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Carbon Capture and Sequestration (CCS) in the United States

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Summary

Carbon capture and sequestration (or storage)—known as CCS—is a process that involves capturing man-made carbon dioxide (CO_2) at its source and storing it permanently underground. (CCS is sometimes referred to as CCUS—carbon capture, *utilization*, and storage.) 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 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. Direct air capture is also an emerging technology, with the promise to remove atmospheric CO_2 directly and reduce its concentration.

The U.S. Department of Energy (DOE) has funded research and development (R&D) of aspects of CCS since 1997 within its Fossil Energy Research and Development (FER&D) portfolio. Since FY2010, Congress has provided more than $5 billion total in appropriations for DOE CCS-related activities. The Trump Administration proposed to reduce FER&D funding substantially in its FY2018 and FY2019 budget requests, but Congress has not agreed to the proposed reductions. In FY2018, Congress increased funding for DOE FER&D by nearly $59 million (9%) compared to FY2017, and the House- and Senate-passed appropriations bills for FY2019 would match or increase the appropriated amount compared to what Congress enacted for FY2018 ($727 million).

The Petra Nova plant in Texas is the only U.S. fossil-fueled power plant currently generating electricity and capturing CO_2 in large quantities (over 1 million tons per year). Globally, the Boundary Dam plant in Canada is the only other large-scale fossil-fueled power plant with CCS. Both facilities retrofitted post-combustion capture technology to units of existing plants, and both offset a portion of the cost of CCS by selling captured CO_2 for the purpose of enhanced oil recovery (EOR). Some CCS proponents point to the expanded Section 45Q of the Internal Revenue Code tax credits for CO_2 capture and sequestration or its use as a tertiary injectant for EOR or natural gas production that were enacted as part of P.L. 115-123 as a significant step toward incentivizing more development of large-scale CCS deployment like Petra Nova and Boundary Dam.

A number of bills introduced in the 115th Congress potentially would affect CCS in the United States. Several bills or provisions of bills address the Section 45Q tax credits (S. 1535, S. 1663, S. 2256, H.R. 1892, H.R. 2010, H.R. 3761, H.R. 4857). H.R. 1892, the Bipartisan Budget Act of 2018, enacted into law as P.L. 115-123, amended Section 45Q and increased the amount of the tax credit from $20 to $50 per ton of CO_2 for permanent sequestration, increased it from $10 to $35 for EOR purposes, and effectively removed the 75 million ton cap on the total amount of CO_2 injected underground, among other changes. Some proponents suggest that enactment of this provision could be a "game changer" for CCS, leading to more widespread adoption of the technology, although others question whether the increased incentives are large enough to affect CCS deployment.

Other bills address a suite of measures to advance CCS. Several would provide additional financial incentives, such as tax-exempt private activity bonds, and provisions that would enable eligibility of master limited partnerships for CCS infrastructure projects (S. 843, S. 2005, H.R. 2011, and H.R. 4118). One bill (S. 2602) could help advance CCS by making CCS infrastructure projects eligible under the FAST Act (42 U.S.C. 4370m(6)). Other bills (S. 2803, S. 2997, H.R. 2296) would support increased R&D for CCS, carbon utilization technologies, and direct air capture of CO_2. One bill (H.R. 4096) would authorize a $5 million prize to promote advances in CCS technology research and development.

There is broad agreement that costs for CCS would need to decrease before the technologies could be deployed commercially across the nation. The issue of greater CCS deployment is fundamental to the underlying reason CCS is deemed important by a range of proponents: to reduce CO_2 emissions (or reduce the concentration of CO_2 in the atmosphere) and to help mitigate against human-induced climate change.

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Carbon capture and sequestration (or storage)—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) purifying, compressing, and transporting the captured CO_2 to the 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 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 Research and Development portfolio (FER&D). Since FY2010, Congress has provided more than $5 billion in total appropriations for CCS activities within DOE FER&D (not including the one-time appropriation of $3.4 billion provided for CCS in the American Recovery and Reinvestment Act of 2009, P.L. 111-5).

In its FY2018 and FY2019 budget requests, the Trump Administration proposed to reduce FER&D funding compared to previous years. The Trump Administration's proposal differs from the policy trends of the previous two Administrations, which supported R&D on CCS and emphasized the development of large-scale demonstration projects—nearly first-of-their-kind ventures using technologies developed at a pilot or smaller scale that have been ramped up to commercial scale—to evaluate how CCS might be deployed commercially.

Congress did not accept the Administration's FY2018 request for DOE FER&D and instead increased funding by nearly $59 million (9%) compared to FY2017. In 2018 Congress also enacted legislation (Title II, Section 4119 of P.L. 115-123) that would increase the tax credit for capturing and sequestering or utilizing CO_2, leading many observers to predict increased CCS activity as a result.

This report includes a primer on the CCS (and carbon utilization) process and discusses the current state of CCS in the United States, as well as the DOE program for CCS R&D and CCS-related legislation in the 115th Congress.

CCS Primer

An integrated CCS system would include three main steps: (1) capturing and separating CO_2 from other gases; (2) purifying, 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 capture step, which is capital-intensive to build and requires a considerable amount of energy to operate (the amount of energy a power plant uses to capture and compress CO_2 is that much less electricity the plant can deliver to its customers; this is sometimes referred to as the *energy penalty* or the *parasitic load*). **Figure 1** shows the CCS process schematically from source to storage.

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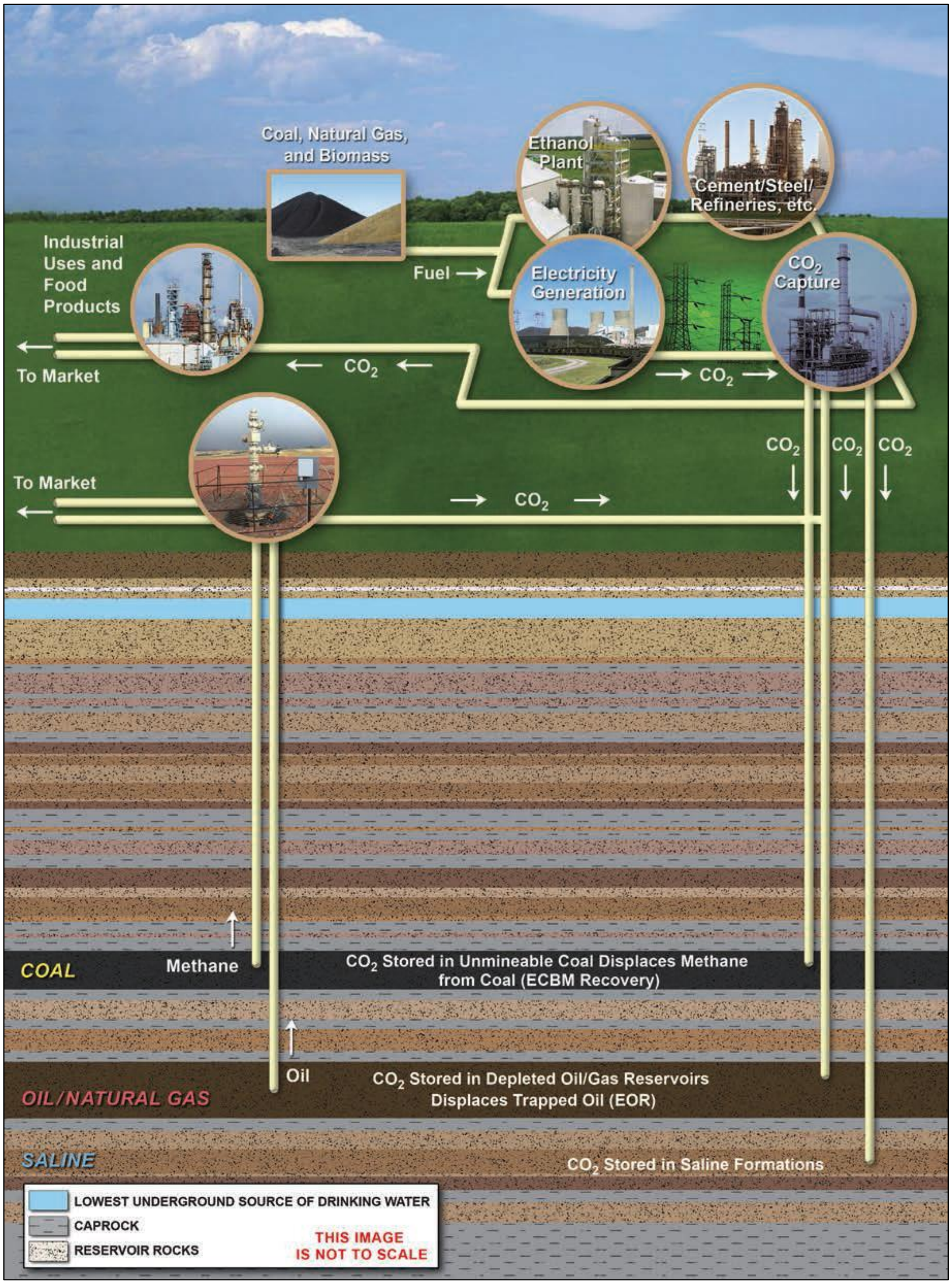
[1] Carbon capture and sequestration (CCS) also could be used to capture carbon dioxide (CO_2) emissions from power plants that use bioenergy sources instead of fossil fuels.

