CCS
inFocus
Carbon Capture & Storage

CO_2 Capture — Does it Work?

The process of capturing carbon dioxide (CO_2) from plant emissions is already a physical reality on a small scale. Current research efforts are focused on systems for capturing CO_2 from large coal-based power plants, because they are the largest stationary sources of CO_2 emissions. The ongoing research and development (R&D) challenge is capturing CO_2 from these facilities in a way that is both efficient and also maintains affordable prices for electricity. Additionally, R&D is also focused on applying carbon capture and storage (CCS) to natural gas-fired power plants and industrial sources. Additional research that includes integrating and scaling up CCS technology by building and operating commercial-scale facilities in a variety of settings is essential for meeting R&D challenges.

Overview

CO_2 capture technology is not new or particularly unique — it has long been used by industry to remove CO_2 from gas streams where it is not wanted, or to separate CO_2 as a product gas.[1] What is novel about it in terms of the climate change debate is the research effort to integrate and optimize existing and emerging technologies for the purpose of reducing human-made atmospheric CO_2 emissions. CCS is a combination of technologies for not only capturing, but also transporting and storing CO_2 emissions from fossil fuels.

The carbon capture process has been used for several decades in the petroleum, chemical, and power industries for a variety of reasons relevant to those industrial processes.[2] Capturing all, or even just three-fourths, of the CO_2 in a typical power plant with current technology would require equipment many orders of magnitude larger — a very expensive and highly energy-intensive option.

> "New or improved technologies for CO_2 capture, combined with advanced power systems and industrial process designs, can significantly reduce the cost of CO_2 capture in the future."
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> United Nations Intergovernmental Panel on Climate Change, Carbon Capture and Storage (2005), 344.
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> Did You Know?

Worldwide, there are today several operational large-scale projects, along with numerous smaller facilities, demonstrating specific elements of the carbon capture process. According to the Global CCS Institute, at the end of 2010 there were 234 active or planned CCS projects globally, identified across a range of technologies, project types

[1] OECD/IEA, "Technology Roadmap: Carbon Capture and Storage," 2009, 9.

[2] National Energy Technology Laboratory, "Carbon Sequestration: FAQ Information Portal," n.d., http://www.netl.doe.gov/technologies/carbon_seq/faqs/carbon-capture.html.

and sectors. Of these, 77 are large-scale integrated projects at various stages of development. Combined, these efforts have successfully demonstrated CCS as a technically feasible CO_2 mitigation technology.[3] However, there are no fully integrated, commercial-scale power plants in operation equipped with CCS. Continued research is needed to aggressively pursue the development of low-CO_2 technologies and deploy cost-competitive CCS for both new and existing plants.

How is CO_2 captured from power plants?

Energy from fossil fuels (coal, oil, and natural gas) is released in the combustion (burning) process. The same chemical reaction that allows fossil fuels to release energy upon combustion also results in the emission of CO_2 as a by-product of the combustion process. In pulverized coal systems, which make up the vast majority of America's existing fleet of coal-based power plants, the CO_2 must be separated at fairly diluted concentrations from the balance of the combustion flue gases; in other systems, such as coal gasification, it can be more easily separated. After separation, the CO_2 is compressed to a liquid-like state (called a "supercritical fluid"), transported (usually by pipeline) to an injection well, and then pumped underground into a secure and continuously monitored geologic storage area, the final stage in the CCS process.

There are three basic types of CO_2 capture: post-combustion, pre-combustion, and oxy-combustion.

- **Post-combustion processes** separate CO_2 from combustion exhaust gases. CO_2 can be captured using a liquid solvent, such as aqueous amine solution. Once absorbed by the liquid solvent, the CO_2 is then released by heating to form a pure CO_2 stream. This technology is widely used to capture CO_2 for use in the food and beverage industry. Post-combustion capture has been carried out successfully, but so far on a relatively small scale.
- **Pre-combustion processes** convert fuel into a gaseous mixture of hydrogen and CO_2. The hydrogen is then separated and can be burned without producing any CO_2 in the exhaust gas. The remaining CO_2 can then be compressed for transport. Compared with post-combustion processes, the pressure and concentration of CO_2 in pre-combustion processes is relatively high — making separation easier to achieve and offering the potential to apply novel capture technologies, such as membranes. The fuel conversion steps required for pre-combustion are more complex than the processes involved in post-combustion. This makes the technology more difficult to apply to existing power plants. Pre-combustion capture is used in industrial processes but has not been demonstrated in much larger coal gasification concepts.
- **Oxyfuel combustion processes** use oxygen rather than air for combustion of fuel. This produces exhaust gas that is mainly water vapor and CO_2, which are easily separated to produce a pure CO_2 stream. Oxyfuel combustion systems are being developed on a small scale, in laboratory or pilot projects. This process can be applied to existing power plants.

Is CO_2 currently being captured from plants that generate electricity from coal?

