ton CO_2 storage per year per project, this suggests almost 0.5 Gt per year of storage potential."[16] In addition to Europe, North America and China, other regions with the largest potential for CO_2/EOR include the Middle East, the former Soviet Union, West Africa and South America.[17] IEA notes that while CO_2/EOR technology is considered mature, continued research is needed to "extend the application of the relevant technologies and to improve their performance. Particular attention needs to be given to developing CO_2/EOR case studies in offshore environments, as there have been none to date."[18] IEA added that many projects are held back by other challenges, including uncertain economics, the lack of appropriate fiscal and legal regimes, the lack of engineering resources, and the lack of infrastructure (such as pipelines for transportation). The bottom line, however, is that CO_2/EOR has a potential for 5–6 million barrels per day of production by 2030, and "lifting a number of the barriers . . . will increase the rate of uptake."

Sources for Additional Information

- United Nations Intergovernmental Panel on Climate Change, http://www.ipcc.ch/
- International Energy Agency, http://www.iea.org/
- World Coal Institute, http://www.worldcoal.org/
- The World Bank, http://www.worldbank.org/
- Zero Emissions Platform, http://www.zeroemissionsplatform.eu/
- Global CCS Institute, http://www.globalccsinstitute.com/

Other inFocus Factsheets:

- Is Geologic CO_2 Storage Safe?
- Underground CO_2 Storage: A Reality?
- Why Carbon Capture and Storage?
- CO_2 Transportation — Is it Safe and Reliable?
- CO_2 Capture – Does it Work?
- 10 Facts About CCS

[16] Ibid, page 93.

[17] Ibid, page 94.

[18] Ibid, page 96.