[2] See, for example, U.S. DOE, National Energy Technology Laboratory, *CO_2 Utilization Focus Area*, at https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development/co2-utilization.

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.

Note: *EOR* is enhanced oil recovery; *ECBM* is enhanced coal bed methane recovery. *Caprock* refers to a relatively impermeable formation. Terms are explained in "CO2 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 in use for EOR in regions of the United States today, and large quantities of fluids have been injected into the deep subsurface for a variety of purposes for decades, such as disposal of wastewater from oil and gas operations or of municipal wastewater. However, the transport and capture steps still face challenges, including economic and regulatory issues, rights-of-way, and questions regarding the permanence of CO_2 sequestration in deep geological reservoirs, as well as ownership and liability 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. Currently, three main approaches are available to capture CO_2 from large-scale industrial facilities or power plants: (1) post-combustion capture, (2) precombustion capture, and (3) oxy-fuel combustion capture. For power plants, current commercial CO_2 capture systems theoretically could operate at 85%-95% capture efficiency—meaning that 85% to 95% of all the CO_2 produced during the combustion process could be captured before it goes up the stack into the atmosphere.[3]

In a worst-case scenario, energy penalty in the capture phase of the CCS process may increase the cost of electricity by 80% and reduce an electricity-generating plant's net capacity by 20%.[4] Further, as much as 70%-90% of the total cost for CCS is associated with the capture and compression phases of CCS.[5] Other estimates indicate that the energy penalty could be lower, resulting in smaller impacts to subsequent electricity costs.[6] A detailed description and assessment of these capture technologies is provided in CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

Post-combustion Capture

The process of post-combustion 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.[7] 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.[8] 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.

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[3] DOE, NETL, "Carbon Capture Program," fact sheet, June 2016, at https://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/Carbon-Capture-Factsheet-June-2016.pdf.

[4] Ibid.

[5] White House, *Report of Interagency Task Force on Carbon Capture and Storage*, August 2010, p. 9, at https://energy.gov/sites/prod/files/2013/04/f0/CCSTaskForceReport2010_0.pdf.

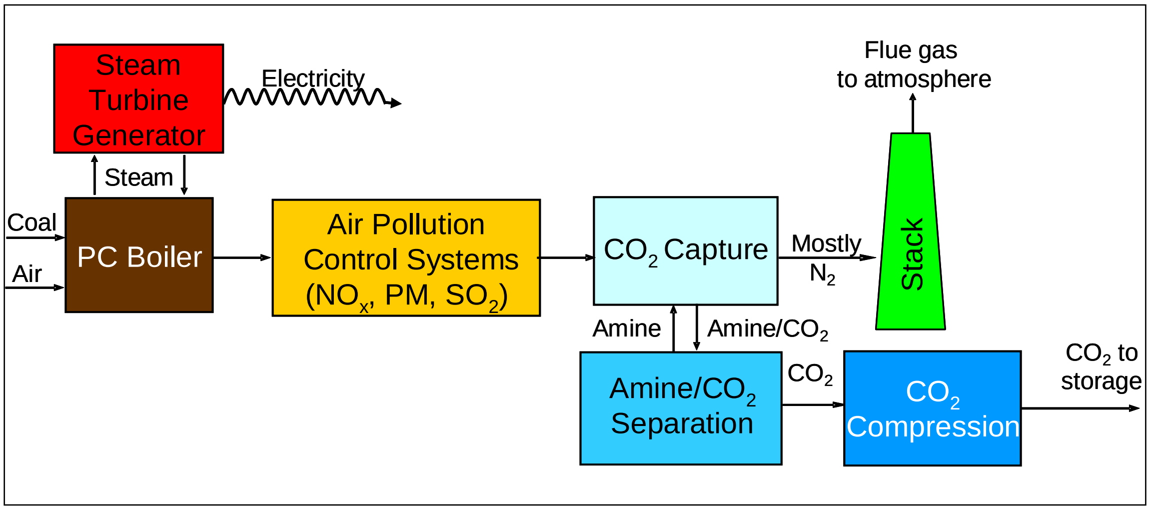
[6] See, for example, Howard J. Herzog, Edward S. Rubin, and Gary T. Rochelle, "Comment on 'Reassessing the Efficiency Penalty from Carbon Capture in Coal-Fired Power Plants,'" *Environmental Science and Technology*, vol. 50 (May 12, 2016), pp. 6112-6113.

[7] Flue gas refers to the emissions from combusting fossil fuels to generate steam at the plant. For post-combustion capture using air, the flue gas consists mostly of nitrogen, CO_2, and water vapor.

[8] 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.

Other than the Petra Nova plant (discussed in "Petra Nova: The First (and Only) Large U.S. Power Plant with CCS"), no large U.S. commercial electricity-generating plants currently capture large volumes of CO_2 (i.e., over 1 million tons per year). As the Petra Nova project indicates, the post-combustion capture process includes proven technologies that are commercially available today.

Figure 2. Diagram of Post-Combustion 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.

Precombustion Capture

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 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**).[9] 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—this is known as an integrated gasification combined-cycle plant (IGCC)—as depicted in **Figure 3**.

