Quick Facts

- Carbon capture and storage (CCS) uses a combination of technologies to capture, transport, and store carbon dioxide (CO_2) emissions from the use of fossil fuels.
- While the component technologies are currently used on industrial scales, CCS has not yet been deployed at a commercial-scale power plant, but it could be incorporated into the construction of future power plants or added as retrofits to existing power plants.
- Carbon dioxide emissions from coal-fueled power plants account for significant amounts of U.S. and global emissions; CCS could help achieve dramatic reductions in CO_2 emissions from the electricity sector.

Background

Coal is a major source of energy both in the United States and globally, and it is abundant and inexpensive. However, coal consumption releases large amounts of CO_2, the primary greenhouse gas (GHG). CCS is a technology that has the potential to yield dramatic reductions in CO_2 emissions from coal use by capturing the CO_2 that is currently released to the atmosphere.

In 2006, the United States generated roughly half of its electricity from coal, and the CO_2 emissions from coal-fueled electricity generation accounted for 83 percent of CO_2 emissions from the U.S. electricity sector and 27 percent of all U.S. GHG emissions.[1,2] Coal is five to ten times less expensive than natural gas or petroleum, and the United States has enough coal to meet current consumptions for hundreds of years.[3] Coal releases nearly twice as much CO_2 per unit of energy compared to natural gas.[4]

Given the extensive use of coal, the large amount of GHG emissions associated with coal-fueled electricity generation, and the high CO_2 emissions rate of coal, CCS coupled with coal-fueled power generation has the potential to significantly reduce GHG emissions. The high capital costs and economies of scale of CCS make large power plants attractive targets for CCS deployment.[5] However, to date, CCS has not been deployed at any commercial-scale coal-fueled power plant.

Description

CCS uses a combination of technologies to capture the CO_2 released by fossil fuel use, transport the CO_2 to a suitable storage location, and store the CO_2 (typically deep underground) where it cannot enter the atmosphere and, thus, does not contribute to climate change. The current status of these different technologies varies and is discussed further below.

Given the magnitude of CO_2 emissions from coal use for electricity and the opportunity for economies of scale, the greatest potential for CCS is with coal-fueled power plants. Three primary methods are discussed for CO_2 capture from coal-fueled power plants:

- **Pre-Combustion Carbon Capture**
  Coal is gasified (rather than combusted) to produce a synthesis gas, or syngas, consisting mainly of carbon monoxide (CO) and hydrogen (H_2). A subsequent shift reaction converts the CO to CO_2, and then a physical solvent typically separates the CO_2 from H_2.

  For power generation, pre-combustion carbon capture can be combined with an integrated gasification combined cycle (IGCC) power plant that burns the H_2 in a combustion turbine and uses the exhaust heat to power a steam turbine.

- **Post-Combustion Carbon Capture**
  Post-combustion capture typically uses chemical solvents to separate CO_2 out of the flue gas of a pulverized coal (PC) power plant.

- **Oxyfuel Carbon Capture**
  Oxyfuel capture requires combustion of coal in pure oxygen (rather than air) so that the exhaust gas is CO_2-rich, which facilitates capture.

Once captured, CO_2 must be transported from its source to a storage site. Pipelines like those used for natural gas present the best option for terrestrial CO_2 transport.

The primary option for storing captured CO_2 is injecting it into geologic formations deep underground, including:

- **Deep Saline Formations**
  The largest potential for geologic storage in the United States is in deep saline formations, which are underground porous rock formations infused with brine.[6] The United States has geological formations sufficient to safely and indefinitely store CO_2 from centuries of continued coal use.[7]

- **Enhanced Oil Recovery Using CO_2 (CO_2-EOR)**
  CO_2-EOR involves the injection of CO_2 into oil wells to increase the amount of oil that can be extracted. West Texas and the Gulf Coast have a 30-year history of CO_2-EOR. There is significant potential for use of captured CO_2 in EOR, and revenue from selling captured CO_2 to EOR operators could help defray the cost of CCS as power plants adopt the technology.[8]

Environmental Benefit / Emission Reduction Potential

CCS technology has the potential to reduce CO_2 emissions from a coal-fueled power plant by as much as 90 percent.[9] CCS is forecast to provide significant CO_2 emission reductions:

