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Carbon Capture and Sequestration: Research, Development, and Demonstration at the U.S. Department of Energy

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Summary

Carbon capture and sequestration (or storage)—known as CCS—is a physical process that involves capturing manmade carbon dioxide (CO_2) at its source and storing it before its release to the atmosphere. The U.S. Department of Energy (DOE) has pursued research and development (R&D) of aspects of the three main steps leading to an integrated CCS system since 1997. Congress has appropriated nearly $7 billion in total since FY2008 for CCS research, development, and demonstration (RD&D) at DOE's Office of Fossil Energy: nearly $3.5 billion in total annual appropriations (including FY2015) and $3.4 billion from the American Recovery and Reinvestment Act (Recovery Act; P.L. 111-5). The large influx of Recovery Act funding for industrial-scale CCS projects was intended to accelerate development and deployment of CCS in the United States. Since enactment of the Recovery Act, DOE has shifted its RD&D emphasis to the demonstration phase of carbon capture technology. To date, however, there are no commercial ventures in the United States that capture, transport, and inject industrial-scale quantities of CO_2 solely for the purpose of carbon sequestration.

The success of DOE CCS demonstration projects likely will influence the outlook for widespread deployment of CCS technologies as a strategy for preventing large quantities of CO_2 from reaching the atmosphere while U.S. power plants continue to burn fossil fuels, mainly coal. One project, the Kemper County Facility, has received $270 million from DOE under its Clean Coal Power Initiative (CCPI) Round 2 program and is slated to begin commercial operation in 2016. The 582 megawatt-capacity facility anticipates capturing 65% of its CO_2 emissions, making it equivalent to a new natural gas-fired combined cycle power plant. Cost and schedule overruns at the Kemper Plant, however, have raised questions over the relative value of environmental benefits from CCS technology compared with construction costs of the facility and its effect on ratepayers.

In 2014, the U.S. Environmental Protection Agency (EPA) proposed emission standards for new and existing fossil-fueled electric generating units under Section 111 of the Clean Air Act. New natural gas-fired stationary power plants should be able to meet the proposed standard for new plants without additional cost and without the need for add-on control technology. However, the only apparent technical way for new coal-fired plants to meet the standard would be to install CCS technology. The proposed rule has sparked increased scrutiny of the future of CCS as a viable technology for reducing CO_2 emissions from coal-fired power plants.

Given the pending EPA rule, congressional interest in the future of coal as a domestic energy source appears directly linked to the future of CCS. Debate has been mixed as to whether the rule would spur development and deployment of CCS for new coal-fired power plants or have the opposite effect. Congressional oversight of the CCS RD&D program could help inform decisions about the level of support for the program and help Congress gauge whether it is on track to meet its goals. In the 114th Congress, a bill has been introduced (S. 601) that would promote CCS for coal-fired utilities by a combination of loan guarantees, tax credits, and supporting the DOE R&D effort in its coal program, among other things. A similar bill was introduced in the 113th Congress but was not enacted.

One issue is whether congressional oversight is needed of the CCS R&D program, particularly of the results from the demonstration projects as they progress. Such a review could help Congress evaluate whether DOE is on track to meet its goal of allowing for an advanced CCS technology portfolio to be ready by 2020 for large-scale demonstration and deployment in the United States.

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Introduction

Carbon capture and sequestration (or storage)—known as CCS—is a physical process that involves capturing manmade carbon dioxide (CO_2) at its source and storing it before its release to the atmosphere. CCS could reduce the amount of CO_2 emitted to the atmosphere from the continued use of fossil fuels at power plants and other large, industrial facilities. An integrated CCS system would include three main steps: (1) capturing CO_2 at its source and separating it from other gases; (2) purifying, compressing, and transporting the captured CO_2 to the sequestration site; and (3) injecting the CO_2 into subsurface geological reservoirs. Following its injection into a subsurface reservoir, the CO_2 would need to be monitored for leakage and to verify that it remains in the target geological reservoir. Once injection operations cease, a responsible party would need to take title to the injected CO_2 and ensure that it stays underground in perpetuity.

The U.S. Department of Energy (DOE) has pursued research and development of aspects of the three main steps leading to an integrated CCS system since 1997.[1] Congress has appropriated nearly $7 billion in total since FY2008 for CCS research, development, and demonstration (RD&D) at DOE's Office of Fossil Energy: nearly $3.5 billion in total annual appropriations (including FY2015) and $3.4 billion from the American Recovery and Reinvestment Act (P.L. 111-5; enacted February 17, 2009, hereinafter referred to as the Recovery Act).[2]

The large and rapid influx of funding for industrial-scale CCS projects from the Recovery Act was intended to accelerate development and demonstration of CCS in the United States. The Recovery Act funding also was likely intended to help DOE achieve its RD&D goals as outlined in the department's 2010 RD&D *CCS Roadmap*.[3] (In part, the roadmap was intended to lay out a path for rapid technological development of CCS so that the United States could continue to use fossil fuels despite potential carbon restrictions.) However, the future deployment of CCS may take a different course if the major components of the DOE program follow a path similar to DOE's FutureGen project. FutureGen had experienced delays and multiple changes of scope and design since its inception in 2003, and on February 3, 2015, DOE announced that it was suspending the project. (For more details, see sections below on "FutureGen—A Special Case?" and "Lessons from FutureGen: A Similar Path for Other Demonstration Projects?")