One example of precombustion capture technology in operation today is at 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 sale in the

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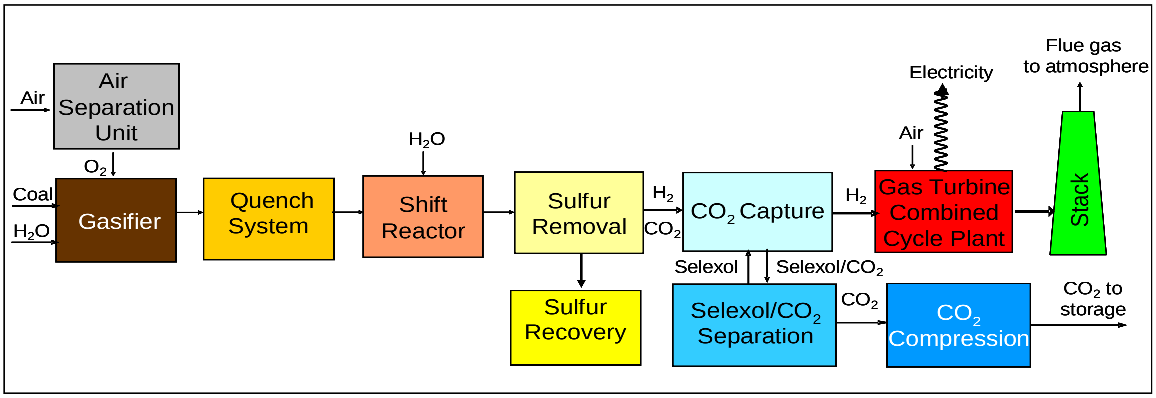
[9] See CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

natural gas market. The process also produces a stream of high-purity CO_2, which is piped northward into Canada for use in enhanced oil recovery (EOR)[10] at the Weyburn oil field.[11]

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.[12]

Currently oxy-fuel combustion projects are at the lab- or bench-scale ranging up to verification testing at a pilot scale.[13]

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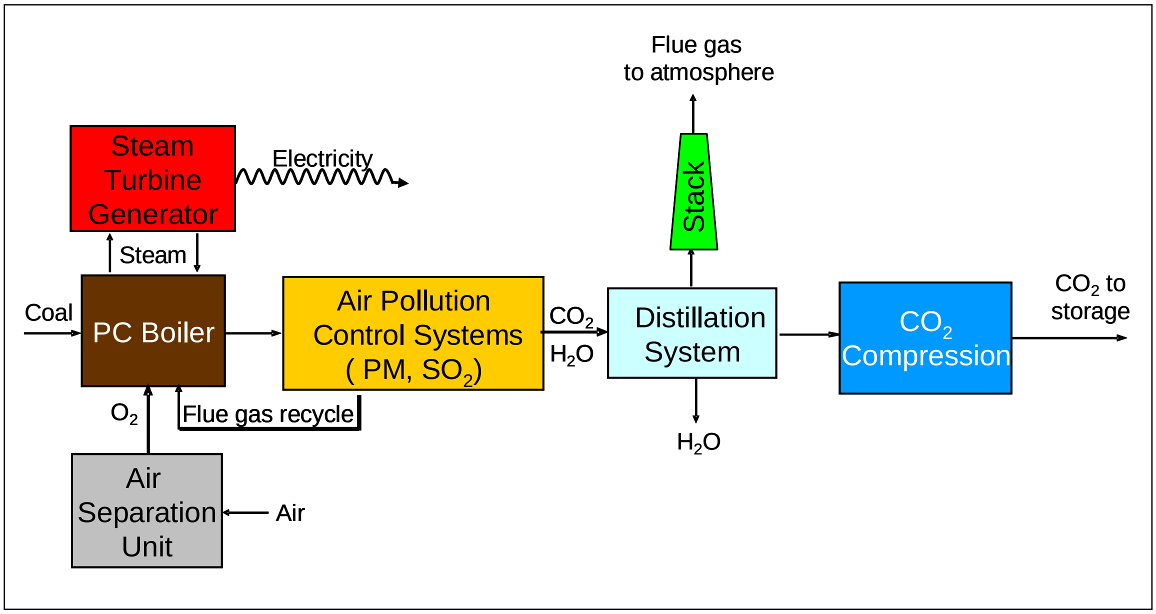
[10] Injecting CO_2 into an oil reservoir often increases or enhances production by lowering the viscosity of the oil, which allows it to be pumped more easily from the formation. The process is sometimes referred to as *tertiary recovery* or *enhanced oil recovery* (EOR).

[11] 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.

[12] Nitrogen oxides emissions lead to the formation of ozone, a criteria pollutant.

[13] For more information see DOE, National Energy Technology Laboratory, *Oxy-Combustion*, at https://www.netl.doe.gov/research/coal/energy-systems/advanced-combustion/oxy-combustion.

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.

CO_2 Transport

After the CO_2 capture step, the gas is purified and compressed to produce a concentrated stream for transport. Pipelines are the most common method for transporting CO_2 in the United States. Currently, approximately 4,500 miles of pipelines transport CO_2 in the United States, predominately to oil fields,[14] where it is used for EOR. 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.[15] Typically, CO_2 would be compressed prior to transportation into a supercritical state,[16] making it dense like a liquid but fluid like a gas.

Using ships may be feasible when CO_2 must be transported over large distances or overseas. Liquefied natural gas, propane, and butane are routinely shipped by marine tankers on a large scale worldwide. Ships transport CO_2 today, but at a small scale because of limited demand. Rail cars and trucks also can transport CO_2, but this mode probably would be uneconomical for large-scale CCS operations.

Costs for pipeline transport vary, depending on construction, operation and maintenance, and other factors, including right-of-way costs, regulatory fees, and more. The quantity and distance transported will mostly determine costs, which also will depend on whether the pipeline is onshore or offshore; the level of congestion along the route; and whether mountains, large rivers,

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[14] Mathew Wallace et al., *A Review of the CO2 Pipeline Infrastructure in the U.S.*, DOE, DOE/NETL-2014/1681, April 21, 2015, at https://energy.gov/sites/prod/files/2015/04/f22/QER%20Analysis%20-%20A%20Review%20of%20the%20CO2%20Pipeline%20Infrastructure%20in%20the%20U.S_0.pdf.

[15] Intergovernmental Panel on Climate Change (IPCC) Special Report, *Carbon Dioxide Capture and Storage*, 2005, p. 181, at https://www.ipcc.ch/report/srccs/. Hereinafter referred to as IPCC Special Report.

[16] Also, when injected underground to depths greater than 800 meters (about half a mile), the overlying pressure keeps CO_2 in a supercritical state, making it less likely to migrate out of the geological formation.

or frozen ground are encountered. Shipping costs are unknown in any detail, because no large-scale CO_2 transport system via ship (in millions of tons of CO_2 per year, for example) is operating.[17] Ship costs might be lower than pipeline transport for distances greater than 1,000 kilometers and for less than a few million tons of CO_2 transported per year.[18]

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 observers note 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 beyond the current joint federal-state regulatory policy.[19] One recommendation from stakeholders is for federal regulators to build on state experience for siting CO_2 pipelines, for example.[20]

CO_2 Sequestration

Three main types of geological formations are being considered for carbon sequestration: (1) depleted oil and gas reservoirs, (2) deep saline reservoirs, and (3) unmineable coal seams. In each case, CO_2 would be injected in a supercritical state—a relatively dense fluid—below ground into a porous rock formation 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 CO2 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.

DOE's Regional Carbon Sequestration Partnership Initiative has been actively pursuing a three-phase approach to the sequestration step in the CCS process since 2003. It is currently in the development phase.[21] The development phase includes implementation of large-scale field testing of approximately 1 million tons of CO_2 per project to confirm the safety, permanence, and economics of industrial-scale CO_2 storage in seven different regions of the United States.[22] The development phase began in 2008 and is projected to last through 2018 and possibly beyond.