No one is currently capturing CO_2 at full scale from plants that generate electricity from coal. However, there are a few CO_2 capture applications at coal-fired plants at small scale. Post-combustion separation processes (amine scrubbers) are currently used commercially in industrial coal-fueled boilers to supply CO_2 to food and beverage processors and in chemical industries, but these applications are at a scale much smaller than that needed for power-producing pulverized coal or Circulating Fluidized Bed (CFB) plants. CO_2 separation processes suitable for Integrated Gasification Combined Cycle (IGCC) plants are used commercially in the oil and gas and chemical industries at a scale close to that ultimately needed, but their application requires the addition of more processing equipment to an IGCC plant and the deployment of gas turbines that can burn nearly pure hydrogen.

[3] World Coal Institute, "Securing the Future: Financing Carbon Capture and Storage in a Post-2012 World," November 2009, 5.

Can CO_2 be captured from all types of plants that generate electricity from coal?

It is technically feasible to integrate CO_2 capture technologies into all types of new coal-based power plants. However, CCS represents a significant financial investment; cost has been identified as perhaps the greatest single hurdle to CCS deployment.[4] The cost of CO_2 capture using currently available technology is very high — on the order of \$100–\$150 per tonne of CO_2 avoided for first-of-a-kind plants and \$30–\$50 per tonne of CO_2 avoided for n^{th}-of-a-kind plants.[5] A new coal-fired plant can be designed to incorporate CCS from the very beginning, or it can be built to include upfront investments that lower the cost of later adding the technology. Retrofitting existing plants for CCS is expected to be more expensive (in terms of dollars per tonne of CO_2 avoided and the incremental impact on the levelized cost of electricity). The incremental cost of CCS varies depending on the choice of capture technology, the percentage of CO_2 captured, the type of coal used, and the distance to and from the geologic storage area. Capture technologies can also be retrofitted to existing power plants but at an even higher cost and provided that sufficient space is available for the equipment. There are also significant integration and engineering considerations that need to be addressed.

Are there any other technical challenges?

All capture systems currently require large amounts of energy for their operation, resulting in decreased plant efficiencies and reduced net power outputs when compared to the same plants without CCS. These "penalties" mean commercially available CCS technologies would add around 80 percent to the cost of electricity for a new pulverized coal plant and around 35 percent to the cost of electricity for a new advanced gasification plant.[6] Research is aggressively pursuing ways to reduce these costs to less than a 10 percent increase in the cost of electricity for new gasification-based energy plants, and less than a 30 percent increase in the cost of electricity for traditional pulverized coal plants. In addition, research is attempting to identify "best practices" that researchers and technology users believe will allow consistently safe and effective long-term CO_2 collection, injection, and storage and provide the basis for a consistent global legal and regulatory framework.

Where does carbon capture technology go from here?

Carbon capture has been clearly demonstrated on a small scale — the vital next step is the successful demonstration of fully integrated, large scale CCS systems on commercial-size power generating stations. There is a global need for significant financial investments to bring numerous commercial-scale demonstration projects on-line in the near future.

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[4] Bryan Hannegan, VP Environment, Electric Power Research Institute, "Future of Coal: Testimony before the U.S. Senate Committee on Energy and Natural Resources," 22 March 2007, 3, 5.

[5] Mohammed A. Al-Juaied and Adam Whitmore, "Realistic Costs of Carbon Capture," Belfer Center for Science and International Affairs, July 2009.

[6] Scott M. Klara, National Energy Technology Laboratory, "Testimony before the U.S. Senate Committee on Appropriations, Subcommittee on Energy and Water Development," 6 May 2009, 3–4, 10–11.

Interesting Facts About Carbon Capture

- One million tonnes of captured CO_2 (in a super-critical liquid state) every year would nearly fill the volume of the Empire State Building in New York City (32 million cubic feet, or 906,000 cubic meters) — source: U.S. National Energy Technology Laboratory (NETL).
- Worldwide there are 234 planned or active CCS projects, 77 of which are large integrated projects in various stages of development — source: Global CCS Institute.
- A 500 megawatt pulverized coal-fired plant produces about 10,000 tons per day of CO_2; a 1000 MW plant emits 6–8 megatonnes (one megatonne = 1 million metric tons) annually — source: Carbon Dioxide Capture and Storage, Howard Herzog, Massachusetts Institute of Technology, pages 265 and 268.
- Total global CO_2 emissions resulting from human activity are currently around 24 gigatonnes per year; the CO_2 storage capacity of hydrocarbon (coal, oil, and gas) reservoirs is estimated to be around 800 gigatonnes (one gigatonne = 1 billion tonnes). The world's deep saline formations may have a storage capacity far greater than this — source: International Energy Agency, Storing CO_2 Underground, page 10.
- Globally there are more than 8,100 CO_2 point sources (primarily fossil fuel electric power plants and industrial facilities) that could conceivably adopt CCS technologies as a means for delivering deep and sustained CO_2 emissions reductions. Collectively these facilities emit about 15 gigatonnes (gigatonne = 1 billion tonnes) of CO_2 annually — source: Global Energy Technology Strategy Program, Carbon Dioxide Capture and Geologic Storage, page 13.
- Governments and businesses need to invest as much as USD $3.4 trillion in 3,400 carbon capture projects worldwide by 2050 as just one measure to cut fossil fuel CO_2 emissions by half from 2005 levels — source: International Energy Agency.

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/
- European Zero Emissions Platform, http://www.zeroemissionsplatform.eu/

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?
- 10 Facts About CCS

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