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Carbon Capture and Sequestration (CCS) in the United States

SUMMARY

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Carbon capture and storage (or sequestration)—known as CCS—is a process that involves capturing man-made carbon dioxide (CO_2) at its source and storing it permanently underground. CCS could reduce the amount of CO_2—an important greenhouse gas—emitted to the atmosphere from the burning of fossil fuels at power plants and other large industrial facilities. The concept of carbon utilization has also gained interest within Congress and in the private sector as a means for capturing CO_2 and converting it into potentially commercially viable products, such as chemicals, fuels, cements, and plastics, thereby reducing emissions to the atmosphere and helping offset the cost of CO_2 capture (CCS is sometimes referred to as CCUS—carbon capture, *utilization*, and storage). Direct air capture is a related and emerging technology designed to remove atmospheric CO_2 directly.

The U.S. Department of Energy (DOE) has funded research and development (R&D) in aspects of CCS since at least 1997 within its Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment program (FECM) portfolio. Since FY2010, Congress has provided $7.3 billion in appropriations for DOE CCS-related activities, including annual increases in recent years. In FY2021, Congress provided $750 million to FECM, of which $228.3 million was directed to CCUS.

Worldwide, according to the Global CCS Institute, 24 facilities capturing and injecting CO_2 facilities were operational in 2020, 12 of which are in the United States. U.S. facilities capturing and injecting CO_2, and projects under development, operate in five industry sectors: chemical production, hydrogen production, fertilizer production, natural gas processing, and power generation. These facilities capture and inject CO_2 with the aim to sequester the CO_2 in underground geologic formations or use the CO_2 to increase oil production from aging oil fields, known as enhanced oil recovery (EOR). The Petra Nova project in Texas was the first and only U.S. fossil-fueled power plant generating electricity and capturing CO_2 in large quantities (over 1 million tons per year) until CCS operations were suspended in 2020.

The U.S. Environmental Protection Agency (EPA), under authorities to protect underground sources of drinking water, regulates CO_2 injection through its Underground Injection Control (UIC) program and associated regulations. While the agency establishes minimum standards and criteria for UIC programs, most states have the responsibility for regulating and permitting wells injecting CO_2 for EOR (classified as Class II recovery wells).

Congress has incentivized development of CCS projects through creation of the Internal Revenue Code Section 45Q tax credit for carbon sequestration or its use as a tertiary injectant for EOR or other designated purposes. Recent Internal Revenue Service guidance and regulations on this tax credit are intended to provide increased certainty for industry by establishing processes and standards for "secure geologic storage of CO_2," among other requirements.

The Consolidated Appropriations Act, 2021 (P.L. 116-260) included several provisions aimed at supporting CCS project development in the United States. The act revised and expanded DOE's ongoing CCS research, development, and demonstration activities, established expedited federal permitting eligibility for CO_2 pipelines (where applicable), and extended the start-of-construction deadline for facilities eligible for the Section 45Q tax credit, among other provisions.

There is broad agreement that costs for CCS would need to decrease before the technologies could be widely deployed across the nation. In the view of many proponents, greater CCS deployment is fundamental to reduce CO_2 emissions (or reduce the concentration of CO_2 in the atmosphere) and to help mitigate human-induced climate change. Congress may also consider that some stakeholders do not support CCS as a mitigation option, citing concerns with continued fossil fuel combustion and the uncertainties of long-term underground CO_2 storage.

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Carbon capture and storage (or sequestration)—known as CCS—is a process that involves capturing man-made carbon dioxide (CO_2) at its source and storing it to avoid its release to the atmosphere. CCS is sometimes referred to as CCUS—carbon capture, *utilization*, and storage. CCS could reduce the amount of CO_2 emitted to the atmosphere from the burning of fossil fuels at power plants and other large industrial facilities.[1] An integrated CCS system would include three main steps: (1) capturing and separating CO_2 from other gases; (2) compressing and transporting the captured CO_2 to the storage or sequestration site; and (3) injecting the CO_2 in underground geological reservoirs (the process is explained more fully below in "CCS Primer"). In recent years, *utilization* as part of CCUS increasingly has been viewed as a potentially important component of the process. Utilization refers to the beneficial use of CO_2—in lieu of storing it—as a means of mitigating CO_2 emissions and converting it to chemicals, cements, plastics, and other products.[2] This report uses the term *CCS* except in cases where utilization is specifically discussed.

The U.S. Department of Energy (DOE) has long supported research and development (R&D) on CCS within its Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment program (FECM).[3] From FY2010 to FY2021, Congress provided $7.3 billion in total appropriations for FECM, much of which was directed to CCS. Additionally, Congress provided a one-time appropriation of $3.4 billion for CCS in the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5). Congress has expressed support for continuing federal investment in CCS research and development—including financial support for demonstration projects—through the appropriations process in recent years and in DOE research reauthorizations provided in the Energy Act of 2020 (Division Z of the Consolidated Appropriations Act, 2021; P.L. 116-260).

In recent years, Congress has also enacted tax credits for facilities that capture and sequester CO_2—one strategy for incentivizing CCS project deployment. In 2018, Congress enacted legislation (Title II, §4119 of P.L. 115-123) that increased the tax credit for sequestering or utilizing CO_2, commonly referred to as the "Section 45Q" tax credit.[4] In P.L. 116-260, Congress extended the deadline for start of construction of facilities seeking the tax credit, which, along with Internal Revenue Service regulations on Section 45Q issued in early 2021, could encourage more project development, according to some analysts.[5]

Congressional interest in addressing climate change has also increased interest in CCS, though debate continues as to what role, if any, CCS should play in deep greenhouse gas reductions. While some policymakers and other stakeholders support CCS as one option for mitigating CO_2 emissions,[6] others raise concerns that CCS may not discourage fossil fuel use and that CO_2 could

[1] Carbon capture and sequestration (CCS) also could be used to capture carbon dioxide (CO_2) emissions from power plants that use bioenergy sources instead of fossil fuels. In that case, the process is known as *bioenergy with carbon capture and storage*, or BECCS.

[2] See, for example, U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), *Carbon Utilization Program*, at https://www.netl.doe.gov/coal/carbon-utilization.

[3] Formerly called Fossil Energy Research and Development.

[4] The credit is codified at 26 U.S.C. §45Q.

[5] Carbon Capture Coalition, *45Q Tax Credit*, at https://carboncapturecoalition.org/45q-legislation/.

[6] For example, the International Energy Agency (IEA) includes CCS as a "key solution" in its 2021 report on achieving global net zero greenhouse gas emissions. IEA anticipates widespread CCS deployment in several industries (e.g., power, cement, and hydrogen production) as well as direct air capture. International Energy Agency (IEA), *Net Zero by 2050: A Roadmap for the Global Energy Sector*, May 2021.

leak from underground reservoirs into the air or other reservoirs, thereby negating any climate benefits of CCS.[7]

This report includes a primer on the CCS (and carbon utilization) process; overviews of the DOE program for CCS R&D, U.S. Environmental Protection Agency (EPA) regulation of underground CO_2 injection used for CCS, and the Section 45Q tax credit for CO_2 sequestration; and a discussion of CCS policy issues for Congress. An evaluation of the fate of injected underground CO_2 and the permanence of CO_2 storage is beyond the scope of this report.