The storage capacity for CO_2 in geological formations is potentially huge if all the sedimentary basins in the world are considered.[23] 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**).[24]

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[17] 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.

[18] IPCC Special Report, p. 31.

[19] Mathew Wallace et al., *A Review of the CO_2 Pipeline Infrastructure in the U.S.*, DOE, April 21, 2015, p. 1.

[20] Ibid.

[21] DOE, NETL, "Regional Carbon Sequestration Partnership (RCSP) Initiative," at https://www.netl.doe.gov/research/coal/carbon-storage/carbon-storage-infrastructure/rcsp.

[22] Ibid.

[23] 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.

[24] For comparison, in 2016 the United States emitted 1.8 billion tons of CO_2 from the electricity generating sector. See U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016*, EPA 430-R-18-003, April 12, 2018, pp. ES-6, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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.[25] For CCS to succeed, 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.

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, enhanced oil recovery) is practiced in the petroleum industry today. 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.[26] 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. Both of the currently operating large electricity-generating plants with CCS, Boundary Dam and Petra Nova (discussed below in "Coal-Fired Power Plants with CCS"), offset some of the costs by selling the captured CO_2 for EOR.

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[25] 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.

[26] 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.

Carbon dioxide 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.[27] 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 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.[28] 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.

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.[29] 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.[30] 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 for offsetting the cost of CO_2 capture. The carbon utilization process is often referred to in legislative language and elsewhere as CCUS.[31] (See, for example, S. 2803, S. 2997, H.R. 2296, discussed below in "CCS-Related Legislation in the 115th Congress.")

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[27] 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.

[28] 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.

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

[30] IPCC Special Report, p. 217.

[31] DOE's Office of Fossil Energy refers to its CCS program activities as the Carbon Capture, Utilization, and Storage

P.L. 115-123, the Bipartisan Budget Act of 2018, defines carbon utilization as

- the fixation of such qualified carbon oxide through photosynthesis or chemosynthesis, such as through the growing of algae of 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].[32]

Figure 2 illustrates an array of potential utilization pathways ranging from food and fuels to solid building materials like cement to fertilizers. DOE notes that many of the uses shown in **Figure 2** are small scale and typically emit the CO_2 back to the atmosphere after use, negating the initial reduction in overall CO_2 emissions.[33] DOE sponsors research to develop technologies capable of manufacturing stable products using CO_2 and storing it in a form that will not escape to the atmosphere. The four main areas of DOE-sponsored research in this area are for (1) cement; (2) polycarbonate plastics; (3) mineralization (conversion of CO_2 to carbonates); and (4) enhanced oil (EOR) and gas recovery.[34] Using CO_2 for EOR currently dominates the estimated 80 million tons of CO_2 used worldwide,[35] and CCUS proponents indicate that EOR likely will continue as the dominant use in the short to medium term.[36]

Research. See https://www.energy.gov/fe/science-innovation/office-clean-coal-and-carbon-management.

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

[33] U.S. DOE, National Energy Technology Laboratory, CO_2 Utilization Focus Area, at https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development/co2-utilization.

[34] U.S. DOE, National Energy Technology Laboratory, CO_2 Utilization Focus Area.

[35] Reflects an estimate as of 2011, which included 50 million tons for EOR in the United States. Global CCS Institute, *Accelerating the Uptake of CCS: Industrial use of Captured Carbon Dioxide*, December 20, 2011, http://hub.globalccsinstitute.com/publications/accelerating-uptake-ccs-industrial-use-captured-carbon-dioxide. CO2 use for EOR in the United States in 2014 was estimated at 68 million tons in 2014 (see footnote 38), so the global amount is likely higher.

[36] Global CCS Institute, 2011.

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

Source: U.S. DOE, National Energy Technology Laboratory, CO_2 Utilization Focus Area, at https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development/co2-utilization.

Notes: Enhanced fuel recovery is not considered carbon utilization under P.L. 115-123 for the purposes of tax credits under Section 45Q of the Internal Revenue Code.

Direct Air Capture

Direct air capture (DAC) is an emerging set of technologies that aims 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").

DAC systems typically employ a chemical capture system to separate CO_2 from ambient air, addition of energy to separate the captured CO_2 from the chemical substrate, and removal of the purified CO_2 to be stored permanently or utilized for other purposes (**Figure 5**).[37]

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 wouldn't 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,

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[37] 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.

compared to the more conventional CCS technologies.[38] A 2011 assessment estimated costs at roughly $600 per ton of captured CO_2.[39] A more recent assessment from one of the companies developing DAC technology, however, projects lower costs for commercially deployed plants between $94 and $232 per ton.[40] By comparison, some estimate costs for conventional CCS from coal-fired electricity generating plants in the United States between $48 and $109 per ton.[41]

Legislation introduced in the 115th Congress, S. 2602 (the USE IT Act, see **Table 2**), includes the purpose "to support carbon dioxide utilization and direct air capture research" among other purposes, and contains language for a technology prize that would be awarded for DAC projects that capture more than 10,000 tons per year at a cost of less than $200 per ton CO_2 captured. H.R. 4096, the Carbon Capture Prize Act, would offer a prize for technology developed to reduce the amount of CO_2 in the atmosphere, which would include DAC technologies.

Coal-Fired Power Plants with CCS

Globally, two fossil-fueled power plants currently generate electricity and capture CO_2 in large quantities: the Boundary Dam plant in Canada and the Petra Nova plant in Texas. Both plants retrofitted post-combustion capture technology to units of existing plants. (The different types of carbon capture technologies are discussed above in "CCS Primer.")

Petra Nova: The First (and Only) Large U.S. Power Plant with CCS

The Petra Nova–W.A. Parish Generating Station is the first industrial-scale coal-fired electricity-generating plant with CCS to operate in the United States. On January 10, 2017, the plant began capturing approximately 5,000 tons of CO_2 per day from its 240-megawatt-equivalent slipstream using post-combustion capture technology.[42] 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 projected to capture between 1.4 million and 1.6 million tons of CO_2 each year.[43] The captured CO_2 is transported via an 82-mile pipeline to the West Ranch oil field, where it is injected for enhanced oil recovery (EOR). NRG Energy, Inc., and JX Nippon Oil & Gas Exploration Corporation, the joint owners of the Petra Nova project, together with Hilcorp

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[38] 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%.

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

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

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

[42] 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.

[43] Global CCS Institute, Projects Database, "Petra Nova Carbon Capture," at http://www.globalccsinstitute.com/projects/petra-nova-carbon-capture-project; and Christa Marshal and Edward Klump, "Carbon Capture Takes a 'Huge Step' with First U.S. Plant," *Energy Wire*, January 10, 2017, at https://www.eenews.net/energywire/stories/1060048090/search?keyword=petra+nova.