This report aims to provide a snapshot of the DOE CCS program, including its current funding levels, together with some discussion of the program's achievements and prospects for success in meeting its stated goals. Other CRS reports provide substantial detail on the technological and policy aspects of CCS.[4]

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[1] U.S. Department of Energy, National Energy Technology Laboratory, *Carbon Sequestration Program: Technology Program Plan*, Enhancing the Success of Carbon Capture and Storage Technologies, February 2011, p. 10, http://www.netl.doe.gov/technologies/carbon_seq/refshelf/2011_Sequestration_Program_Plan.pdf.

[2] U.S. Department of Energy annual budget justifications, FY2010 through FY2015.

[3] U.S. Department of Energy, National Energy Technology Laboratory, *DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap*, December 2010. Hereinafter referred to as the DOE 2010 *CCS Roadmap*. See http://www.netl.doe.gov/File%20Library/Research/Carbon%20Seq/Reference%20Shelf/CCSRoadmap.pdf.

[4] See, for example, CRS Report R42532, *Carbon Capture and Sequestration (CCS): A Primer;* CRS Report R41325, *Carbon Capture: A Technology Assessment*.

Issues for Congress

U.S. Environmental Protection Agency (EPA) proposed rules and guidelines for reducing greenhouse gas (GHG) emissions from new and existing coal-fired power plants have been a focal point of discussion in Congress about CCS. How the demise of FutureGen will affect that debate is yet to be seen. Legislation regarding CCS in the last Congress mainly focused on two issues: stopping or slowing implementation of the EPA GHG rules and guidelines and providing federal incentives to accelerate the demonstration and development of CCS at commercial scales.

EPA Proposed Rule: Limiting CO_2 Emissions from Power Plants[5]

In 2014, EPA proposed emission standards for new and existing fossil-fueled electric generating units under Section 111 of the Clean Air Act. EPA's regulatory proposal stems from the Obama Administration's stated goal to take action on climate change in the absence of congressional action to reduce GHG emissions through legislation. In June 2013, President Obama directed EPA to propose standards for GHG emissions from new fossil-fueled power plants by September 20, 2013, and to propose guidelines for existing power plants by June 1, 2014.[6] EPA met both deadlines and may finalize the power plant rules by mid-summer 2015.[7]

New Power Plants

According to EPA, new natural gas-fired stationary power plants should be able to meet the proposed standard without additional cost and without the need for add-on control technology. However, the only apparent technical way for new coal-fired plants to meet the standard would be to install CCS technology to capture about 40% of the CO_2 they typically produce. The proposed standard allows for a seven-year compliance period for coal-fired plants but would demand a more stringent standard for those plants that comply over seven years; CO_2 emissions for these plants would be limited to an average of 1,000-1,050 pounds per megawatt-hour.[8]

The prospects for building new coal-fired electricity generating plants depend on many factors, such as costs of competing fuel sources (e.g., natural gas), electricity demand, regulatory costs, infrastructure (including rail), and electric grid development. However, the EPA proposed rule clearly identifies CCS as the essential technology required if new coal-fired power plants are to be built in the United States.[9] The re-proposed standard places a new focus on DOE's CCS RD&D program—whether it will achieve its vision of "having an advanced CCS technology portfolio ready by 2020 for large-scale CCS demonstration that provides for the safe, cost-

[5] For a fuller discussion of the proposed rule and EPA standards for greenhouse gas (GHG) emissions from power plants, see CRS Report R43127, *EPA Standards for Greenhouse Gas Emissions from New Power Plants*, by James E. McCarthy

[6] President Obama directed EPA to re-propose the standards for new power plants. The standards were first proposed in 2012. The re-proposed standards were published in the *Federal Register*, January 8, 2014, at 79 *Federal Register* 1430; the guidelines for existing plants were published in the *Federal Register*, June 18, 2014, at 79 *Federal Register* 34830.

[7] A broader and more detailed discussion of the EPA proposals and possible options for Congress can be found in CRS Report R41212, *EPA Regulation of Greenhouse Gases: Congressional Responses and Options*, by James E. McCarthy.

[8] The proposal and background information is available at http://www2.epa.gov/carbon-pollution-standards/2013-proposed-carbon-pollution-standard-new-power-plants.

[9] Ibid.

effective carbon management that will meet our Nation's goals for reducing [greenhouse gas] emissions."[10]

Existing Power Plants

One analysis concluded that the debate over EPA's proposed rule for *new* power plants is largely symbolic and that its real significance is that without the promulgation of a rule for new sources, EPA could not proceed to regulate *existing* power plants under the Clean Air Act.[11] The proposed guidelines for existing plants would establish different goals for each state based on four factors: improved efficiency at coal-fired plants; substitution of natural gas combined cycle generation for coal-fired power; zero-emission generation from renewables and nuclear power; and demand-side efficiency.[12] Although CCS was not specifically included as a factor, or as part of the four factors listed above, the rule would not preclude CSS as an option for reducing emissions to help states meet their emissions target.