- The U.S. Environmental Protection Agency's (EPA) modeling analysis of the Lieberman-Warner Climate Security Act of 2008 projected that, under the proposed cap-and-trade program, power plants with CCS would provide 28 percent and 38 percent of all U.S. electricity by 2030 and 2050, respectively.[10]

- Modeling done by the International Energy Agency (IEA) forecasts that CCS could provide 20 percent of total global GHG emission reductions by 2050.[11]

Cost

New coal-fueled power plants (PC or IGCC) can be designed to incorporate CCS from the start of their operation, and existing plants can be retrofit for CCS. Retrofitting existing plants for CCS is expected to be more expensive (in terms of dollars per metric ton of CO_2 avoided and the incremental impact on the levelized cost of electricity) than building new plants to incorporate CCS from the start.[12] New coal plants built without CCS can include upfront investments that lower the cost of later retrofitting the plants for CCS.[13]

The incremental cost of CCS varies depending on parameters such as the choice of capture technology, the percentage of CO_2 captured, the type of coal used, and the distance to and type of geologic storage.

For example, a 2007 study by researchers at Carnegie Mellon University estimated that, compared to an IGCC plant without CCS, a new IGCC plant built with CCS that captured 90 percent of CO_2 emissions would produce electricity at a 42 percent higher levelized cost and reduce GHG emissions at a cost of $32 per metric ton of CO_2 avoided ($32/t$CO_2$) in 2005 dollars (with capture, transport, and storage accounting for 75, 9, and 16 percent of this cost, respectively).[14]

Another study estimated that carbon capture at a coal-fueled power plant would cost $25-65/t$CO_2$ with CO_2 transport and storage adding $12-15/t$CO_2$.[15] The cost of CCS is expected to be higher for the first projects and to decline thereafter as the technology moves along its "learning curve."[16,17]

Current Status of CCS

Currently, there are no commercial-scale power plants that employ CCS; however, several demonstration projects are underway or planned.[18] The statuses of the CCS component technologies are reviewed below.

- **Carbon Capture**
  Carbon capture technologies have long been used for industrial processes like natural gas processing and CO_2 generation for the food and beverage industry. Projects in the United States and elsewhere are underway to demonstrate carbon capture with coal-fueled power plants.

- **CO_2 Transport**
  The United States already has more than 3,000 miles of CO_2 pipelines used to transport CO_2 for EOR.[19] CO_2 pipeline transport is commercially proven.

- **CO_2 Storage**
  The U.S. Department of Energy (DOE) has been supporting Regional Partnerships focused on geologic CO_2 storage since 2003.[20] The partnerships are initiating large-scale tests to determine how geologic storage reservoirs and their surroundings respond to large amounts of injected CO_2 in a variety of geologic formations and regions across the United States.

Worldwide, other large-scale projects for geologic CO_2 storage have been underway for a number of years, and monitoring has shown that the CO_2 is remaining safely in the target reservoirs.[21]

Obstacles to Further Development or Deployment of CCS

- **Lack of a Price on Carbon or GHG Emission Performance Standards**
  Deploying CCS at a coal-fueled power plant (new-build or retrofit) requires large incremental investments in capital equipment and higher operating costs. A policy, such as cap and trade (see *Climate Change 101: Cap and Trade*), that places a financial cost on GHG emissions, or policies that otherwise limit GHG emissions, are crucial for spurring firms to invest in CCS.

- **Need for Initial Commercial-Scale CCS Projects**
  The first commercial-scale CCS projects integrated with power plants will generate valuable information on the actual cost and performance of CCS as well as the optimal configuration of the technologies. Large-scale, real-world CCS projects will provide much-needed data to guide firms' investments in CCS and will lead to cost reductions via technology improvements.

- **Uncertainty in CO_2 Storage Regulations**
  Regulations for CO_2 storage are needed to specify: site selection criteria; well, injection, and closure operational requirements; long-term monitoring and verification requirements; and long-term liability.

Policy Options to Help Promote CCS

- **Putting a Price on Carbon**
  Policies that place a price on GHG emissions, such as a cap and trade, would discourage investments in traditional fossil-fuel use and spur investments in a range of clean energy technologies, including CCS.