Energy Company (which handles the injection and EOR), expect to increase West Ranch oil production from 300 barrels per day before EOR to 15,000 barrels per day after EOR.[44]

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 (Recovery Act; P.L. 111-5) together with other DOE FER&D funding for a total of more than $190 million of federal funds for the $1 billion retrofit project.[45] Petra Nova is the only CCPI Round 3 project that expended its Recovery Act funding and is currently operating.[46] The three other CCPI Round 3 demonstration projects funded using Recovery Act appropriations, (as well as the FutureGen project—slated to receive nearly $1 billion in Recovery Act appropriations) all have been canceled, have been suspended, or remain in development.[47]

The Petra Nova plant is projected to capture more CO_2 per year than the other currently operating power plant with CCS, Canada's Boundary Dam (which is designed to capture about 1 million tons per year; see "Boundary Dam: World's First Addition of CCS to a Large Power Plant," below). Petra Nova also generates more electricity than Boundary Dam, about 240 megawatts compared to Boundary Dam's 115 megawatts. Both projects retrofitted one unit of much larger multi-unit electricity-generating plants. The Petra Nova project retrofitted Unit 8 of the W.A. Parish power plant, which in total consists of four coal-fired units and six gas-fired units, comprising more than 3.7 gigawatts of gross capacity, making it one of the largest U.S. power plants.

In 2015, the entire W.A. Parish complex emitted nearly 15 million tons of CO_2 from all of its generating units.[48] The Petra Nova project reduces CO_2 emissions overall from the entire complex by about 11%. By comparison, in 2016, total U.S. CO_2 emissions from the electricity-generating sector were about 1.8 billion tons.[49] The Petra Nova project would reduce that total by a small percentage (about 0.08%). However, according to DOE, a purpose of Petra Nova was to demonstrate that post-combustion capture and reuse can be done economically for existing plants when there is an opportunity to recover oil from nearby oilfields. DOE also has stated that the success of Petra Nova has the potential to enhance the long-term viability and sustainability of coal-fueled power plants across the United States and throughout the world.[50]

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[44] 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.

[45] 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.

[46] 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.

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

[48] U.S. Environmental Protection Agency, "2015 Greenhouse Gas Emissions from Large Facilities, W.A. Parish," at https://ghgdata.epa.gov/ghgp/service/facilityDetail/2015?id=1006868&ds=E&et=FC_CL&popup=true.

[49] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016*, EPA 430-R-18-003, April 12, 2018, pp. ES-6, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

[50] DOE, 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.

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,[51] cost approximately $1.3 billion according to one source.[52] 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.[53]

Similar to the Petra Nova project discussed above, 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 April 2018, the plant had captured over 2 million tons of CO_2 since full-time operations began in October 2014.[54] The 115-megawatt (net) plant plans to capture at least 1 million tons of CO_2 per year.[55]

The DOE CCS Program

DOE has funded R&D of aspects of the three main steps leading to an integrated CCS system since 1997. Since FY2010, Congress has provided more than $5 billion total in annual appropriations for CCS activities at DOE. The Recovery Act provided an additional $3.4 billion to that total.[56]

CCS-focused R&D has come to dominate the coal program area within DOE FER&D since 2010. However, the Trump Administration's FY2019 budget request proposes to shift to other priorities, decreasing the overall FER&D budget by nearly $225 million compared to what Congress enacted for FY2018. The FY2019 budget request cites early-stage research as its focus: "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." The Trump Administration's approach would be a reversal of Obama Administration and George W. Bush Administration DOE policies, which supported large carbon-capture demonstration projects and large injection and sequestration demonstration projects. The Administration previously proposed cuts to FER&D in its FY2018

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

[52] 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.

[53] Ibid.

[54] SaskPower, *BD3 Status Update: April 2018*, at https://www.saskpower.com/about-us/our-company/blog/bd3-status-update-april-2018.

[55] Net power refers to the gross amount of power generated by the plant minus the electricity used to operate the plant. In this case, the electricity used to operate the plant includes the amount of electricity used for carbon capture.

[56] Authority to expend American Recovery and Reinvestment Act (Recovery Act; P.L. 111-5) funds expired in 2015. An analysis of Recovery Act 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.

budget request; however, Congress increased funding by nearly $59 million (9%) compared to FY2017.

For FY2019, House-passed appropriations legislation would increase overall funding for DOE FER&D by over $58 million compared to the FY2018 amount, and $283 million above the Administration budget request.[57] The Senate-passed version of the appropriations bill would fund DOE FER&D at about the same level as the FY2018 amount, $727 million, also substantially greater than the Administration's request for $502 million.[58]

Table 2 shows the funding for DOE CCS programs under FER&D from FY2010 through FY2018 and includes the President's FY2019 budget request. **Table 2** groups mostly CCS-related programs under the Coal CCS and Power Systems category and the remainder of fossil energy spending under Other Fossil Energy R&D. This grouping follows how Congress has funded these programs. Congress did not accept the Administration's proposed restructuring of the FER&D portfolio in FY2018.

Coal CCS and Power Systems

Compared to the FY2018 total of $727 million enacted for all FER&D, the Administration's FY2019 request of $502 million would be a reduction of approximately 31%. Carbon capture and carbon storage (**Table 2**) would receive $40 million total under the Administration's request, compared to nearly $200 million for FY2018, an 80% reduction.

The Administration's FY2019 budget request would prioritize the Advanced Energy Systems (AES) account, requesting $175 million, $63 million above the FY2018-enacted amount, nearly a 44% increase. The budget request indicates that AES would focus on six activities: advanced combustion/gasification, advanced turbines, solid oxide fuel cells, advanced sensors and controls, power generation efficiency, and advanced energy materials. Other accounts under the Coal CCS & Power Systems program area are proposed to be funded slightly above or slightly below FY2018 levels, with the exception of CCS activities. Reductions to CCS-related funding would comprise nearly all of the proposed decreased funding for activities in the Coal CCS & Power Systems program area.

Other Fossil Energy Research and Development

The budget request for FY2019 proposes to decrease funding for programs under Other Fossil Energy R&D by nearly $87 million, a 35% reduction compared to FY2018. Program Direction ($60 million in FY2018) provides DOE headquarters support and federal field and contractor support of the FER&D programs overall. Program Direction and National Energy Technology Laboratory (NETL) Coal R&D together provide support to CCS-related activities directly and indirectly.

The budget request proposes to decrease funding for Natural Gas Technologies and Unconventional Fossil activities compared to what Congress enacted in FY2018, from $90 million to $19.5 million for both programs combined. For FY2018, Congress increased funding

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[57] U.S. Congress, House Committee on Appropriations, Subcommittee on Energy and Water Development, and Related Agencies, *Energy and Water Development Appropriations Bill, 2019*, Report to accompany H.R. 5895, 115th Cong., 2nd sess., May 21, 2018, H.Rept. 115-697 (Washington: GPO, 2018), p. 93.

[58] U.S. Congress, Senate Committee on Appropriations, Subcommittee on Energy and Water Development, *Energy and Water Development Appropriations Bill, 2019*, report to accompany S. 2975, 115th Cong., 2nd sess., May 24, 2018, S.Rept. 115-258 (Washington: GPO, 2018), p. 84.

for those activities (by $16 million compared to FY2017), which support collaborative research to foster development of shale gas resources, the reduction of methane emissions from natural gas infrastructure, and research on gas hydrates. The budget request proposes to eliminate funding for Transformational Coal Pilot programs (called New Fossil Pilot in FY2017). Congress provided $50 million for the program in FY2017 and $35 million in FY2018.[59]

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[59] In FY2017, Congress rescinded $240 million in unobligated balances from the total FER&D account. The FY2019 Administration request subtracted the rescission from the total FY2017 FER&D enacted amount in its budget justification. **Table 2** does not show that rescission, but it reflects what Congress included in its budget documents for FY2017—$668 million total enacted for FER&D. The congressional Joint Explanatory Statement for FY2017 shows the $240 million rescission offsetting DOE's total appropriations.