Implications for CCS Research, Development, and Deployment

Given the pending EPA rule, congressional interest in the future of coal as a domestic energy source also appears to be linked to the future of CCS. The debate has been mixed as to whether the proposed rule for new plants would spur development and deployment of CCS for new coal-fired power plants or have the opposite effect. Multiple analyses indicate that there will be retirements of U.S. coal-fired capacity; however, virtually all analyses agree that coal will continue to play a substantial role in electricity generation for decades. How many retirements will take place and what role EPA regulations will play in causing them are matters of dispute.[13]

Part of the argument over the proposed rule for new plants has focused on whether CCS is the best system of emissions reduction (BSER) for coal plants and whether it has been "adequately demonstrated" as required under the Clean Air Act. In its re-proposed rule, EPA cites the "existence and apparent ongoing viability" of several ongoing CCS demonstration projects as examples that justify a separate determination of BSER for coal-fired plants and integrated gasification combined-cycle plants. (The second BSER determination is for gas-fired power plants.)[14] EPA noted that these projects had reached advanced stages of construction and development, "which suggests that proposing a separate standard for coal-fired units is appropriate."

[10] DOE 2010 *CCS Roadmap*, p. 3.

[11] See, for example, CRS Report R43127, *EPA Standards for Greenhouse Gas Emissions from New Power Plants*, by James E. McCarthy

[12] Ibid.

[13] For a detailed discussion of the EPA's regulation of coal, see CRS Report R41914, *EPA's Regulation of Coal-Fired Power: Is a "Train Wreck" Coming?*, by James E. McCarthy and Claudia Copeland.

[14] The projects cited in the re-proposed rule are the Southern Company Kemper County Energy Facility, the SaskPower Boundary Dam CCS project, the Summit Power Texas Clean Energy Project, and the Hydrogen Energy California Project. The Boundary Dam project is a Canadian venture; the other three projects are in the United States and are receiving funding from DOE.

The Natural Gas Alternative?

The huge increases in the U.S. domestic supply of natural gas in recent years, due largely to the exploitation of unconventional shale gas reservoirs through the use of hydraulic fracturing, has also led to a shift to natural gas for electricity production.[15] The shift appears to be largely due to the cheaper and increasingly abundant fuel—natural gas—compared to coal for electricity production. The EPA re-proposed rule noted that "power companies often choose the lowest cost form of generation when determining what type of new generation to build. Based on [Energy Information Administration] modeling and utility [Integrated Resource Plans], there appears to be a general acceptance that the lowest cost form of new power generation is [natural gas combined-cycle]." Cheap gas, due to the rapid increase in the domestic natural gas supply as an alternative to coal, in combination with regulations that curtail CO_2 emissions may lead electric power producers to invest in natural gas-fired plants, which emit approximately half the amount of CO_2 per unit of electricity produced compared to coal-fired plants. Regulations and abundant cheap gas may raise questions about the rationale for funding CCS demonstration projects (e.g., see "Lessons from FutureGen: A Similar Path for Other Demonstration Projects?").

Alternatively, and despite increasingly abundant domestic natural gas supplies, EPA regulations could provide the necessary incentives for the industry to accelerate CCS development and deployment for coal-fired power plants. As part of its re-proposed ruling for new power plants, EPA cited technology as one of four factors that it considers in making a BSER determination.[16] Specifically, EPA stated that it "considers whether the system promotes the implementation and further development of technology," in this case referring to CCS technology. It appears that EPA asserted that its rule would likely promote CCS development and deployment rather than hinder it. Those arguing against the re-proposed rule do so on the basis that CCS technology has not been adequately demonstrated, and that it violates provisions in P.L. 109-58, the Energy Policy Act of 2005, that prohibit EPA from setting a performance standard based on the use of technology from certain DOE-funded projects, such as the three projects cited in the EPA re-proposal, among other reasons.[17]

FutureGen—A Special Case?

On February 27, 2003, President George W. Bush proposed a 10-year, $1 billion project known as FutureGen to build a coal-fired power plant that would integrate carbon sequestration and hydrogen production at a 275 megawatt-capacity plant, enough to power about 150,000 average U.S. homes. As originally conceived, the plant would have been a coal-gasification facility and would have produced and sequestered between 1 million and 2 million tons of CO_2 annually. On January 30, 2008, DOE announced that it was "restructuring" the FutureGen program away from a single, state-of-the-art "living laboratory" of integrated R&D technologies—a single plant—to

[15] For a detailed discussion of how natural gas is affecting electric power generation, see CRS Report R42814, *Natural Gas in the U.S. Economy: Opportunities for Growth* , by Robert Pirog and Michael Ratner.

[16] The other three are feasibility, cost, and size of emission reductions.