- **Funding for Initial CCS Projects**
  To foster the initial, large-scale CCS projects needed to fully demonstrate the technology, the government can offer financial incentives for CCS. For example, the government could create a trust fund that could competitively award money to CCS projects to help them overcome financing hurdles.[22]

  A study prepared for the Pew Center found that coal power plant owners would require between $300 and $650 million in funds to cover the investments in equipment and lost capacity necessary for the initial commercial-scale deployments of CCS, depending on the plant type and whether plants are newly built with CCS or retrofit.[23]

- **Mandating GHG Emission Rates**
  Policymakers could rely on performance standards to drive CCS deployment by enacting new regulations that require CCS via a new source performance standard for power plants or a low-

carbon performance standard (similar to the renewable portfolio standards that many states already have). Illinois enacted such a policy in 2009.[24]

- **Defining a CO_2 Storage Regulatory Framework**
  Uncertainty regarding the legal framework governing CO_2 storage may hinder investment in CCS. In particular, the government may have a role in assuming long-term liability for stored CO_2. For example, charges levied on injected CO_2 could feed a CO_2 Storage Fund that could assume long-term liability from stored CO_2 from private-sector entities.

Related Business Environmental Leadership Council (BELC) Company Activities

- Air Products
- American Electric Power (AEP)
- BP
- Duke Energy
- GE
- Rio Tinto
- Royal Dutch Shell
- TransAlta
- Wisconsin Energy Corporation

Related Pew Center Resources

Addressing Emissions from Coal Use in Power Generation, 2008. http://www.pewclimate.org/DDCF-Briefs/Coal

Climate Change 101: Technology, 2009. http://www.pewclimate.org/global-warming-basics/climate_change_101

Coal and Climate Change Facts, 2008. http://pewclimate.com/global-warming-basics/coalfacts.cfm

Coal Initiative Reports http://pewclimate.com/white_papers/coal_initiative

- *A Program to Accelerate the Deployment of CO_2 Capture and Storage: Rationale, Objectives, and Cost*, 2007.
- *A Resource and Technology Assessment of Coal Utilization in India*, 2008.
- *State Options for Low-Carbon Coal Policy*, 2008.
- *A Trust Fund Approach to Accelerating Deployment of CCS: Options and Considerations*, 2007.

Creating Power, Technology, and Products: The Role of Coal Gasification in Ohio's Economy and Energy Future, 2007. http://www.pewclimate.org/Ohio-Coal-Gasification

The Role of CO2 Enhanced Oil Recovery in Ohio's Economy and Energy Future, 2007. http://www.pewclimate.org/node/6170

The U.S. Electric Power Sector and Climate Change Mitigation, 2005. http://pewclimate.com/global-warming-in-depth/all_reports/electricity

Further Reading / Additional Resources

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CCSReg Project. See http://www.ccsreg.org

Congressional Research Service, *Capturing CO_2 from Coal-Fired Power Plants: Challenges for a Comprehensive Strategy*, 2008. http://opencrs.cdt.org/document/RL34621/2008-08-15%2000:00:00

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Massachusetts Institute of Technology (MIT)

- Carbon Capture and Sequestration Technologies Program. http://sequestration.mit.edu
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Natural Resources Defense Council (NRDC) and Environmental Defense Fund (EDF). Carbon Capture and Sequestration Public Workshops, February 2008 and March 2009, Presentations and Bibliography. See http://ccsworkshop.eventbrite.com/

World Resources Institute (WRI). Carbon Capture and Sequestration Project. http://www.wri.org/project/carbon-capture-sequestration

U.S. Department of Energy (DOE)

- Carbon Sequestration Program. http://fossil.energy.gov/programs/sequestration/index.html
- National Energy Technology Laboratory (NETL), *Technologies: Carbon Sequestration*. http://www.netl.doe.gov/technologies/carbon_seq/index.html

[1] U.S. Energy Information Administration (EIA). *Electric Power Annual with Data for 2007*, 2009. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

[2] U.S. Environmental Protection Agency (EPA), *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007,* 2009. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

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[23] Kuuskraa, 2007.

[24] For details on the CCS-related policies enacted by Illinois, see http://www.pewclimate.org/node/6363.