Table 2. Funding for DOE Fossil Energy Research, Development, and Demonstration Program Areas

(FY2010 through FY2018, including the Trump Administration's FY2019 budget request)

FER&D Coal 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 Request ($1,000)
Coal CCS and Power Systems	**Carbon Capture**	—	58,703	66,986	63,725	92,000	88,000	101,000	101,000	100,671	20,000
	Carbon Storage	—	120,912	112,208	106,745	108,766	100,000	106,000	95,300	98,096	20,000
	Advanced Energy Systems	—	168,627	97,169	92,438	99,500	103,000	105,000	105,000	112,000	175,000
	Cross-Cutting Research	—	41,446	47,946	45,618	41,925	49,000	50,000	45,500	58,350	53,300
	Supercritical CO_2 Technology	—	—	—	—	—	10,000	15,000	24,000	24,000	25,000
	NETL Coal R&D	—	—	35,011	33,338	50,011	50,000	53,000	53,000	53,000	50,000
	Transformational Coal Pilots	—	—	—	—	—	—	—	—	35,000	0
Subtotal Coal		**393,485**	**389,688**	**359,320**	**341,864**	**392,202**	**400,000**	**430,000**	**423,800**	**481,117**	**343,300**
Other FER&D	**Natural Gas Technologies**	17,364	0	14,575	13,865	20,600	25,121	43,000	43,000	50,000	5,500
	Unconventional Fossil	19,474	0	4,859	4,621	15,000	4,500	20,321	21,000	40,000	14,000
	Program Direction	158,000	164,725	119,929	114,201	120,000	119,000	114,202	60,000	60,000	61,070
	Plant and Capital	20,000	19,960	16,794	15,982	16,032	15,782	15,782	—	—	—
	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	200
	NETL R&D	—	—	—	—	—	—	0	43,000	50,000	40,000
	NETL Inf. & Ops	—	—	—	—	—	—	0	40,500	45,000	38,000
	Coop R&D	4,868	—	—	—	—	—	—	—	—	—

	New Fossil Pilot	—	—	—	—	—	—	—	50,000	—	—
	Directed Projects	35,879	—	—	—	—	—	—	—	—	—
Subtotal Other FER&D		**266,285**	**195,364**	**164,754**	**156,851**	**178,229**	**171,000**	**202,000**	**258,200**	**245,700**	**158,770**
Rescissions/Use of Prior-Year Balances		—	(151,000)	(187,000)	—	—	—	—	(14,000)	—	—
Total FER&D		**659,770**	**434,052**	**337,074**	**498,715**	**570,431**	**571,000**	**632,000**	**668,000**	**726,817**	**502,070**
								FY2010-FY2018	**Grand Total**	**$5.1B**	

Sources: U.S. Department of Energy annual budget justifications for FY2012 through FY2019; explanatory statement for P.L. 115-141, Division D (Consolidated Appropriations Act, 2018, https://rules.house.gov/bill/115/hr-1625-sa).

Notes: CO_2 = Carbon dioxide; CCS = carbon capture and sequestration (or storage); FER&D = Fossil Energy Research and Development; NETL = National Energy Technology Laboratory; Inf. & Ops = Infrastructure and Operations; Coop = Cooperative; R&D = Research and development. Directed Projects refer to congressionally directed projects. Grand total for FY2010-FY2018 subject to rounding. Amounts provided by the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) are not shown in the table or included in the grand total.

CCS-Related Legislation in the 115th Congress

A number of bills introduced in the 115th Congress would potentially affect CCS in the United States. Several bills or provisions of bills address Internal Revenue Code, Section 45Q, providing tax credits for CO_2 capture and sequestration or use as a tertiary injectant for EOR or natural gas production (S. 1535, S. 1663, S. 2256, H.R. 1892, H.R. 2010, H.R. 3761, H.R. 4857, (see **Appendix**). H.R. 1892, the Bipartisan Budget Act of 2018, was enacted into law as P.L. 115-123. The provisions of P.L. 115-123 that amended Section 45Q and their implications are discussed in more detail in the text box below.

Other bills also would amend the Internal Revenue Code in ways affecting CCS. For example, S. 843 and H.R. 2011 would amend Section 142 of the Internal Revenue Code to allow qualified CO_2 capture facilities that capture 65% or more of their CO_2 emissions to be eligible for tax-exempt private activity bonds.[60] The bills assert that

> allowing tax-exempt financing for the purchase of capital equipment that is used to capture carbon dioxide will reduce the costs of developing carbon dioxide capture projects, accelerate their deployment, and, in conjunction with carbon dioxide utilization and long-term storage, help the United States meet critical environmental, economic, and national security goals.

Several bills would address federal efforts to enhance CCS or emphasize different aspects of the process across three different federal agency and departmental jurisdictions: EPA, DOE, and the Department of Agriculture. S. 2602, for example, would authorize activities under EPA jurisdiction to support direct air capture and utilization of CO_2, and would include carbon capture infrastructure projects as eligible under the FAST Act, as part of the bill's intent to expedite the permitting process for CCS. The legislation would add CCS infrastructure projects explicitly as eligible *covered* projects, meaning any infrastructure construction activity requiring authorization or environmental review by a federal agency.[61]

S. 2803 would amend the Energy Policy Act of 2005 (P.L. 109-58) to authorize DOE to further its CCS research, development, and deployment (RD&D) activities, and place a greater emphasis on CO_2 utilization. The bill would also authorize a project aimed to achieve net-negative CO_2 emissions—projects utilizing biomass and fossil fuels to produce electricity, fuels, or chemicals—with a net removal of CO_2 from the atmosphere. S. 2997 would authorize the Secretary of Agriculture to pursue biomass-related CCS R&D projects, and would authorize the use of loans or loan guarantees for biomass-related CO_2 capture and utilization activities. H.R. 2296 would focus on DOE CCS-related activities and require the department to evaluate its RD&D projects and make recommendations whether each project should continue to receive funding based on progress toward its CCS goals. Lastly, H.R. 4096 would establish a $5 million prize for CCS-

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[60] The Findings section of both bills states that "since 1968, tax-exempt private activity bonds have been used to provide access to lower-cost financing for private businesses that are purchasing new capital equipment for certain specified environmental facilities, including facilities that reduce, recycle, or dispose of waste, pollutants, and hazardous substances."

[61] P.L. 114-94, the Fixing America's Surface Transportation Act (FAST Act). Currently under the FAST Act, "the term 'covered project' means any activity in the United States that requires authorization or environmental review by a Federal agency involving construction of infrastructure for renewable or conventional energy production, electricity transmission, surface transportation, aviation, ports and waterways, water resource projects, broadband, pipelines, manufacturing, or any other sector as determined by a majority vote of the Council." See 42 U.S.C. 4370m(6).

related technology development and commercialization, pursuant to Section 24 of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3719).[62]

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[62] P.L. 96-480.

P.L. 115-123: Amending the 45Q Tax Credit for CCS

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 enhanced oil recovery (EOR) or natural gas development 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.) Prior to enactment, the 45Q Section allowed for a tax credit of $20 per ton of CO_2 captured and permanently sequestered, and $10 per ton for CO_2 captured and used as a tertiary injectant (typically for enhanced oil recovery, EOR). These credit amounts were adjusted annually for inflation, and for 2017 the credit amounts were $22.48 and $11.24. The credit is effectively capped at 75 million metric tons of qualified CO_2 captured or injected.