[17] See for example, the November 15, 2013, letter to EPA Administrator Gina McCarthy from Representative Fred Upton, chair of the House Committee on Energy and Commerce, http://www.eenews.net/assets/2013/11/22/document_daily_03.pdf; and the December 19, 2013, letter to Administrator McCarthy from Representative Lamar Smith, chair of the House Committee on Science, Space, and Technology, http://science.house.gov/sites/republicans.science.house.gov/files/documents/Letters/121913_mccarthy.pdf.

pursue instead a new strategy of multiple commercial demonstration projects.[18] In the restructured program, DOE announced that it would support up to two or three demonstration projects of at least 300 megawatts that would sequester at least 1 million tons of CO_2 per year.[19]

In the Bush Administration's FY2009 budget, DOE requested $156 million for the restructured FutureGen program and specified that the federal cost share would cover only the CCS portions of the demonstration projects, not the entire power system. However, after the Recovery Act was enacted on February 17, 2009, Secretary of Energy Chu announced an agreement with the FutureGen Alliance—an industry consortium—to advance construction of the FutureGen plant built in Mattoon, Illinois, the site selected by the FutureGen Alliance in 2007.[20] Further, DOE anticipated that $1 billion of funding from the Recovery Act would be used to support the project.[21]

On August 5, 2010, Secretary Chu announced the $1 billion award, from Recovery Act funds, to the FutureGen Alliance, Ameren Energy Resources, Babcock & Wilcox, and Air Liquide Process & Construction, Inc., to build FutureGen 2.0.[22] FutureGen 2.0 differed from the original concept for the plant because it aimed to retrofit Ameren's existing power plant in Meridosia, Illinois, with oxy-combustion technology at a 202 megawatt oil-fired unit,[23] rather than build a new, state-of-the-art plant in Mattoon.

On February 3, 2015, DOE announced it was canceling funding for the FutureGen project.[24] The most pressing reason for the program's suspension is the September 30, 2015, deadline for spending the Recovery Act funding and the likelihood that the FutureGen Alliance would not be able to commit the funds by that date, which, in turn, led to uncertainty about the alliance's ability to secure private-sector funding to make up the rest of the project costs after Recovery Act funding was exhausted. The FutureGen Alliance had spent approximately $200 million of the nearly $1 billion in Recovery Act funding appropriated and allocated to FutureGen. Other factors also may have played a role in DOE's decision.[25]

[18] See http://www.fossil.energy.gov/news/techlines/2008/08003-DOE_Announces_Restructured_FutureG.html.

[19] For more information on FutureGen, see CRS Report R43028, *The FutureGen Carbon Capture and Sequestration Project: A Brief History and Issues for Congress*, by Peter Folger.

[20] Before DOE first announced it would restructure the program in 2008, the FutureGen Alliance announced on December 18, 2007, that it had selected Mattoon, IL, as the host site from a set of four finalists. The four were Mattoon, IL; Tuscola, IL; Heart of Brazos (near Jewett, TX); and Odessa, TX.

[21] See DOE announcement on June 12, 2009, http://www.fossil.energy.gov/news/techlines/2009/09037-DOE_Announces_FutureGen_Agreement.html.

[22] See DOE Techline, http://www.netl.doe.gov/publications/press/2010/10033-Secretary_Chu_Announces_FutureGen_.html.

[23] Ameren had planned to replace the oil-fired boiler with a coal-fired boiler using oxy-combustion technology to allow carbon capture. See http://www.futuregenalliance.org/pdf/FutureGen%20FAQ-General%20042711.pdf.

[24] As reported in Manuel Quinones, "Lawmakers Likely to Scrutinize DOE Closeout of FutureGen Project," *Environment & Energy Daily*, February 4, 2015, http://www.eenews.net/eedaily/stories/1060012838/search?keyword=futuregen.

[25] See, for example, Thomas Overton, "DOE Pulls The Plug on FutureGen," *Power*, February 4, 2015, http://www.powermag.com/doe-pulls-the-plug-on-futuregen/.

Lessons from FutureGen: A Similar Path for Other Demonstration Projects?

Following the announcement that DOE was suspending the FutureGen project, one question for Congress is whether FutureGen represented a unique case of a first mover in a complex, expensive, and technically challenging endeavor. Another is whether some of the challenges that ultimately stopped FutureGen also apply to other large DOE-funded CCS demonstration projects once they move past the planning stage. DOE committed approximately $3.3 billion of Recovery Act funding to large demonstration projects (approximately $800 million less now, with the demise of FutureGen). One rationale for committing such a substantial level of funding was to scale up and quicken the pace of CCS RD&D.

Some argue that FutureGen was unique from its original conception. None of the other large-scale demonstration projects in the United States share the same original ambitious vision to create a new, one-of-a-kind, near-zero emission CCS plant from the ground up. Even though the individual components of FutureGen as it was originally conceived were not themselves new innovations, combining the capture, transportation, and storage components into a 250-megawatt functioning power plant could be considered unprecedented and therefore likely to experience delays at each step in development.