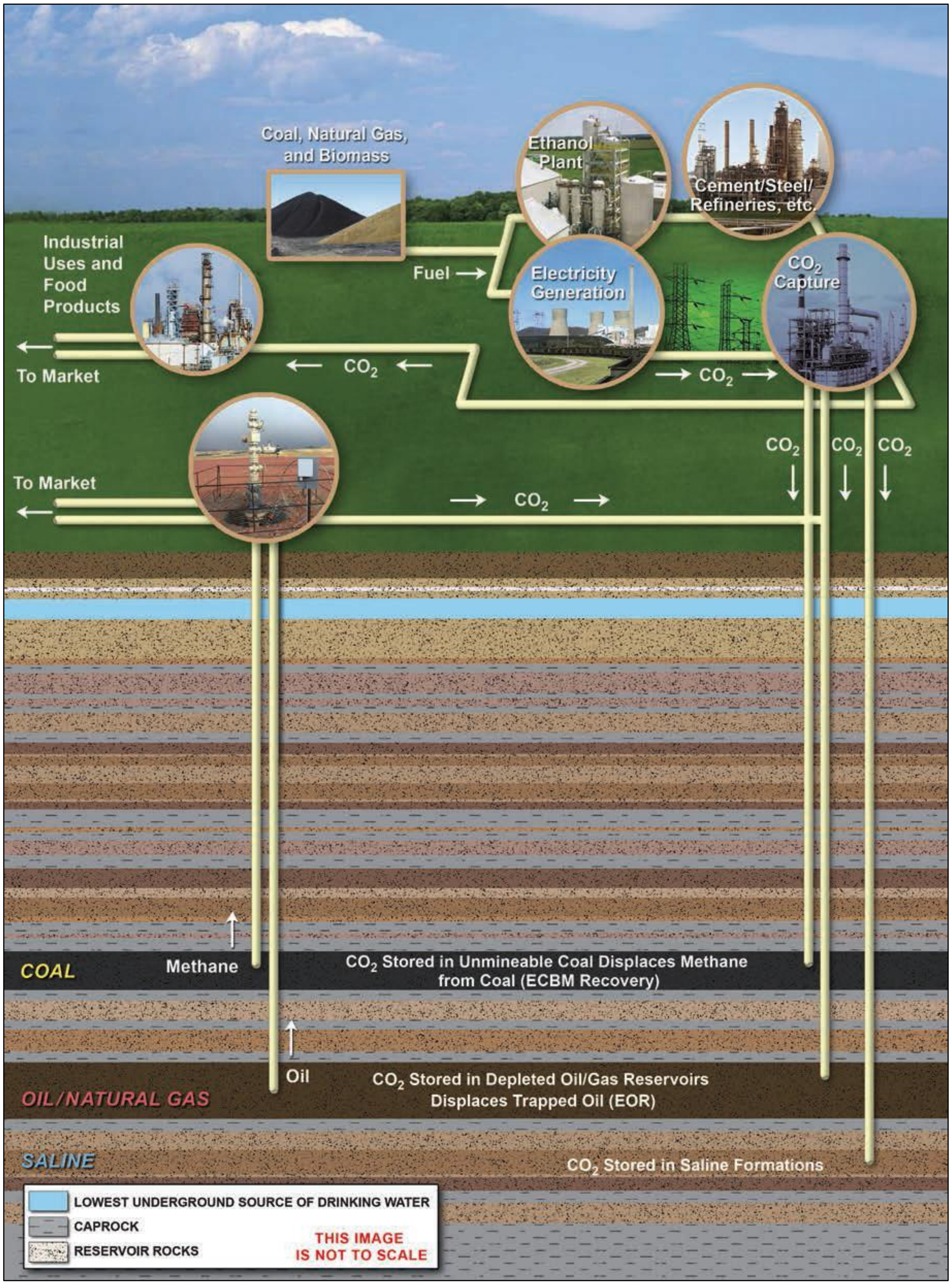
CCS Primer

An integrated CCS system includes three main steps: (1) capturing and separating CO_2 from other gases; (2) compressing and transporting the captured CO_2 to the sequestration site; and (3) injecting the CO_2 in subsurface geological reservoirs. The most technologically challenging and costly step in the process is the first step, carbon capture. Carbon capture equipment is capital-intensive to build and energy-intensive to operate. Power plants can supply their own energy to operate CCS equipment, but the amount of energy a power plant uses to capture and compress CO_2 is that much less electricity the plant can sell to its customers. This difference, sometimes referred to as the *energy penalty* or the *parasitic load*, has been reported to be around 20% of a power plant's capacity.[8] **Figure 1** shows the CCS process schematically from source to storage.

[7] For example, see White House Environmental Justice Advisory Council, *Climate and Economic Justice Screening Tool and Justice 40 Interim Final Recommendations*, May 13, 2021, p. 58; and Richard Conniff, "Why Green Groups Are Split on Subsidizing Carbon Capture Technology," *YaleEnvironment360*, April 9, 2018.

[8] See, for example, Howard J. Herzog, Edward S. Rubin, and Gary T. Rochelle, "Comment on 'Reassessing the Efficiency Penalty from Carbon Capture in Coal-Fired Power Plants,'" *Environmental Science and Technology*, vol. 50 (May 12, 2016), pp. 6112-6113.

Figure 1. The CCS Process



Source: U.S. Department of Energy, Office of Fossil Energy, "Carbon Utilization and Storage Atlas," Fourth Edition, 2012, p. 4.

Notes: *EOR* is enhanced oil recovery; *ECBM* is enhanced coal bed methane recovery. *Caprock* refers to a relatively impermeable formation. Terms are explained in "CO2 Injection and Sequestration."

The transport and injection/storage steps of the CCS process are not technologically challenging per se, as compared to the capture step. Carbon dioxide pipelines are used for enhanced oil recovery (EOR) in regions of the United States today, and for decades large quantities of fluids have been injected into the deep subsurface for a variety of purposes, such as disposal of wastewater from oil and gas operations or of municipal wastewater.[9] However, the transport and storage steps still face challenges, including economic and regulatory issues, rights-of-way, questions regarding the permanence of CO_2 sequestration in deep geological reservoirs, and ownership and liability issues for the stored CO_2, among others.

CO_2 Capture

The first step in CCS is to capture CO_2 at the source and separate it from other gases.[10] As noted above, this is typically the most costly part of a CCS project, representing up to 75% of project costs in some cases.[11] Current carbon capture costs are estimated at $43-$65 per ton CO_2 captured, though cost reductions of 50%-70% may be possible as the industry matures.[12]

Currently, three main approaches are available to capture CO_2 from large-scale industrial facilities or power plants: (1) postcombustion capture; (2) precombustion capture; and (3) oxy-fuel combustion capture.

The following sections summarize each of these approaches. A detailed description and assessment of the carbon capture technologies is provided in CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

Postcombustion Capture

The process of postcombustion capture involves extracting CO_2 from the flue gas—the mix of gases produced that goes up the exhaust stack—following combustion of fossil fuels or biomass. Several commercially available technologies, some involving absorption using chemical solvents (such as an *amine*; see **Figure 2**), can in principle be used to capture large quantities of CO_2 from flue gases.[13] In a vessel called an *absorber*, the flue gas is "scrubbed" with an amine solution, typically capturing 85% to 90% of the CO_2. The CO_2-laden solvent is then pumped to a second vessel, called a *regenerator*, where heat is applied (in the form of steam) to release the CO_2. The resulting stream of concentrated CO_2 is then compressed and piped to a storage site, while the depleted solvent is recycled back to the absorber.

Other than the Petra Nova project (discussed below in "Petra Nova: The First Large U.S. Power Plant with CCS"), no large U.S. commercial electricity-generating plant has been equipped with carbon capture equipment, though several projects are under development.

[9] Injecting CO_2 into an oil reservoir often increases or enhances production by lowering the viscosity of the oil, which allows it to be pumped more easily from the formation. The process is sometimes referred to as *tertiary recovery* or *enhanced oil recovery* (EOR).

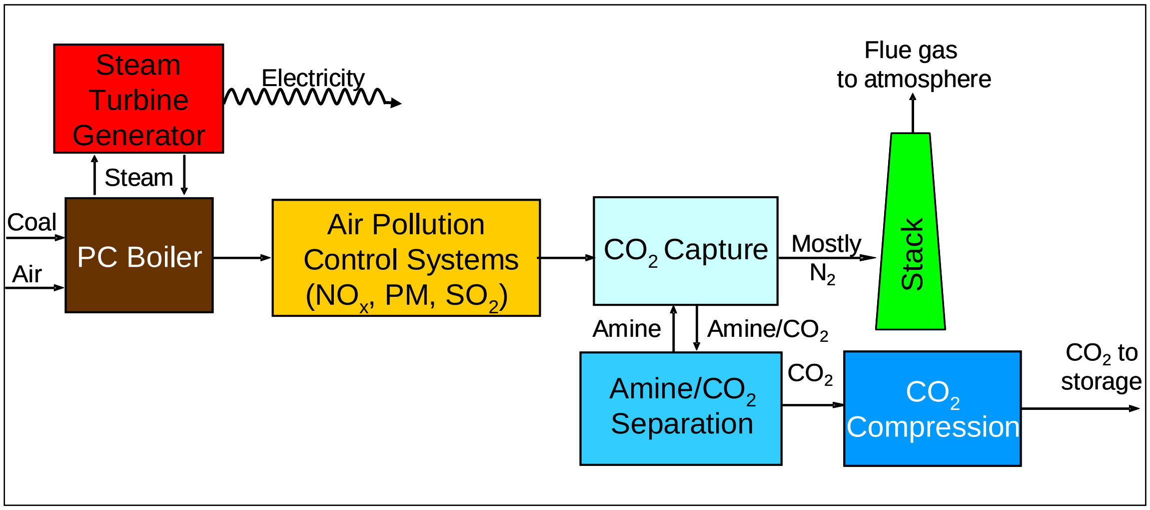
[10] Carbon capture is related to, but distinct from, direct air capture (DAC), a process that captures CO_2 from the atmosphere. DAC is discussed in more detail in later sections of this report. For a comparison of CCS and DAC, see CRS In Focus IF11501, *Carbon Capture Versus Direct Air Capture*, by Ashley J. Lawson.

[11] National Petroleum Council (NPC), *Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage, Chapter 5*, July 17, 2020.

[12] Greg Kelsall, *Carbon Capture Utilisation and Storage - Status, Barriers, and Potential*, International Energy Agency (IEA) Clean Coal Centre, July 2020.

[13] *Amines* are a family of organic solvents, which can "scrub" the CO_2 from the flue gas. When the CO_2-laden amine is heated, the CO_2 is released to be compressed and stored, and the depleted solvent is recycled.

Figure 2. Diagram of Postcombustion CO_2 Capture in a Coal-Fired Power Plant Using an Amine Scrubber System



Source: E. S. Rubin, "CO_2 Capture and Transport," *Elements*, vol. 4 (2008), pp. 311-317.

Notes: Other major air pollutants (nitrogen oxides-NO_x, particulate matter-PM, and sulfur dioxide-SO_2) are removed from the flue gas prior to CO_2 capture. PC = pulverized coal. N_2 = nitrogen gas.