Some observers noted that the 75 million ton cap did not provide enough financial certainty for investors in typically capital-intensive CCS construction projects. Proponents of CCS also pointed to the difficulty in transferability of the credits, and the small value of the credits, as impediments to more widespread adoption of CCS.

The new law raises the tax credit linearly from $22.66 to $50 per ton over the period from 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 would be indexed to inflation. It also removes the 75 million ton cap, but requires that the credit be claimed over a 12-year period after operations begin. Additionally, to qualify, facilities must begin construction before 2024.

To qualify, a minimum amount of CO_2 is required to be captured and stored or utilized by the facility. 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 doesn't meet the other criteria just described must capture at least 100,000 tons per year.

The modifications to 45Q in P.L. 115-97 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. CCS proponents indicate that this provides greater flexibility for companies with different business models to utilize the tax credit effectively, including cooperative and municipal utilities.

Some stakeholders suggest that the changes to 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. 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 the 45Q expansion include 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. 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 fiscal years 2018 and 2027. Other groups note that measures in addition to the 45Q expansion will be needed to lower CCS costs and promote broader deployment.

Sources: P.L. 115-123; Center for Carbon Removal, *What Does 45Q Mean for Carbontech?*, April 15, 2018, http://www.centerforcarbonremoval.org/blog-posts/2018/4/15/what-does-45q-mean-for-carbontech-1; Frederick R. Eames and Davis S. Lowman, Jr., *Section 45Q Tax Credit Enhancements Could Boost CCS*, The Nickel Report, Hunton & Williams LLP, February 22, 2018, at https://www.huntonnickelreportblog.com/2018/02/section-45q-tax-credit-enhancements-could-boost-ccs/; Bellona Europa, *Will Changes to the US Budget Act of 2018 Incentivise CCS in the US?*, March 8, 2018, http://bellona.org/news/ccs/2018-03-will-changes-to-the-us-budget-act-of-2018-incentivise-ccs-in-the-us; Carbon Capture Coalition, *Key Provisions of Congressional Legislation to Extend and Reform the Federal 45Q Tax Credit*, at http://carboncapturecoalition.org/legislation/; Clean Water Action, *Sign-On Letter: Oppose Expanding the Section 45Q Tax Credit for Oil, Gas and Coal Companies*, November 7, 2017, https://www.cleanwateraction.org/publications/sign-letter-oppose-expanding-section-45q-tax-credit-oil-gas-and-coal-companies; and Joint Committee on Taxation, *Estimated Effects of the Revenue Provisions Contained in the*

"Bipartisan Budget Act of 2018," JCX-4-18, February 8, 2018, https://www.jct.gov/publications.html?func=startdown&id=5061; Center for Climate and Energy Solutions (C2ES), *Letter to Senate Leaders*, https://www.c2es.org/press-release/letter-to-senate-leaders/.

Discussion

Currently the Petra Nova plant in Texas is the sole U.S. commercial large-scale fossil-fueled power plant with CCS, capturing over 1 million tons of CO_2 annually. The Boundary Dam power plant in Canada is the only other commercial fossil-fueled electricity generating plant in the world operating with CCS and capturing a nearly equivalent volume of CO_2. Both plants offset a portion of the cost of CCS by selling CO_2 for the purpose of enhanced oil recovery. Some CCS proponents have hailed the expanded tax credit provision enacted as part of P.L. 115-123, increasing the value of tax credits under Section 45Q of the Internal Revenue Code, as a potential "game changer" for incentivizing more development of large-scale CCS deployment like Petra Nova and Boundary Dam.

Some CCS proponents advocate for other incentives, such as tax-exempt private activity bonds, and enabling eligibility of master limited partnerships for CCS infrastructure projects, which could also increase the financial attractiveness of large-scale capital-intensive CCS endeavors. According to CCS proponents, private activity bonds would allow CCS project developers access to tax-exempt debt, thus lowering their capital costs. Master limited partnerships would allow a corporate structure to combine the tax benefits of a partnership with a corporation's ability to raise capital, reducing the cost of equity and providing access to capital on more favorable terms, according to proponents.

Members of Congress have introduced legislation that would authorize these financial incentives, as well as a suite of other bills aimed at advancing CCS by making CCS infrastructure projects eligible under the FAST Act (42 U.S.C. 4370m(6)), supporting increased research and development for conventional CCS and for carbon utilization technologies and direct air capture of CO_2. Several bills would authorize technology prizes for advances in CCS R&D, including for utilization technologies and direct air capture.

P.L. 115-123 was enacted on February 9, 2018, and it likely will take time to evaluate the impact on U.S. CCS activities. Other factors, such as the price of oil, which could affect demand for EOR and thus CO_2, and the price of natural gas—which could affect the substitution of natural gas for coal in electricity production—will also shape the extent and rapidity of CCS adoption as well. Enactment of other legislation introduced in the 115th Congress (**Appendix**) that would provide additional incentives for CCS could also influence future CCS activities.

Ultimately the success of legislative approaches advocated by bill sponsors, and more broadly by CCS proponents, will be measured by how those approaches reduce costs for CCS, through financial incentives, technology development, and commercially viable CO_2-based products, so that the suite of CCS technologies would be more broadly deployed. Absent a policy mandate for reducing CO_2 emissions, or rewarding CO_2 capture and storage or utilization (apart from the 45Q tax incentives enacted in P.L. 115-123), there is broad agreement that costs for CCS would need to decrease before the technologies are commercially deployed across the nation.

The issue of greater CCS deployment is fundamental to the underlying reason CCS is deemed important by a range of proponents: to reduce CO_2 emissions (or reduce the concentration of CO_2 in the atmosphere) and help mitigate against human-induced climate change. The conventional concept of CCS whereby CO_2 emissions from large stationary sources in the United States, such as fossil fuel electricity generating plants, refineries, cement plants, and others was recognized early on as a potential pathway to reducing a large amount greenhouse gas emissions from a relatively small number of point sources.[63] The U.S. fossil fuel electricity generation sector alone emitted 1.8 billion tons of CO_2 in 2016, or 34% of total U.S. CO_2 emissions (5.31 billion tons) that year.[64]

The emerging technologies for utilizing CO_2 for a variety of uses and products (carbon utilization, see **Figure 5**) has energized some CCS advocates because of the commercial potential and prospects for the sequestration of CO_2 in long-lasting products such as cements and plastics. A challenge for utilization advocates is whether the market for carbon utilization products and uses is sufficiently large so that the amount of CO_2 captured or removed from the atmosphere has some measurable effect on human-induced climate change.

Direct air capture (DAC) also has energized some CCS advocates as it offers the promise of net-negative carbon removal if the CO_2 removed by DAC is permanently stored or sequestered. The challenge for DAC is fairly straightforward—how to reduce the cost per ton of CO_2 removed.

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[63] IPCC Special Report.