Scholars have described the stages of technological change in different schemes, such as

- invention, innovation, adoption, diffusion;[26] or
- technology readiness levels (TRLs) ranging from TRL 1 (basic technology research) to TRL 9 (system test, launch, and operations);[27] or
- conceptual design, laboratory/bench scale, pilot plant scale, full-scale demonstration plant, and commercial process.[28]

FutureGen was difficult to categorize within these schemes, in part because the project spanned a range of technology development levels irrespective of the particular scheme. The original conception of the FutureGen project arguably had aspects of conceptual design through commercial processes—all five components of the scheme listed as the third bullet above—which meant the project was intended to march through all stages in a linear fashion. As some scholars have noted, however, the stages of technological change are highly interactive, requiring learning by doing and learning by using, once the project progresses past its innovative stage into larger-scale demonstration and deployment.[29] The task of tackling all the stages of technology development in one project—the original FutureGen—might have been too daunting and, in addition to other factors, contributed to the project's erratic progress since 2003. It remains to be seen whether the remaining large-scale demonstration projects funded by DOE under the Clean

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[26] E. S. Rubin, "The Government Role in Technology Innovation: Lessons for the Climate Change Policy Agenda," Institute of Transportation Studies, 10th Biennial Conference on Transportation Energy and Environmental Policy, University of California, Davis, CA (August 2005).

[27] National Aeronautics and Space Administration, "Definition of Technology Readiness Levels," at http://esto.nasa.gov/files/TRL_definitions.pdf.

[28] For a more thorough discussion of different schemes describing stages of technology development, see chapter 4 of CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

[29] E. S. Rubin, "The Government Role in Technology Innovation: Lessons for the Climate Change Policy Agenda," Institute of Transportation Studies, 10th Biennial Conference on Transportation Energy and Environmental Policy, University of California, Davis, CA (August 2005).

Coal Power Initiative (CCPI) Round 3 follow the path of FutureGen or achieve their technological development goals on time and within their current budgets. Presumably, lessons learned during the planning, construction, and operation of these demonstration projects will be shared with the broader electric power industry.[30]

Legislation

Although DOE has pursued aspects of CCS RD&D since 1997, the Energy Policy Act of 2005 (P.L. 109-58) provided a 10-year authorization for the basic framework of CCS research and development at DOE.[31] The Energy Independence and Security Act of 2007 (EISA, P.L. 110-140) amended the Energy Policy Act of 2005 to include, among other provisions, authorization for seven large-scale CCS demonstration projects (in addition to FutureGen) that would integrate the carbon capture, transportation, and sequestration steps.[32] (Large-scale demonstration programs and their potential significance are discussed below.) It can be argued that, since enactment of EISA, the focus and funding within the CCS RD&D program has shifted toward large-scale capture technology development through these and other demonstration projects.

In addition to the annual appropriations provided for CCS RD&D, the Recovery Act (P.L. 111-5) has been the most significant legislation that promotes and supports federal CCS RD&D program activities since passage of EISA. As discussed below, $3.4 billion in funding from the Recovery Act was intended to expand and accelerate the commercial deployment of CCS technologies to allow for commercial-scale demonstration in both new and retrofitted power plants and industrial facilities by 2020.

114th Congress

On February 26, 2015, Senators Heitkamp and Kaine introduced S. 601, the Advanced Clean Technology Investment in Our Nation Act of 2015, which would promote CCS for coal-fired utilities by a combination of loan guarantees, tax credits, and support for the DOE R&D effort in its coal program, among other things. The bill closely resembles legislation introduced by Senator Heitkamp in the 113th Congress, S. 2152 (discussed below).

113th Congress

More than a dozen bills introduced in the 113th Congress would have addressed the proposed EPA rules and guidelines for reducing GHG emissions from new and existing coal-fired power plants. H.R. 3826, the Electricity Security and Affordability Act, would have set requirements EPA must meet before the agency could issue GHG emission regulations under Section 111 of the Clean Air Act. The bill would have, in part, prohibited EPA from promulgating or implementing GHG

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[30] Another possible source of uncertainty for large industrial CCS projects is cost recovery during the operating phase of the plant after the construction phase and initial capital investments are made. "Learning by doing" should increase operating efficiency, but it is unclear by how much and over what time span. For more discussion on cost trajectories and expected efficiency gains, see CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

[31] P.L. 109-58, Title IX, Subtitle F, §963; 42 U.S.C. 16293.

[32] P.L. 110-140, Title VII, Subtitles A and B.

emissions standards for fossil-fueled power plants until at least six power plants representative of the operating characteristics of electric generation units at different locations across the United States had demonstrated compliance with proposed emission limits for a continuous period of 12 months on a commercial basis. Companion legislation, S. 1905, was referred to the Senate Committee on Environment and Public Works.

Several bills introduced in the 113th Congress would have provided federal incentives for accelerating the RD&D of CCS. For example, S. 2152 would have increased DOE CCS research and development, allowed for loan guarantees to qualified CCS projects, provided an investment tax credit for certain CCS facilities, and created a clean energy coal bond, among other things. Two related bills would have dealt with tax credits and loan guarantees. S. 2287 would have revised part of the tax code that allows a tax credit for CCS and would have amended EPAct to broaden the loan guarantee program for CCS, among other things. S. 2288 would have amended the tax code to expand the tax credits for CCS. S. 2776 would have established a fund for DOE to administer in establishing at least 10 commercial-scale CCS projects over 10 years. Several other bills introduced in the 113th Congress would have touched on CCS-related issues.