Precombustion Capture (Gasification)

The process of precombustion capture separates CO_2 from the fuel by combining the fuel with air and/or steam to produce hydrogen for combustion and a separate CO_2 stream that could be stored. For coal-fueled power plants, this is accomplished by reacting coal with steam and oxygen at high temperature and pressure, a process called *partial oxidation*, or *gasification* (**Figure 3**).[14] The result is a gaseous fuel consisting mainly of carbon monoxide and hydrogen—a mixture known as *synthesis gas*, or *syngas*—which can be burned to generate electricity. After particulate impurities are removed from the syngas, a two-stage *shift reactor* converts the carbon monoxide to CO_2 via a reaction with steam (H_2O). The result is a mixture of CO_2 and hydrogen. A chemical solvent, such as the widely used commercial product Selexol (which employs a glycol-based solvent), then captures the CO_2, leaving a stream of nearly pure hydrogen that is burned in a combined cycle power plant to generate electricity—known as an *integrated gasification combined-cycle plant* (IGCC)—as depicted in **Figure 3**. Existing IGCC power plants in the United States do not capture CO_2.[15]

One example of gasification technology in operation today is the Polk Power Station about 40 miles southeast of Tampa, FL.[16] The 250 megawatt (MW) unit generates electricity from coal-derived syngas produced and purified onsite. The Polk Power Station does not capture CO_2. An example of precombustion capture technology, though not for power generation, is the Great Plains Synfuels Plant in Beulah, ND. The Great Plains plant produces synthetic natural gas from lignite coal through a gasification process, and the natural gas is shipped out of the facility for

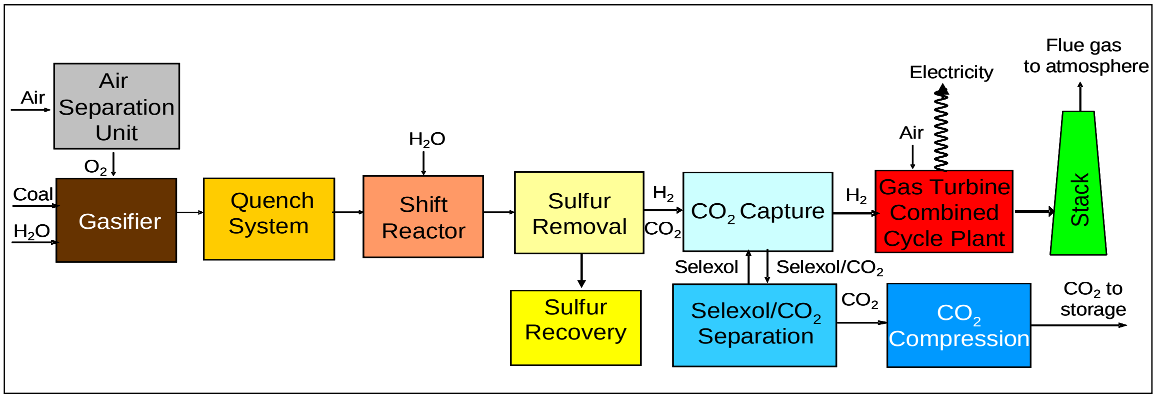
[14] See CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

[15] One integrated gasification combined-cycle project in Edwardsport, IN, was designed with sufficient space to add carbon capture in the future. For further discussion, see DOE, NETL, "IGCC Project Examples," at https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/project-examples.

[16] For more information about the Polk Power Station, see DOE, NETL, "Tampa Electric Integrated Gasification Combined-Cycle Project," at https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/tampa.

sale in the natural gas market. The process also produces a stream of high-purity CO_2, which is piped northward into Canada for use in EOR at the Weyburn oil field.[17]

Figure 3. Diagram of Precombustion CO_2 Capture from an IGCC Power Plant



Source: E. S. Rubin, "CO_2 Capture and Transport," *Elements*, vol. 4 (2008), pp. 311-317.

Oxy-Fuel Combustion Capture

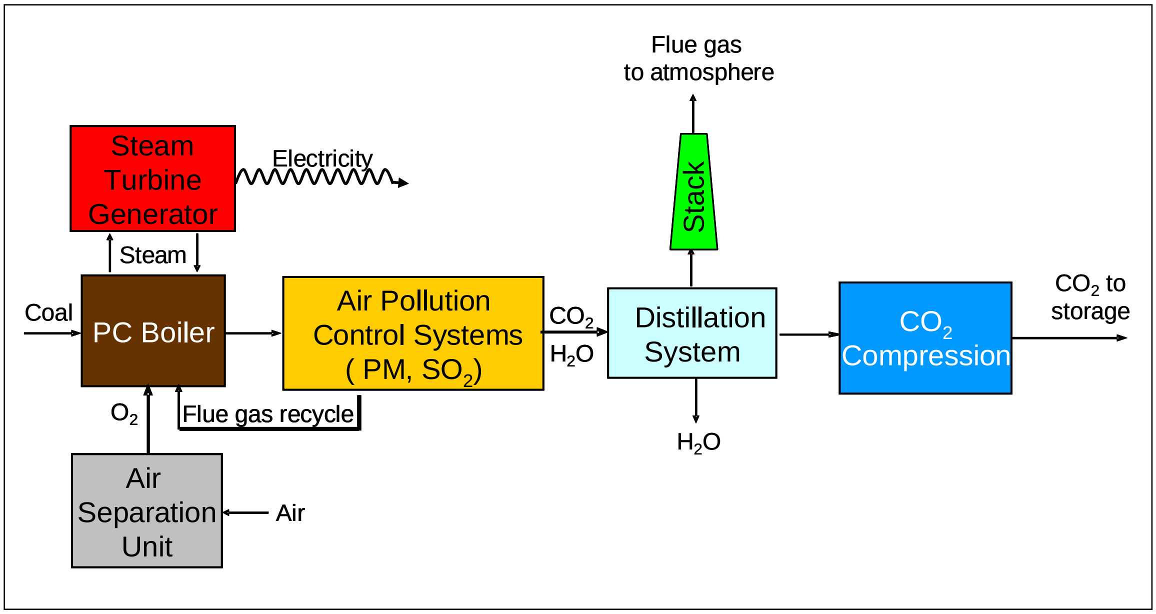
The process of oxy-fuel combustion capture uses pure oxygen instead of air for combustion and produces a flue gas that is mostly CO_2 and water, which are easily separable, after which the CO_2 can be compressed, transported, and stored (**Figure 4**). Oxy-fuel combustion requires an oxygen production step, which would likely involve a cryogenic process (shown as the air separation unit in **Figure 4**). The advantage of using pure oxygen is that it eliminates the large amount of nitrogen in the flue gas stream, thus reducing the formation of smog-forming pollutants like nitrogen oxides.

Currently oxy-fuel combustion projects are at the lab- or bench-scale, ranging up to verification testing at a pilot scale.[18]

[17] For a more detailed description of the Great Plains Synfuels plant, see DOE, NETL, "SNG from Coal: Process & Commercialization," at https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/great-plains.

[18] For more information, see NETL, *Oxy-Combustion*, at https://netl.doe.gov/node/7477.

Figure 4. Diagram of Oxy-Combustion CO_2 Capture from a Coal-Fired Power Plant



Source: E. S. Rubin, "CO_2 Capture and Transport," *Elements*, vol. 4 (2008), pp. 311-317.

Allam Cycle

The Allam Cycle is a novel power plant design that uses supercritical CO_2 (sCO_2) to drive an electricity-generating turbine.[19] sCO_2 is CO_2 held at certain temperature and pressure conditions, giving it unique chemical and physical properties. In contrast, most power plants in operation today (and most proposed power plants using CCS) use steam (i.e., water) to drive a turbine. Power plants using the Allam Cycle combust fossil fuels in pure oxygen, producing CO_2 and water.[20] The CO_2 can be reused multiple times to generate electricity, or piped away for utilization or storage. The excess CO_2 produced by the cycle is sufficiently pure to be directly transported or used without requiring an additional capture or purification step. For power plant operations, sCO_2 may be more efficient than steam. Initial estimates indicate that power plants using the Allam Cycle could have comparable efficiencies to natural gas combined cycle power plants without CCS.[21]

The NET Power demonstration facility in La Porte, TX, is the first power plant to use the Allam Cycle. Plans for two commercial-scale Allam Cycle power plants—one in Colorado and one in Illinois—were announced in April 2021.[22]

[19] NET Power, *The Allam-Fetvedt Cycle*, at https://netpower.com/the-cycle/.

[20] The operational NET Power facility uses natural gas as a fuel, but coal may also be used. One of the NET Power project developers, 8 Rivers Capital, received a DOE grant in 2019 to study the design of a coal-fired power plant using the Allam Cycle. DOE, "U.S. Department of Energy Invests $7 Million for Projects to Advance Coal Power Generation Under Coal FIRST Initiative," at https://netl.doe.gov/node/9282.

[21] Rodney Allam et al., "Demonstration of the Allam Cycle: An update on the development status of a high efficiency supercritical carbon dioxide power process employing full carbon capture," *Energy Procedia*, vol. 114 (2017), pp. 5948-5966.

[22] Akshat Rathi, "U.S. Startup Plans to Build First Zero-Emission Gas Power Plants," *Bloomberg Green*, April 15, 2021.

CO_2 Transport

After the CO_2 capture step, the gas is purified and compressed (typically into a supercritical state) to produce a concentrated stream for transport. Pipelines are the most common method for transporting CO_2 in the United States. Currently, approximately 5,000 miles of pipelines transport CO_2 in the United States, predominantly to oil fields, where it is used for EOR.[23] Transporting CO_2 in pipelines is similar to transporting fuels such as natural gas and oil; it requires attention to design, monitoring for leaks, and protection against overpressure, especially in populated areas.