[64] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016*, EPA 430-R-18-003, April 12, 2018, pp. ES-6, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Table A-1. CCS-Related Legislation in the 115th Congress

Bill Number	Short Title	Status	Short Summary
S. 843	Carbon Capture Improvement Act of 2017	Referred to Committee on Finance	Amends the Internal Revenue Code to authorize the issuance of tax-exempt facility bonds for the financing of qualified carbon dioxide capture facilities. Related bill H.R. 2011.
S. 1535	Furthering Carbon Capture, Utilization, Technology, Underground Storage, and Reduced Emissions Act	Referred to Committee on Finance	Amends the Internal Revenue Code, Section 45Q, to increase the carbon oxide sequestration credit from $20 per metric ton for permanent sequestration, and $10 per ton as a tertiary injectant for enhanced oil and gas recovery, to $22.66 up to $50 per ton through 2027 and $12.83 up to $35 per ton over the same time span for permanent sequestration and enhanced oil and gas recovery, respectively. Includes direct air capture facilities with other industrial facilities as qualified facilities for the credits. Includes carbon utilization as one of the categories eligible for the credit. Related bills S. 2256, H.R. 1892, H.R. 3761.
S. 1663	CO_2 Regulatory Certainty Act	Referred to Committee on Finance	Amends the Internal Revenue Code to revise requirements for the secure geological storage of carbon dioxide for the purpose of the tax credit for carbon dioxide sequestration. Establishes a December 31, 2017, deadline and requirements for regulations that the Internal Revenue Service (IRS) is required, under current law, to establish for determining adequate security measures for the geological storage of the carbon dioxide such that carbon dioxide does not escape into the atmosphere. Related bills H.R. 2010, H.R. 4857.
S. 2005	Master Limited Partnerships Parity Act	Referred to Committee on Finance	Amends the Internal Revenue Code, with respect to the tax treatment of publicly traded partnerships as corporations, to expand the definition of “qualifying income" for such partnerships (known as master limited partnerships) to include income and gains from renewable and alternative energy generation projects, including carbon capture in secure geological storage. Related bill H.R. 4118.
S. 2256	Tax Extender Act of 2017	Referred to Committee on Finance	Title IV: amends the Internal Revenue Code, Section 45Q, to increase the carbon oxide sequestration credit from $20 per metric ton for permanent sequestration, and $10 per ton as a tertiary injectant for enhanced oil and gas recovery, to $22.66 up to $50 per ton through 2027 and $12.83 up to $35 per ton over the same time span for permanent sequestration and enhanced oil and gas recovery, respectively. Includes direct air capture facilities with other industrial facilities as qualified facilities for the credits. Includes carbon utilization as one of the categories eligible for the credit. Related bills H.R. 1892, H.R. 3761, S. 1535.
S. 2602	Utilizing Significant Emissions with Innovative Technologies Act	Placed on Senate Legislative Calendar	Title I: authorizes the Administrator of the EPA to support activities that help develop direct air capture of CO_2, including a technology prize program; authorizes the EPA Administrator to carry out an R&D program to promote CO_2 utilization. Title II: amends FAST Act (42 U.S.C. 4370m(6)) to include CO_2 pipelines and infrastructure for carbon capture within the definition of eligible projects.

Bill Number	Short Title	Status	Short Summary
S. 2803	Fossil Energy Utilization , Enhancement, and Leadership Act of 2018	Referred to Committee on Energy and Natural Resources	Amends the Energy Policy Act of 2005 (EPAct, P.L. 109-58) to establish a coal technology program to include an R&D program, pilot-scale and demonstration projects, net-negative CO_2 emissions projects, and a front-end engineering and design program for fossil fuel power plants that would include carbon capture, utilization, and storage. Amends EPAct to establish a carbon utilization program; establishes a task force on CO_2 pipelines; establishes a DOE program for extracting rare-earth elements from coal.
S. 2997	Carbon Utilization Act of 2018	Referred to Committee on Agriculture, Nutrition, and Forestry	Amends the 2002 farm bill (P.L. 107-171) to include CO_2 capture, utilization, and sequestration from biomass-related facilities; authorizes a carbon utilization education program; authorizes the Secretary of Agriculture to provide loans or loan guarantees for CO_2 capture and utilization.
H.R. 1892	Bipartisan Budget Act of 2018	Enacted as P.L. 115-123	Title II, Section 41119: amended the Internal Revenue Code, Section 45Q, to increase the carbon oxide sequestration credit from $20 per metric ton for permanent sequestration, and $10 per ton as a tertiary injectant for enhanced oil and gas recovery, to $22.66 up to $50 per ton through 2027 and $12.83 up to $35 per ton over the same time span for permanent sequestration and enhanced oil and gas recovery, respectively. Includes direct air capture facilities with other industrial facilities as qualified facilities for the credits. Includes carbon utilization as one of the categories eligible for the credit.
H.R. 2010	CO_2 Regulatory Certainty Act	Referred to Committee on Ways and Means	Amends the Internal Revenue Code to revise requirements for the secure geological storage of carbon dioxide for the purpose of the tax credit for carbon dioxide sequestration. Establishes a December 31, 2017, deadline and requirements for regulations that the Internal Revenue Service (IRS) is required, under current law, to establish for determining adequate security measures for the geological storage of the carbon dioxide such that carbon dioxide does not escape into the atmosphere. Related bills S. 1663, H.R. 4857.
H.R. 2011	Carbon Capture Improvement Act of 2017	Referred to Committee on Ways and Means	Amends the Internal Revenue Code to authorize the issuance of tax-exempt facility bonds for the financing of qualified carbon dioxide capture facilities. Related bill S. 843.
H.R. 2296	Advancing CCUS Technology Act	Referred to Committee on Energy and Commerce, Committee on Science, Space, and Technology	Amends the Energy Policy Act of 2005 (P.L. 109-58) to direct the Department of Energy (DOE) to carry out research and develop technology to improve the conversion, use, and storage of carbon dioxide from fossil fuels. It also revises the program of research and commercial application for coal and power systems to require DOE, during each fiscal year after FY2017, to identify cost and performance goals for technologies allowing large-scale demonstration and the continued cost-competitive commercial use of coal.

Bill Number	Short Title	Status	Short Summary
H.R. 3761	Carbon Capture Act	Referred to Committee on Ways and Means	Amends the Internal Revenue Code, Section 45Q, to allow credit for certain qualified projects for the sequestration or utilization of CO_2 for 15 years beginning on the date the equipment was placed in service; increases the credit to up to $35 per ton for certain qualified projects over the 15-year time span. Includes direct air capture facilities with other industrial facilities as a qualified facility.
H.R. 4096	Carbon Capture Prize Act	Referred to Committee on Science, Space, and Technology	Authorizes the Secretary of Energy to award a $5 million prize to the winner or winners of a competition for research, development, or commercialization of a technology that would reduce the amount of carbon in the atmosphere including by capturing and sequestering CO_2 or reducing CO_2 emissions.
H.R. 4118	Master Limited Partnerships Parity Act	Referred to Committee on Ways and Means	Amends the Internal Revenue Code, with respect to the tax treatment of publicly traded partnerships as corporations, to expand the definition of "qualifying income" for such partnerships (known as master limited partnerships) to include income and gains from renewable and alternative energy generation projects, including carbon capture in secure geological storage. Related bill S. 2005.
H.R. 4857	Regulatory Certainty Act	Referred to Committee on Ways and Means	Amends the Internal Revenue Code to revise requirements for the secure geological storage of carbon dioxide for the purpose of the tax credit for carbon dioxide sequestration. Establishes a December 31, 2018, deadline and requirements for regulations that the Internal Revenue Service (IRS) is required, under current law, to establish for determining adequate security measures for the geological storage of the carbon dioxide such that carbon dioxide does not escape into the atmosphere. Related bills H.R. 2010, S. 1663.

Source: CRS.

Notes: CCS is carbon capture and sequestration (or storage). CCUS is carbon capture, utilization, and storage. 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.

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