CCS Research, Development, and Demonstration: Overall Goals

The U.S. Department of Energy states that the mission for the DOE Office of Fossil Energy is "to ensure the availability of ultra-clean (near-zero emissions), abundant, low-cost domestic energy from coal to fuel economic prosperity, strengthen energy security, and enhance environmental quality."[33] Over the past several years, the DOE Fossil Energy Research and Development Program has increasingly shifted activities performed under its Coal Program toward emphasizing CCS as the main focus.[34] The Coal Program represented between 68% and 70% of total Fossil Energy Research and Development appropriations from FY2012 to FY2015,[35] indicating that CCS has come to dominate coal R&D at DOE. This reflects DOE's view that "there is a growing consensus that steps must be taken to significantly reduce [greenhouse gas] emissions from energy use throughout the world at a pace consistent to stabilize atmospheric concentrations of CO_2, and that CCS is a promising option for addressing this challenge."[36] The FY2016 President's budget request, however, would reduce the total funding for the Coal Program compared with the previous two fiscal years. In the FY2016 request, the coal program would represent 66% of the total Fossil Energy R&D appropriation.

DOE acknowledges that the cost of deploying currently available CCS technologies is very high and that to be effective as a technology for mitigating GHG emissions from power plants, the costs for CCS must be reduced. For example, in 2010 DOE stated that the cost of deploying available CCS post-combustion technology on a supercritical pulverized coal-fired power plant would increase the cost of electricity by 80%.[37] The challenge of reducing the costs of CCS

[33] DOE 2010 *CCS Roadmap*, p. 2.

[34] The Coal Program contains CCS RD&D activities and is within DOE's Office of Fossil Energy, Fossil Energy Research and Development, as listed in DOE detailed budget justifications for each fiscal year.

[35] U.S. Department of Energy, FY2013, FY2014, and FY2015 Congressional Budget Requests.

[36] DOE 2010 *CCS Roadmap*, p. 3.

[37] DOE 2010 *CCS Roadmap*, p. 3.

technology is difficult to quantify. The Boundary Dam Plant in Canada is the only commercial-scale coal-fired power plant equipped with CCS, and it has been operating for less than one year.

Nor is it easy to predict when lower-cost CCS technology will be available for widespread deployment in the United States. Nevertheless, DOE observes that "the United States can no longer afford the luxury of conventional long-lead times for RD&D to bear results."[38] Thus the coal RD&D program is focused on achieving results that would allow for an advanced CCS technology portfolio to be ready by 2020 for large-scale demonstration.

The following section describes the components of the CCS activities within DOE's coal R&D program and their funding history since FY2012. This report focuses on this time period because during that time DOE obligated Recovery Act funding for its CCS programs, greatly expanding the CCS R&D portfolio. This was expected to accelerate the transition of CCS technology to industry for deployment and commercialization.[39] In addition, one remaining active project in the CCPI program that received funding in Round 2, prior to enactment of the Recovery Act—the Kemper County Energy Facility—also is discussed. Lastly, the Boundary Dam Project is described briefly, although it is a Canadian venture, because of its unique status as the only currently operating commercial-scale coal-fired power plant with CCS in the world.

Program Areas

The 2010 RD&D *CCS Roadmap* described 10 different program areas pursued by DOE's Coal Program within the Office of Fossil Energy: (1) Innovations for Existing Plants (IEP); (2) Advanced Integrated Gasification Combined Cycle (IGCC); (3) Advanced Turbines; (4) Carbon Sequestration; (5) Solid State Energy Conversion Fuel Cells; (6) Fuels; (7) Advanced Research; (8) CCPI; (9) FutureGen; and (10) Industrial Carbon Capture and Storage Projects (ICCS).[40]

Coal Program Areas

DOE changed the program structure for coal after FY2010, renaming and consolidating program areas. The program areas are divided into two main categories: (1) CCS Demonstration Programs and (2) CSS and Power Systems. **Table 1** shows the current program structure and indicates which programs received Recovery Act funding. In its FY2016 budget justification, DOE states that the CCS and Power Systems R&D program

> supports secure, affordable, and environmentally acceptable near-zero emissions fossil energy technologies through research, development, and demonstration (RD&D) to improve the performance of advanced CCS technologies.[41]

Some programs are directly focused on one or more of the three steps of CCS: capture, transportation, and storage. For example, the carbon capture program supports R&D on post-combustion, pre-combustion, and natural gas capture. The carbon storage program supports the

[38] DOE 2010 *CCS Roadmap*, p. 3.

[39] DOE 2010 *CCS Roadmap*, p. 2.

[40] DOE 2010 *CCS Roadmap*, p. 11.

[41] U.S. Department of Energy, FY2016 Congressional Budget Request, volume 3, *Fossil Energy Research and Development*, p. 569.

regional carbon sequestration partnerships, geological storage technologies, and other aspects of permanently sequestering CO_2 underground. In contrast, FutureGen from the outset was envisioned as combining all three steps: a zero-emission fossil fuel plant that would capture its emissions and sequester them in a geologic reservoir.