Costs for pipeline construction vary, depending upon length and capacity; right-of-way costs; whether the pipeline is onshore or offshore; whether the route crosses mountains, large rivers, or frozen ground; and other factors. The quantity and distance transported will mostly determine shipping costs. Shipping rates for CO_2 pipelines in the United States may be negotiated between the operator and shippers, or may be subject to rate regulation if they are considered open access pipelines with eminent domain authority. Siting of CO_2 pipelines is under the jurisdiction of the states, although the federal government regulates their safety.

Even though regional CO_2 pipeline networks currently operate in the United States for EOR, developing a more expansive network for CCS could pose regulatory and economic challenges. Some studies have suggested that development of a national CO_2 pipeline network that would address the broader issue of greenhouse gas reduction using CCS may require a concerted federal policy, in some cases including federal incentives for CO_2 pipeline development.[24] In 2020, enacted legislation included provisions to facilitate the study and development of CO_2 pipelines that could be used for CCS.[25]

Using marine vessels also may be feasible for transporting CO_2 over large distances or overseas. Liquefied natural gas and liquefied petroleum gases (i.e., propane and butane) are routinely shipped by marine tankers on a large scale worldwide.[26] Marine tankers transport CO_2 today, but at a small scale because of limited demand. Marine tanker costs for CO_2 shipping are uncertain, because no large-scale CO_2 transport system via vessel (in millions of tons of CO_2 per year, for example) is operating, although such an operation has been proposed in Europe.[27] Marine tanker shipping might be less costly than pipeline transport for distances greater than 1,000 kilometers and for less than a few million tons of CO_2 transported per year.[28]

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[23] Pipeline and Hazardous Materials Safety Administration, "Annual Report Mileage for Hazardous Liquid or Carbon Dioxide Systems," web page, July 1, 2020, at https://www.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-hazardous-liquid-or-carbon-dioxide-systems.

[24] See, for example, Elizabeth Abramson et al., "Transport Infrastructure for Carbon Capture and Storage," Regional Carbon Capture Deployment Initiative, June 2020; Ryan W. J. Edwards and Michael A. Celia, "Infrastructure to Enable Deployment of Carbon Capture, Utilization, and Storage in the United States," *Proceedings of the National Academy of Sciences*, September 18, 2018.

[25] USE IT Act (H.R. 1166 and S. 383), 116th Congress, and enacted as part of P.L. 116-260.

[26] Rail cars and trucks also can transport CO_2, but this mode probably would be uneconomical for large-scale CCS operations.

[27] See IEA Clean Coal Centre, "Northern Lights – Send Us Your CO2," July 2, 2020. In this report, the amount of CO_2 is stated in metric tons, or 1,000 kilograms, which is approximately 2,200 pounds. Hereinafter, the unit *tons* means metric tons.

[28] Intergovernmental Panel on Climate Change (IPCC) Special Report, *Carbon Dioxide Capture and Storage*, 2005, p. 31.

CO_2 Injection and Sequestration

Three main types of geological formations are being considered for underground CO_2 injection and sequestration: (1) depleted oil and gas reservoirs, (2) deep saline reservoirs, and (3) unmineable coal seams. In each case, CO_2 in a supercritical state would be injected into a porous rock formation below ground that holds or previously held fluids (**Figure 1**). When CO_2 is injected at depths greater than about half a mile (800 meters) in a typical reservoir, the pressure keeps the injected CO_2 supercritical, making the CO_2 less likely to migrate out of the geological formation. The process also requires that the geological formation have an overlying *caprock* or relatively impermeable formation, such as shale, so that injected CO_2 remains trapped underground (**Figure 1**). Injecting CO_2 into deep geological formations uses existing technologies that have been primarily developed and used by the oil and gas industry and that potentially could be adapted for long-term storage and monitoring of CO_2.

The storage capacity for CO_2 in geological formations is potentially very large if all the sedimentary basins in the world are considered.[29] In the United States alone, DOE has estimated the total storage capacity to range between about 2.6 trillion and 22 trillion tons of CO_2 (see **Table 1**).[30] The suitability of any particular site, however, depends on many factors, including proximity to CO_2 sources and other reservoir-specific qualities such as porosity, permeability, and potential for leakage.[31] For CCS to succeed in mitigating atmospheric emissions of CO_2, it is assumed that each reservoir type would permanently store the vast majority of injected CO_2, keeping the gas isolated from the atmosphere in perpetuity. That assumption is untested, although part of the DOE CCS R&D program has been devoted to experimenting and modeling the behavior of large quantities of injected CO_2. Theoretically—and without consideration of costs, regulatory issues, public acceptance, infrastructure needs, liability, ownership, and other issues—the United States could store its total CO_2 emissions from large stationary sources (at the current rate of emissions) for centuries.

Table 1. Estimates of the U.S. Storage Capacity for CO_2

(in billions of metric tons)

	Low	Medium	High
Oil and Natural Gas Reservoirs	186	205	232
Unmineable Coal	54	80	113
Saline Formations	2,379	8,328	21,633
Total	**2,618**	**8,613**	**21,978**

Source: U.S. Department of Energy, National Energy Technology Laboratory, *Carbon Storage Atlas*, 5th ed., August 20, 2015, at https://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/atlasv/ATLAS-V-2015.pdf.

[29] *Sedimentary basins* refer to natural large-scale depressions in the Earth's surface that are filled with sediments and fluids and are therefore potential reservoirs for CO_2 storage.

[30] For comparison, in 2019 the United States emitted 1.6 billion tons of CO_2 from the electricity generating sector. See U.S. Environmental Protection Agency, *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019*, p. ES-7, at https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019.

[31] *Porosity* refers to the amount of open space in a geologic formation—the openings between the individual mineral grains or rock fragments. *Permeability* refers to the interconnectedness of the open spaces, or the ability of fluids to migrate through the formation. *Leakage* means that the injected CO_2 can migrate up and out of the intended reservoir, instead of staying trapped beneath a layer of relatively impermeable material, such as shale.

Notes: Data current as of November 2014. The estimates represent only the physical restraints on storage (i.e., the pore volume in suitable sedimentary rocks) and do not consider economic or regulatory constraints. The low, medium, and high estimates correspond to a calculated probability of exceedance of 90%, 50%, and 10%, respectively, meaning that there is a 90% probability that the estimated storage volume will exceed the low estimate and a 10% probability that the estimated storage volume will exceed the high estimate. Numbers in the table may not add precisely due to rounding.

Oil and Gas Reservoirs

Pumping CO_2 into oil and gas reservoirs to boost production (that is, EOR) has been practiced in the oil and gas industry for several decades. The United States is a world leader in this technology, and oil and gas operators inject approximately 68 million tons of CO_2 underground each year to help recover oil and gas resources.[32] Most of the CO_2 used for EOR in the United States comes from naturally occurring geologic formations, however, not from industrial sources. Using CO_2 from industrial emitters has appeal because the costs of capture and transport from the facility could be partially offset by revenues from oil and gas production. The majority of existing CCS facilities offset some of the costs by selling the captured CO_2 for EOR. According to some studies, EOR using CO_2 captured from an industrial source can produce crude oil with a lower lifecycle greenhouse gas emissions intensity than either oil produced without EOR or oil produced through EOR using naturally occurring CO_2.[33] CO_2 can be used for EOR onshore or offshore. To date, most U.S. CO_2 projects associated with EOR are onshore, with the bulk of activities in western Texas.[34] Carbon dioxide also can be injected into oil and gas reservoirs that are completely depleted, which would serve the purpose of long-term sequestration but without any offsetting financial benefit from oil and gas production.

Deep Saline Reservoirs

Some rocks in sedimentary basins contain saline fluids—brines or brackish water unsuitable for agriculture or drinking. As with oil and gas, deep saline reservoirs can be found onshore and offshore; they are often part of oil and gas reservoirs and share many characteristics. The oil industry routinely injects brines recovered during oil production into saline reservoirs for disposal.[35] As **Table 1** shows, deep saline reservoirs constitute the largest potential for storing CO_2 by far. However, unlike oil and gas reservoirs, storing CO_2 in deep saline reservoirs does not have the potential to enhance the production of oil and gas or to offset costs of CCS with revenues from the produced oil and gas.

[32] As of 2014. See Vello Kuuskraa and Matt Wallace, "CO2-EOR Set for Growth as New CO2 Supplies Emerge," *Oil and Gas Journal*, vol. 112, no. 4 (April 7, 2014), p. 66. Hereinafter Kuuskraa and Wallace, 2014.

[33] For example, one study comparing lifecycle greenhouse gas emissions of EOR using different sources of CO_2 found that using CO_2 captured from an IGCC power plant or a natural gas combined cycle power plant resulted in oil with 25%-60% lower lifecycle greenhouse gas emissions. CO_2 source is not the only determinant of the net emissions reductions associated with EOR. The types of EOR technology and methods also affect estimated emissions reductions in scientific studies. To a certain extent, EOR can be optimized for CO_2 storage (i.e., conducted in such a way as to attempt to maximize the storage of CO_2 as opposed to maximizing the production of oil).

[34] As of 2014, nearly two-thirds of oil production using CO_2 for EOR came from the Permian Basin, located in western Texas and southeastern New Mexico. Kruskaa and Wallace, 2014, p. 67.

[35] The U.S. Environmental Protection Agency (EPA) regulates this practice under authority of the Safe Drinking Water Act, Underground Injection Control (UIC) program. See the EPA UIC program at https://www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells.