Table 1. Funding for DOE Fossil Energy Research, Development, and Demonstration Program Areas

(funding in nominal dollars [thousands], FY2012-FY2016, including Recovery Act)

Fossil Energy Research and Development Coal Program Areas	Program	Recovery Act	FY2012	FY2013	FY2014	FY2015	FY2016 Request
CCS Demonstrations	**FutureGen 2.0**[a]	1,000,000	0	0	0	0	0
	Clean Coal Power Initiative (CCPI)	800,000	0	0	0	0	0
	Industrial Carbon Capture and Storage Projects (ICCS)	1,520,000	0	0	0	0	0
	Site Characterization, Training, Program Direction	80,000	0	0	0	0	0
Carbon Capture and Storage, and Power Systems	**Carbon Capture**	—	66,986	63,725	92,000	88,000	116,631
	Carbon Storage	—	112,208	106,745	108,766	100,000	108,768
	Advanced Energy Systems	—	97,169	92,438	99,500	103,000	39,385
	Cross Cutting Research	—	47,946	45,618	41,925	49,000	51,242
	Supercritical CO_2 Technology	—	0	0	0	10,000	19,300
	NETL Coal Research and Development	—	35,011	33,338	50,011	50,000	34,031
Subtotal Coal		**3,400,000**	**359,320**	**341,864**	**392,202**	**400,000**	**369,357**
Other Fossil Energy R&D	**Natural Gas Technologies**	—	14,991	13,865	20,600	25,121	44,000
	Unconventional Fossil	—	4,997	4,621	15,000	4,500	0
	Program Direction	—	119,929	114,201	120,000	119,000	114,202

Fossil Energy Research and Development Coal Program Areas	Program	Recovery Act	FY2012	FY2013	FY2014	FY2015	FY2016 Request
	Plant & Capital	—	16,794	15,982	16,032	15,782	18,044
	Env. Restoration	—	7,897	7,515	5,897	5,897	8,197
	Supercomputer	—	0	0	0	0	5,500
	Special Recruitment	—	700	667	700	700	700
Subtotal Other Fossil R&D		**—**	**165,308**	**156,851**	**178,229**	**171,000**	**190,643**
Total Fossil Energy R&D		**3,400,000**	**524,628**	**498,715**	**570,431**	**571,000**	**560,000**

Sources: U.S. Department of Energy, FY2016. Congressional Budget Request, volume 3, *Fossil Energy Research and Development*, http://energy.gov/sites/prod/files/2015/02/f19/FY2016BudgetVolume3_7.pdf. Other sources include the U.S. DOE Congressional Budget Requests for FY2015, FY2014, and FY2013.

Notes: FY2012-FY2015 numbers denote enacted funding except for FY2013, which denotes the FY2013 continuing resolution annualized to a full year per P.L. 112-175. NETL = National Energy Technology Laboratory.

a. On February 3, 2015, DOE announced that it was canceling the FutureGen program. Statement by DOE spokesman Bill Gibbons, reported by Manuel Quinones, in Environment & Energy Daily, February 4, 2015, http://www.eenews.net/eedaily/stories/1060012838/search?keyword=futuregen.

Within the CCS Demonstrations Program Area, RD&D is also divided among different industrial sectors. The Clean Coal Power Initiative (CCPI) program area originally provided federal support to new coal technologies that helped power plants cut sulfur, nitrogen, and mercury pollutants. As CCS became the focus of coal RD&D, the CCPI program shifted to reducing GHG emissions by boosting plant efficiencies and capturing CO_2.[42] In contrast, the ICCS program area demonstrates carbon capture technology for the non-power plant industrial sector.[43] Both these program areas focus on the *demonstration* component of RD&D, and account for $2.3 billion of the $3.4 billion appropriated for CCS RD&D in the Recovery Act in FY2009. From the budgetary perspective, the Recovery Act funding shifted the emphasis of CCS RD&D to large, industrial demonstration projects for carbon capture. The CCPI and ICCS program areas are discussed in more detail below.

This shift in emphasis to the demonstration phase of carbon capture technology is not surprising, and appears to heed recommendations from many experts who have called for large, industrial-scale carbon capture demonstration projects.[44] Primarily, the call for large-scale CCS

[42] U.S. Department of Energy, FY2015 Congressional Budget Request, volume 3, *Fossil Energy Research and Development*, p. 551.

[43] DOE 2010 *CCS Roadmap*, p. 12.

[44] See, for example, the presentations given by Edward Rubin of Carnegie Mellon University, Howard Herzog of the Massachusetts Institute of Technology, and Jeff Phillips of the Electric Power Research Institute, at the CRS seminar *Capturing Carbon for Climate Control: What's in the Toolbox and What's Missing*, November 18, 2009. (Presentations available from Peter Folger at 7-1517.) Rubin stated that at least 10 full-scale demonstration projects would be needed to establish the reliability and true cost of CCS in power plant applications. Herzog also called for at least 10 demonstration plants worldwide that capture and sequester a million metric tons of CO_2 per year. In his presentation, Phillips stated that large-scale demonstrations are critical to building confidence among power plant owners.

demonstration projects that capture 1 million metric tons or more of CO_2 per year reflects the need to reduce the additional costs to the power plant or industrial facility associated with capturing the CO_2 before it is emitted to the atmosphere. The capture component of CCS is the costliest component, according to most experts.[45] The higher estimated costs to build and operate power plants with CCS compared with plants without CCS, and the uncertainty in cost estimates, results in part from a dearth of information about outstanding technical questions in carbon capture technology at the industrial scale.[46] Some cost data are emerging, however, now that the Kemper County Energy Facility is close to completion and the Canadian Boundary Dam project is operating (both discussed below).