Unmineable Coal Seams

U.S. coal resources that are not mineable with current technology are those in which the coal beds are not thick enough, are too deep, or lack structural integrity adequate for mining.[36] Even if they cannot be mined, coal beds are commonly permeable and can trap gases, such as methane, which can be extracted (a resource known as *coal-bed methane*, or CBM). Methane and other gases are physically bound (adsorbed) to the coal. Studies indicate that CO_2 binds to coal even more tightly than methane binds to coal.[37] CO_2 injected into permeable coal seams could displace methane, which could be recovered by wells and brought to the surface, providing a source of revenue to offset the costs of CO_2 injection. Unlike EOR, injecting CO_2 and displacing, capturing, and selling CBM (a process known as *enhanced coal bed methane recovery*, or ECBM) to offset the costs of CCS is not yet part of commercial production. Currently, nearly all CBM is produced by removing water trapped in the coal seam, which reduces the pressure and enables the release of the methane gas from the coal.

Carbon Utilization

The concept of carbon utilization has gained increasingly widespread interest within Congress and in the private sector as a means for capturing CO_2 and storing it in potentially useful and commercially viable products, thereby reducing emissions to the atmosphere and offsetting the cost of CO_2 capture. EOR is currently the main use of captured CO_2, and some observers envision EOR will continue to dominate carbon utilization for some time, supporting the scale-up of capture technologies that could later rely upon other utilization pathways.[38] Nonetheless, research activities and congressional interest in utilization tend to focus on uses other than EOR. For example, P.L. 115-123, the Bipartisan Budget Act of 2018, which expanded the Section 45Q tax credit for carbon capture and sequestration, excludes EOR from the definition of carbon utilization. P.L. 115-123 defines carbon utilization as[39]

- the fixation of such qualified carbon oxide through photosynthesis or chemosynthesis, such as through the growing of algae or bacteria;
- the chemical conversion of such qualified carbon oxide to a material or chemical compound in which such qualified carbon oxide is securely stored; and
- the use of such qualified carbon oxide for any other purpose for which a commercial market exists (with the exception of use as a tertiary injectant in a qualified enhanced oil or natural gas recovery project), as determined by the Secretary [of the Treasury].[40]

P.L. 116-260 provides two authorizations for a DOE carbon utilization research program (to be coordinated as a single program) in the aforementioned USE IT Act and Energy Act of 2020.

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[36] *Coal bed* and *coal seam* are interchangeable terms.

[37] IPCC Special Report, p. 217.

[38] For example, "For good reasons, many seek to find ways to use CO_2 to create economic value in a climate-positive way. Today, the primary use of CO_2 is for enhanced oil recovery. This is an important near-term pathway and provides opportunities to finance projects, scale-up technologies and reduce costs." Written testimony of Dr. S. Julio Friedmann, U.S. Congress, Senate Committee on Energy and Natural Resources, *Full Committee Hearing to Examine Development and Deployment of Large-Scale Carbon Dioxide Management Technologies*, 116th Cong., 2nd sess., July 28, 2020.

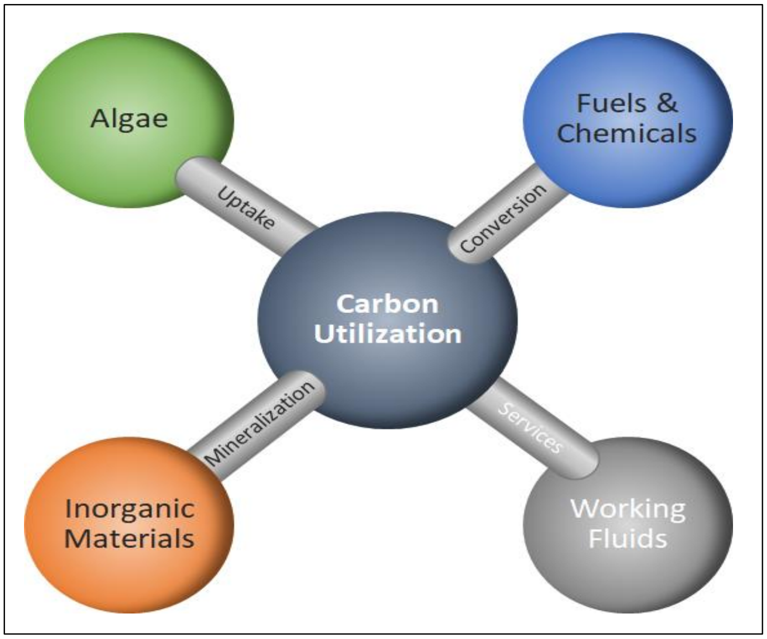
[39] CRS In Focus IF11455, *The Tax Credit for Carbon Sequestration (Section 45Q)*, by Angela C. Jones and Molly F. Sherlock.

[40] P.L. 115-123, §41119. A *tertiary injectant* refers to the use of CO_2 for EOR or enhanced natural gas recovery.

Both focus on "novel uses" for carbon and CO_2, such as "chemicals, plastics, building materials, fuels, cement, products of coal utilization in power systems or in other applications, and other products with demonstrated market value."[41]

Figure 5 illustrates an array of potential utilization pathways: uptake using algae (for biomass production), conversion to fuels and chemicals, mineralization into inorganic materials, and use as a working fluid (e.g., for EOR) or other services.

Figure 5. Schematic Illustration of Current and Potential Uses of CO_2



Source: U.S. DOE, National Energy Technology Laboratory (NETL), at https://www.netl.doe.gov/coal/carbon-utilization.

Direct Air Capture

Direct air capture (DAC) is an emerging set of technologies that aim to remove CO_2 directly from the atmosphere, as opposed to the point source capture of CO_2 from a source like a power plant (as described above in "CO2 Capture").[42]

DAC systems typically employ a chemical capture system to separate CO_2 from ambient air, add energy to separate the captured CO_2 from the chemical substrate, and remove the purified CO_2 to be stored permanently or utilized for other purposes.[43]

[41] P.L. 116-260, Division S, §102(c).

[42] CRS In Focus IF11501, *Carbon Capture Versus Direct Air Capture*, by Ashley J. Lawson. Some DAC processes capture CO_2 from seawater instead of the atmosphere.

[43] For a detailed assessment of DAC technology, see the American Physical Society, *Direct Air Capture of CO_2 with Chemicals*: *A Technology Assessment for the APS Panel on Public Affairs*, June 1, 2011, at https://www.aps.org/policy/reports/assessments/upload/dac2011.pdf. Hereinafter American Physical Society, 2011. Additional background information is also available in National Academies of Sciences, Engineering, and Medicine, *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*, 2019.

DAC systems have the potential to be classified as net carbon negative, meaning that if the captured CO_2 is permanently sequestered or becomes part of long-lasting products such as cement or plastics, the end result would be a reduction in the atmospheric concentration of CO_2. In addition, DAC systems can be sited almost anywhere—they do not need to be near power plants or other point sources of CO_2 emissions. They could be located, for example, close to manufacturing plants that require CO_2 as an input, and would not necessarily need long pipeline systems to transport the captured CO_2.

The concentration of CO_2 in ambient air is far lower than the concentration found at most point sources. Thus, a recognized drawback of DAC systems is their high cost per ton of CO_2 captured, compared to the more conventional CCS technologies.[44] A 2011 assessment estimated costs at roughly $600 per ton of captured CO_2.[45] A more recent assessment from one of the companies developing DAC technology, however, projects lower costs for commercially deployed plants of between $94 and $232 per ton.[46] By comparison, some estimate costs for conventional CCS from coal-fired electricity generating plants in the United States between $48 and $109 per ton.[47]

Congress has sometimes combined support for CCS and DAC into single proposals, despite the differences in the technologies. For example, the federal tax credit for carbon sequestration applies to CCS and DAC projects (with CO_2 injection for sequestration).[48] In other cases, though, Congress has treated the technologies separately. For example, the Energy Act of 2020 provided CCS R&D authorizations primarily in Title IV—Carbon Management, while most DAC R&D authorizations are in Title V—Carbon Removal.

Commercial CCS Facilities

According to one set of data collected by the Global CCS Institute (GCCSI), 24 commercial CCS facilities were capturing and injecting CO_2 throughout the world in 2020, 12 of which are in the United States.[49] These facilities have a cumulative capacity to capture and store an estimated 40 million tons of CO_2 each year.[50] Additionally, according to GCCSI, 3 more commercial facilities were under construction, 34 pilot or demonstration-scale CCS facilities were operational, and 8 CCS technology test centers were operational worldwide, as of 2020.[51]

[44] Generally, the more dilute the concentration of CO_2, the higher the cost to extract it, because much larger volumes are required to be processed. By comparison, the concentration of CO_2 in the atmosphere is about 0.04%, whereas the concentration of CO_2 in the flue gas of a typical coal-fired power plant is about 14%.

[45] American Physical Society, 2011, p. 13.

[46] Robert F. Service, "Cost Plunges for Capturing Carbon Dioxide from the Air," *Science*, June 7, 2018, at http://www.sciencemag.org/news/2018/06/cost-plunges-capturing-carbon-dioxide-air.

[47] Lawrence Irlam, *The Costs of CCS and Other Low-Carbon Technologies in the United States-2015 Update,* Global CCS Institute, July 2015, p. 1, at http://www.globalccsinstitute.com/publications/costs-ccs-and-other-low-carbon-technologies-2015-update.

[48] For more information, see CRS In Focus IF11455, *The Tax Credit for Carbon Sequestration (Section 45Q)*, by Angela C. Jones and Molly F. Sherlock.

[49] Global CCS Institute, *Global Status Report 2020*, December 1, 2020. Two facilities, Petra Nova and Lost Cabin, stopped CCS operations in 2020. The Global CCS Institute defines a *commercial facility* as a facility capturing CO_2 for permanent storage as part of an ongoing commercial operation, that generally has an economic life similar to the host facility whose CO_2 it captures, and that supports a commercial return while operating and/or meets a regulatory requirement.

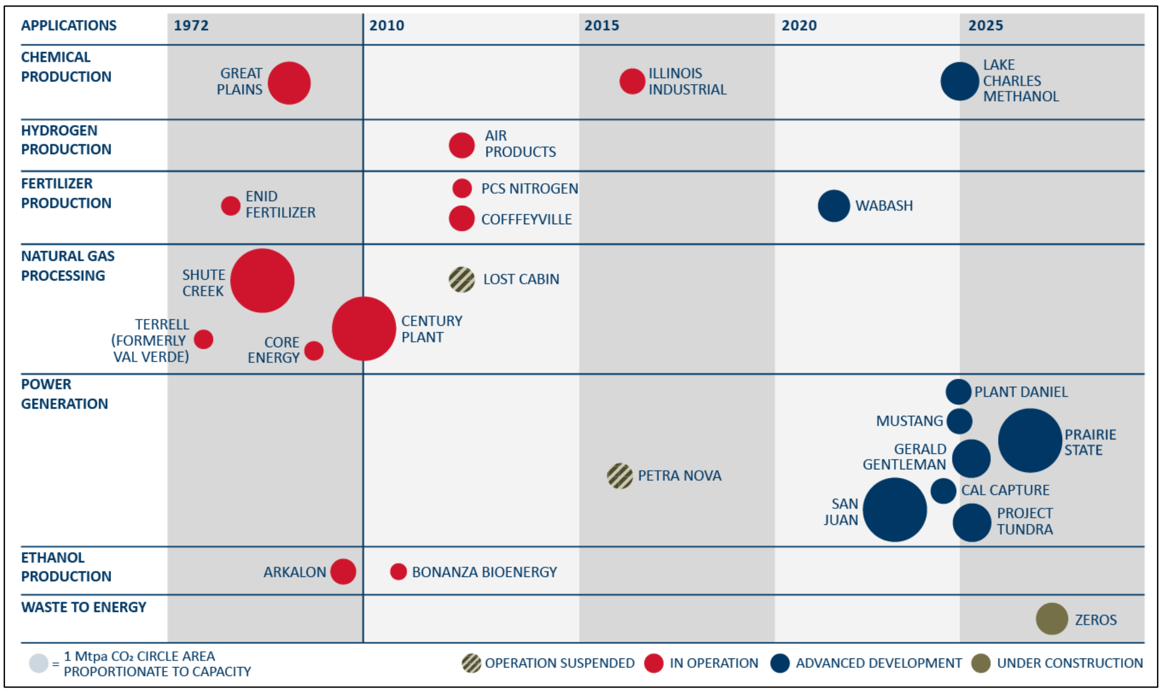
[50] Global CCS Institute, *Global Status Report 2020*, p. 19.

[51] Global CCS Institute, *Global Status Report 2020*, p. 19.

U.S. CCS facilities in operation or under development occur in five industrial sectors, according to GCCSI data: chemical production, hydrogen production, fertilizer production, natural gas processing, and power generation.[52] The Archer Daniels Midland (ADM) facility in Decatur, IL, is the only facility injecting the CO_2 solely for geologic sequestration. The facility injects CO_2 captured from ethanol production into a saline reservoir and as of 2019 reported that 1.5 million metric tons of CO_2 had been injected at the site.[53]

Figure 6.Operational and Planned CCS Facilities in the United States Injecting CO2 for Geologic Sequestration and EOR

Global CCS Institute data, as of 2020



Source: CRS, adapted from Global CCS Institute, *Global Status Report 2020*, 2020.

Notes: Mtpa = million tons per annum (year); circle placement indicates initial year of operations or anticipated initial year of operations for projects under development, according to GCCSI (the first time frame in the figure represents 38 years, while the other time frames each represent a five-year period). Some projects under development anticipate multiple CO_2 sources; in these cases, circle placement indicates the initial application being studied.

Particular attention has been paid to two power generation projects: Boundary Dam, in Saskatchewan, Canada, and Petra Nova, near Houston, TX. Both projects involved retrofitting coal-fired electricity generators with carbon capture equipment and have been lauded as successful examples of carbon capture technology. At the same time, both projects have been criticized for high costs and for sequestering carbon via EOR. In May 2020, Petra Nova's owners

[52] Global CCS Institute, *Global Status Report 2020*. "Under development" indicates that some project development. activity has occurred (e.g., feasibility or design studies), but the facility is not actively capturing and/or injecting CO_2. Projects may be in different stages of development.

[53] EPA FLIGHT database, accessed November 16, 2020. For comparison, that facility reported emitting 17.5 million metric tons of covered GHGs for that same period.

stopped operating the CCS equipment, citing unfavorable economics due to low crude oil prices, though reports suggest the facility may have experienced prior mechanical challenges.[54]

Petra Nova: The First Large U.S. Power Plant with CCS

On January 10, 2017, the Petra Nova–W.A. Parish Generating Station became the first industrial-scale coal-fired power plant with CCS to operate in the United States. The plant began capturing approximately 5,000 tons of CO_2 per day from its 240-megawatt-equivalent slipstream using post combustion capture technology.[55] The capture technology is approximately 90% efficient (i.e., it captures about 90% of the CO_2 in the exhaust gas after the coal is burned to generate electricity) and is designed to capture 1.4 million tons of CO_2 each year.[56] The captured CO_2 is transported via an 82-mile pipeline to the West Ranch oil field, where it is injected for EOR. NRG Energy Inc., and JX Nippon Oil & Gas Exploration Corporation, the joint owners of the Petra Nova project, together with Hilcorp Energy Company (which handles the injection and EOR), anticipated increasing West Ranch oil production from 300 barrels per day before EOR to 15,000 barrels per day after EOR.[57] Petra Nova's operators turned off the CCS equipment in May 2020, citing low oil prices caused, in part, by the COVID-19 pandemic.[58]

DOE provided Petra Nova with more than $160 million from its Clean Coal Power Initiative (CCPI) Round 3 funding, using funds appropriated under the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5) together with other DOE funding for a total of more than $190 million of federal funds for the $1 billion retrofit project.[59] Petra Nova is the only CCPI Round 3 project that expended its ARRA funding and began operating.[60] The three other CCPI Round 3 demonstration projects funded using ARRA appropriations (as well as the FutureGen project—slated to receive nearly $1 billion in ARRA appropriations) all have been canceled, have been suspended, or remain in development.[61]

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[54] Jeremy Dillon and Carlos Anchondo, "Low Oil Prices Force Petra Nova Into 'Mothball Status,'" *E&E News*, July 28, 2020; and Nichola Groom, "Problems Plagued U.S. CO2 Capture Project Before Shutdown: DOE Document," Reuters, August 6, 2020.

[55] *Slipstream* refers to the exhaust gases emitted from the power plant. NRG News Release, "NRG Energy, JX Nippon Complete World's Largest Post-Combustion Carbon Capture Facility On-Budget and On-Schedule," January 10, 2017, at http://investors.nrg.com/phoenix.zhtml?c=121544&p=irol-newsArticle&ID=2236424.

[56] U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), "Recovery Act: Petra Nova Parish Holdings: W.A. Parish Post-Combustion CO2 Capture and Sequestration Project," at https://www.netl.doe.gov/research/coal/project-information/fe0003311.

[57] NRG News Release, "NRG Energy, JX Nippon Complete World's Largest Post-Combustion Carbon Capture Facility On-Budget and On-Schedule," January 10, 2017, at http://investors.nrg.com/phoenix.zhtml?c=121544&p=irol-newsArticle&ID=2236424.

[58] L.M.Sixel, "NRG Mothballs Carbon Capture Project at Coal Plant," *Houston Chronicle*, July 31, 2020.

[59] U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), "Recovery Act: Petra Nova Parish Holdings: W.A. Parish Post-Combustion CO2 Capture and Sequestration Project," at https://www.netl.doe.gov/research/coal/project-information/fe0003311.

[60] For an analysis of carbon capture and sequestration (CCS) projects funded by the American Recovery and Reinvestment Act (P.L. 111-5), see CRS Report R44387, *Recovery Act Funding for DOE Carbon Capture and Sequestration (CCS) Projects*, by Peter Folger.

[61] FutureGen is discussed in more detail in CRS Report R44387, *Recovery Act Funding for DOE Carbon Capture and Sequestration (CCS) Projects*, by Peter Folger.

Boundary Dam: World's First Addition of CCS to a Large Power Plant

The Boundary Dam project was the first commercial-scale power plant with CCS in the world to begin operations. Boundary Dam, a Canadian venture operated by SaskPower,[62] cost approximately $1.3 billion, according to one source.[63] Of that amount, $800 million was for building the CCS process and the remaining $500 million was for retrofitting the Boundary Dam Unit 3 coal-fired generating unit. The project also received $240 million from the Canadian federal government. Boundary Dam started operating in October 2014, after a four-year construction and retrofit of the 150-megawatt generating unit. The final project was smaller than earlier plans to build a 300-megawatt CCS plant, but that original idea may have cost as much as $3.8 billion. The larger-scale project was discontinued because of the escalating costs.[64]

Boundary Dam captures, transports, and sells most of its CO_2 for EOR, shipping 90% of the captured CO_2 via a 41-mile pipeline to the Weyburn Field in Saskatchewan. CO_2 not sold for EOR is injected and stored about 2.1 miles underground in a deep saline aquifer at a nearby experimental injection site. By June 2020, the plant had captured over 3.4 million tons of CO_2 since full-time operations began in October 2014.[65]

The DOE CCS Program

DOE has funded R&D of aspects of the three main steps of an integrated CCS system since 1997, primarily through its Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment program (FECM).[66] CCS-focused R&D has come to dominate the coal program area within DOE FECM since 2010. Since FY2010, Congress has provided $7.3 billion total in annual appropriations for FECM (see **Table 2**). ARRA provided an additional $3.4 billion to that total, specifically for CCS projects.[67]

The Trump Administration proposed shifting FECM's focus to early-stage research, as summarized in the FY2021 budget request for FECM: "This Budget Request focuses DOE resources toward early-stage R&D and reflects an increased reliance on the private sector to fund later-stage research, development, and commercialization of energy technologies."[68] The Trump Administration's approach would have been a reversal of Obama Administration and George W.

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[62] SaskPower is the principal electric utility in Saskatchewan, Canada.

[63] MIT Carbon Capture & Sequestration Technologies, CCS Project Database, "Boundary Dam Fact Sheet: Carbon Capture and Storage Project," at http://sequestration.mit.edu/tools/projects/boundary_dam.html.

[64] Ibid.

[65] SaskPower, *BD3 Status Update: June 2020*, at https://www.saskpower.com/about-us/our-company/blog/bd3-status-update-june-2020.

[66] The Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment appropriations account was previously known as the Fossil Energy Research and Development (FER&D) account. The Biden Administration renamed the Office of Fossil Energy as the Office of Fossil Energy and Carbon Management in 2021. This name change was also adopted by appropriators throughout the FY2022 appropriations process. See DOE, "Our New Name Is Also a New Vision," July 8, 2021, at https://www.energy.gov/fe/articles/our-new-name-also-new-vision.

[67] Authority to expend American Recovery and Reinvestment Act (ARRA; P.L. 111-5) funds expired in 2015. An analysis of ARRA funding for CCS activities at DOE is provided in CRS Report R44387, *Recovery Act Funding for DOE Carbon Capture and Sequestration (CCS) Projects*, by Peter Folger.

[68] DOE, *FY2021 Congressional Budget Request*, Volume 3 Part 2, February 2021, p. 195.

Bush Administration DOE policies, which supported large carbon-capture demonstration projects and large injection and sequestration demonstration projects. Congress instead provided annual increases in the first three years of the Trump Administration and continued support for demonstration projects. The Biden Administration has also supported funding CCS demonstration projects. **Table 2** shows the funding for DOE CCS programs under FECM from FY2010 through FY2021.[69]

[69] For information on FY2021 and FY2022 appropriations, see CRS In Focus IF11861, *Funding for Carbon Capture and Carbon Removal at DOE*, by Ashley J. Lawson.

Table 2. Funding for DOE Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment Program (FECM) Program Areas

FY2010 through FY2021

FECM Program Areas	Program/ Activity	FY2010 ($1,000)	FY2011 ($1,000)	FY2012 ($1,000)	FY2013 ($1,000)	FY2014 ($1,000)	FY2015 ($1,000)	FY2016 ($1,000)	FY2017 ($1,000)	FY2018 ($1,000)	FY2019 ($1,000)	FY2020 ($1,000)	FY2021 ($1,000)
CCUS and Power Systems	**Carbon Capture**	—	58,703	66,986	63,725	92,000	88,000	101,000	101,000	100,671	100,671	117,800	126,300
	Carbon Utilization												23,000
	Carbon Storage	—	120,912	112,208	106,745	108,766	100,000	106,000	95,300	98,096	98,096	100,000	79,000
	Advanced Energy Systems	—	168,627	97,169	92,438	99,500	103,000	105,000	105,000	112,000	129,683	120,000	122,000
	Cross-Cutting Research	—	41,446	47,946	45,618	41,925	49,000	50,000	45,500	58,350	56,350	56,000	72,000
	Supercritical CO_2 Technology	—	—	—	—	—	10,000	15,000	24,000	24,000	22,430	16,000	14,500
	NETL Coal R&D	—	—	35,011	33,338	50,011	50,000	53,000	53,000	53,000	54,000	61,000	0
	Transformational Coal Pilots[a]	—	—	—	—	—	—	—	50,000[a]	35,000	25,000	20,000	10,000
Subtotal CCUS and Power Systems		**393,485**	**389,688**	**359,320**	**341,864**	**392,202**	**400,000**	**430,000**	**423,800**	**481,117**	**486,230**	**490,800**	**446,800**
Other FECM	**Natural Gas Technologies**	17,364	0	14,575	13,865	20,600	25,121	43,000	43,000	50,000	51,000	51,000	57,000
	Unconventional Fossil	19,474	0	4,859	4,621	15,000	4,500	20,321	21,000	40,000	46,000	46,000	46,000
	Program Direction	158,000	164,725	119,929	114,201	120,000	119,000	114,202	60,000	60,000	61,070	61,500	61,500
	Plant and Capital	20,000	19,960	16,794	15,982	16,032	15,782	15,782	—	—	—	—	—

FECM Program Areas	Program/ Activity	FY2010 ($1,000)	FY2011 ($1,000)	FY2012 ($1,000)	FY2013 ($1,000)	FY2014 ($1,000)	FY2015 ($1,000)	FY2016 ($1,000)	FY2017 ($1,000)	FY2018 ($1,000)	FY2019 ($1,000)	FY2020 ($1,000)	FY2021 ($1,000)
	Env. Restoration	10,000	9,980	7,897	7,515	5,897	5,897	7,995	—	—	—	—	—
	Special Recruitment	700	699	700	667	700	700	700	700	700	700	700	700
	NETL Research and Operations	—	—	—	—	—	—	0	43,000	50,000	50,000	50,000	83,000
	NETL Infrastructure	—	—	—	—	—	—	0	40,500	45,000	45,000	50,000	55,000
	Coop R&D	4,868	—	—	—	—	—	—	—	—	—		
	Directed Projects	35,879	—	—	—	—	—	—	—	—	—		
Subtotal Other FECM		**266,285**	**195,364**	**164,754**	**156,851**	**178,229**	**171,000**	**202,000**	**258,200**	**245,700**	**253,770**	**259,200**	**303,200**
Rescissions/Use of Prior-Year Balances		—	(151,000)	(187,000)	—	—	—	—	(14,000)	—	—		
Total FECM		**659,770**	**434,052**	**337,074**	**498,715**	**570,431**	**571,000**	**632,000**	**668,000**	**726,817**	**740,000**	**750,000**	**750,000**
FY2010-FY2021	**Grand Total**	**$7.3B**											

Sources: U.S. Department of Energy annual budget justifications for FY2012 through FY2021; explanatory statement for P.L. 115-141, Division D (Consolidated Appropriations Act, 2018, at https://rules.house.gov/bill/115/hr-1625-sa).

Notes: CO_2 = carbon dioxide; CCUS = carbon capture utilization and sequestration (or storage); FECM = Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment program; NETL = National Energy Technology Laboratory; Inf. & Ops = infrastructure and operations; Coop = cooperative; R&D = research and development. Directed Projects refer to congressionally directed projects. Program areas are as used in the explanatory statement for FY2021 appropriations; previous appropriations language used alternative names for some program areas and may not be completely comparable. Grand total for FY2010-FY2021 subject to rounding. Amounts provided by the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5) are not shown in the table or included in the grand total. The carbon utilization program was first authorized for FY2021 as part of P.L. 116-260.

a. Funding for Transformational Coal Pilots was first provided as a proviso in FY2017 appropriations. See explanatory statement for P.L. 115-31, Consolidated Appropriations Act, 2017, Division D at https://www.gpo.gov/fdsys/pkg/CPRT-115HPRT25289/pdf/CPRT-115HPRT25289.pdf.

EPA Regulation of Underground Injection in CCS

EPA issues regulations for underground injection of CO_2 as part of its responsibilities for underground injection control (UIC) programs under the Safe Drinking Water Act (SDWA). EPA also develops guidance to support state program implementation, and in some cases, directly administers UIC programs in states.[70] The agency has established minimum requirements for state UIC programs and permitting for injection wells. These requirements include performance standards for well construction, operation and maintenance, monitoring and testing, reporting and recordkeeping, site closure, financial responsibility, and, for some types of wells, post injection site care. Most states implement the day-to-day program elements for most categories of wells, which are grouped into "classes" based on the type of fluid injected. Owners or operators of underground injection wells must follow the permitting requirements and standards established by the UIC program authority in their state.

EPA has issued regulations for six classes of underground injection wells based on type and depth of fluids injected and potential for endangerment of underground sources of drinking water (USDWs). Class II wells are used to inject fluids related to oil and gas production, including injection of CO_2 for EOR. Class VI wells are used to inject CO_2 for geologic sequestration. There are more than 119,500 EOR wells injecting CO_2 in the United States, predominantly in California, Texas, Kansas, Illinois, and Oklahoma.[71] This includes EOR wells used to inject CO_2 captured from anthropogenic sources and wells using naturally derived CO_2. Two EPA-permitted wells are currently operating for sequestration in the United States, both located at the ADM facility in Illinois.[72]

To protect USDWs from injected CO_2 or movement of other fluids in an underground formation, Class II EOR wells must transition to Class VI geologic sequestration wells under certain conditions.[73] Class II well owners or operators who inject CO_2 primarily for long-term storage (rather than oil production) must obtain a Class VI permit when there is an increased risk to USDWs compared to prior Class II operations using CO_2. The Class VI Program Director (EPA or a delegated state) determines whether a Class VI permit is required based on site-specific risk factors associated with USDW endangerment. To date, no such transition has been required.

[70] 40 C.F.R. §§144-147.

[71] EPA, *FY19 State UIC Injection Well Inventory*, accessed November 27, 2020.

[72] EPA has granted North Dakota and Wyoming primary enforcement authority for Class VI well programs in those states.

[73] 40 C.F.R. §144.19.

The 45Q Tax Credit for CCS[74]

Title II, Section 41119 of P.L. 115-123, the Bipartisan Budget Act of 2018, amended Internal Revenue Code Section 45Q to increase the tax credit for capture and sequestration of "carbon oxide," or for its use as a tertiary injectant in EOR operations. Carbon oxide is defined variously in the legislation to include CO_2, or any other carbon oxide—such as carbon monoxide—that qualifies under provisions of the enacted law. The law raises the tax credit linearly from $22.66 to $50 per ton over the period from calendar year 2017 until calendar year 2026 for CO_2 captured and permanently stored, and from $12.83 to $35 per ton over the same period for CO_2 captured and used as a tertiary injectant. Starting with calendar year 2027, the tax credit will be adjusted for inflation. It also requires that the credit be claimed over a 12-year period after operations begin. Additionally, to qualify, facilities must begin construction before January 1, 2026.[75]

To qualify, a minimum amount of CO_2 is required to be captured and stored or utilized by the facility.[76] This amount varies with the type of facility. An electricity generating facility that emits more than 500,000 tons of CO_2 per year, for example, must capture a minimum 500,000 tons of CO_2 annually to qualify for the tax credit. A facility that captures CO_2 for the purposes of utilization—fixing CO_2 through photosynthesis or chemosynthesis, converting it to a material or compound, or using it for any commercial purpose other than tertiary injection or natural gas recovery (as determined by the Secretary of the Treasury)—and emits less than 500,000 tons of CO_2 must capture at least 25,000 tons per year. A direct air capture facility or a facility that does not meet the other criteria just described must capture at least 100,000 tons per year.

The modifications to 45Q in P.L. 115-123 also changed taxpayer eligibility for claiming the credit. For equipment placed in service before February 9, 2018, the credit is attributable to the person that captures and physically or contractually ensures the disposal or use of qualified CO_2, unless an election is made to allow the person disposing of the captured CO_2 to claim the credit. For equipment placed in service after February 9, 2018, the credit is attributable to the person that owns the carbon capture equipment and physically or contractually ensures the disposal or use of the qualified CO_2. The credits can be transferred to the person that disposes of or uses the qualified CO_2. Proponents of this change suggest it provides greater flexibility for companies with different business models to use the tax credit effectively, including cooperative and municipal utilities.

Some stakeholders have suggested that the 2018 tax credit increases in Section 45Q could be a "game changer" for CCS developments in the United States, by providing high-enough incentives for investments into CO_2 capture and storage.[77] They note that EOR has been the main driver for CCS development until now, and the new tax credit incentives might result in an increased shift toward CO_2 capture for permanent storage apart from EOR.

Opponents to 45Q include some environmental groups that broadly oppose measures that extend the life of coal-fired power plants or provide incentives to private companies to increase oil production.[78] Another factor to consider is the cost. According to the Joint Committee on Taxation (JCT), the changes enacted in P.L. 115-123 will reduce federal tax revenue by an estimated $689 million between FY2018 and FY2027.[79] Other groups note that measures in addition to the 45Q tax credits will be needed to lower CCS costs and promote broader deployment.

The Internal Revenue Service (IRS) continues to issue guidance and promulgate regulations on implementation of the Section 45Q tax credit. In January 2021, the IRS issued final regulations on demonstration of "secure geologic storage," utilization of qualified carbon oxide, eligibility, and credit recapture, among other provisions (86 *Federal Register*, January 15, 2021, 4728-4773).

Discussion

In recent Congresses, proposed and enacted CCS-related legislation has addressed federal CCS RD&D activities and funding, CO_2 pipelines, and the carbon sequestration tax credit. More than

[74] For additional background, see CRS InFocus IF11455, *The Tax Credit for Carbon Sequestration (Section 45Q)*, by Angela C. Jones and Molly F. Sherlock.

[75] The begin-construction deadline was extended from January 1, 2024, to January 1, 2026, in the Taxpayer Certainty and Disaster Tax Relief Act of 2020 (Division EE of the Consolidated Appropriations Act, 2021; P.L. 116-260).

[76] Taxpayers must physically or contractually dispose of captured carbon oxide in secure geological storage. See IRS Prop. Reg. §1.45Q-1, Prop. Reg. §1.45Q-2, Prop. Reg. §1.45Q-3, Prop. Reg. §1.45Q-4, and Prop. Reg. §1.45Q-5; and Department of the Treasury, "Credit for Carbon Oxide Sequestration," 85 *Federal Register* 34050-34075, June 2, 2020.

55 bills were introduced in the 116th Congress that contained provisions addressing CCS. Some of these bills, or provisions thereof, were enacted as part of the Consolidated Appropriations Act, 2021 (P.L. 116-260). Potential implementation and oversight issues related to these provisions might be of interest in the 117th Congress. In 2021, the Biden Administration has announced climate change mitigation goals and strategies, and new climate-focused groups and initiatives that may also be of interest when considering CCS-related oversight, appropriations, or legislation.

In the 116th Congress, as part of the Consolidated Appropriations Act, 2021 (P.L. 116-260), Congress reauthorized the DOE CCS research program. Among other provisions, the law expanded the scope of DOE's research to noncoal applications (e.g., natural gas-fired power plants, other industrial facilities).[80] The law also authorized a DOE carbon utilization research program and specific activities related to direct air capture (e.g., a DAC technology prize). As is also true for other DOE applied research programs, some criticize such activities as an inappropriate role for government, arguing the private sector is better suited to develop technologies that can compete in the marketplace.

Costs have been, and remain, a key challenge to CCS development in the United States. In recent years, Congress has attempted to address this challenge in two main ways—federal R&D and federal tax credits. P.L. 116-260 also extended the start of construction deadline for facilities claiming the 45Q tax credit. The tax credit is considered by some stakeholders as one of the strongest policies supporting CCS in the world.[81] In January 2021, the IRS promulgated regulations establishing requirements for carbon storage under Section 45Q. Congress remains interested in the efficacy of the tax credit in promoting CCS development and could consider additional adjustments to it.

The issue of expanded CCS deployment is closely tied to the issue of reducing greenhouse gas emissions to mitigate human-induced climate change. In two January 2021 executive orders, President Biden outlined new federal climate policies; created new White House and Department of Justice climate offices; and established new task forces, workgroups, and advisory committees on climate change science and policy.[82] At this early stage, the implications of these executive branch policies and actions on CCS project development and deployments are unclear.

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[77] Emma Foehringer Merchant, "Can Updated Tax Credits Bring Carbon Capture Into the Mainstream?," *Greentech Media*, February 22, 2018; James Temple, "The Carbon Capture Era May Finally Be Starting," *MIT Technology Review*, February 20, 2018.

[78] "Capturing Carbon Pollution While Moving Beyond Fossil Fuels," Natural Resources Defense Council, assessed on November 27, 2019, at https://www.nrdc.org/experts/david-doniger/capturing-carbon-pollution-while-moving-beyond-fossil-fuels; Richard Conniff, "Why Green Groups are Split on Subsidizing Carbon Capture Technology," *YaleEnvironment360*, April 9, 2018.

[79] Joint Committee on Taxation, *Estimated Effects of the Revenue Provisions Contained in the "Bipartisan Budget Act of 2018,"* JCS-4-18, February 8, 2018.

[80] For additional information, see CRS In Focus IF11861, *Funding for Carbon Capture and Carbon Removal at DOE*, by Ashley J. Lawson.

[81] For example, "45Q: The most progressive CCS-specific incentive globally," Lee Beck, *The U.S. Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update*, Global CCS Institute, p. 2, April 2020.

[82] Executive Order 13990, *Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis*, January 20, 2021; and Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad*, January 27, 2021.

An additional consideration in the congressional policy discussion is that not all advocates for actions to address climate change support CCS technology.[83] Some argue that CCS supports continued reliance on fossil fuels, which runs counter to reducing greenhouse gas emissions and other environmental goals. They tend to prefer policies that phase out the use of fossil fuels altogether. Other CCS opponents raise concerns about the long-term safety and environmental uncertainties of injecting large volumes of CO_2 underground.

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[83] For example, in its May 2021 interim final recommendations, the White House Environmental Justice Advisory Council (WHEJAC) listed CCS projects as among those projects that would not benefit communities (WHEJAC, *Justice40, Climate and Economic Justice Screening Tool & Executive Order 12898 Revisions: Interim Final Recommendations*, May 13, 2021). See also Carlos Anchondo, "Industry warns lawmakers of CCS threats," *Energywire*, November 25, 2019; and Richard Conniff, "Why Green Groups Are Split on Subsidizing Carbon Capture Technology," *YaleEnvironment360*, April 9, 2018.