Other Fossil Research and Development

The Administration requests approximately $191 million for FY2016 for other programs pursuing fossil energy R&D and support activities. The largest activity is program direction ($114 million requested), which provides for DOE headquarters support and for federal field and contractor support of the overall fossil energy R&D programs. These activities would support CCS-related activities directly and indirectly. The second-largest activity is natural gas technologies ($44 million), which supports collaborative research to foster safe and prudent development of shale gas resources, the reduction of methane emissions from natural gas infrastructure, and research on gas hydrates.[47] The other activities listed in **Table 1**, plant and capital, environmental restoration, and supercomputer, total approximately $33 million in the FY2016 request.[48]

Evolution of Costs

In comparative studies of cost estimates for other environmental technologies, such as for power plant scrubbers that remove sulfur and nitrogen compounds from power plant emissions (SO_2 and NOx), some experts note that the farther away a technology is from commercial reality, the more uncertain is its estimated cost. At the beginning of the RD&D process, initial cost estimates could be low, but could typically increase through the demonstration phase before decreasing after successful deployment and commercialization. **Figure 1** shows a cost estimate curve of this type.

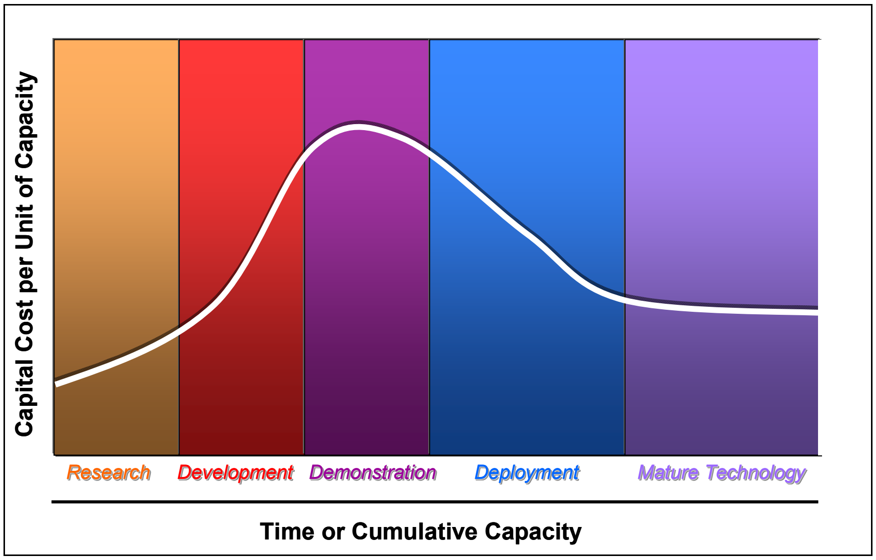
[45] For example, an MIT report estimated that the costs of capture could be 80% or more of the total CCS costs. John Deutsch et al., *The Future of Coal*, Massachusetts Institute of Technology, An Interdisciplinary MIT Study, 2007, Executive Summary, p. xi.

[46] *The Future of Coal*, p. 97.

[47] U.S. Department of Energy, FY2016. Congressional Budget Request, volume 3, pp. 603-616.

[48] Apart from Recovery Act funding, annual appropriations for the Office of Fossil Energy at DOE are provided in the Energy and Water Development appropriations bill. For more information, see CRS Report R43567, *Energy and Water Development: FY2015 Appropriations*, coordinated by Mark Holt.

Figure 1. Typical Trend in Cost Estimates for a New Technology As It Develops from a Research Concept to Commercial Maturity



Source: Adapted from S. Dalton, "CO_2 Capture at Coal Fired Power Plants—Status and Outlook," 9th International Conference on Greenhouse Gas Control Technologies, Washington, DC, November, 16-20, 2008.

Deploying commercial-scale CCS demonstration projects—an emphasis within the DOE CCS RD&D program—would therefore provide cost estimates closer to operational conditions rather than laboratory- or pilot-plant-scale projects. In the case of SO_2 and NOx scrubbers, efforts typically took two decades or more to bring new concepts (such as combined SO_2 and NOx capture systems) to the commercial stage. As **Figure 1** indicates, costs for new technologies tend to fall over time with successful deployment and commercialization. It would be reasonable to expect a similar trend for CO_2 capture costs if the technologies become widely deployed.[49]

First U.S. Full-Scale Project? The Kemper County Energy Facility

DOE awarded Southern Company Services a cooperative agreement under the CCPI Round 2 program, prior to enactment of the Recovery Act and the CCPI Round 3 awards, to develop technology at the Kemper County Energy Facility in Kemper County, Mississippi. The $270 million award was aimed to provide direct financial support for the development and deployment of a gasification technology called Transport Integrated Gasification (TRIG™).[50]

The Kemper County Project is an integrated gasification combined-cycle (IGCC)[51] power plant that will be owned and operated by Mississippi Power Company, a subsidiary of Southern Company, and which will use lignite as a fuel source. The plant is expected to have an estimated peak net output capability of 582 megawatts, and is designed to capture 65% of the total CO_2

[49] For a fuller discussion of the relationship between costs of developing technologies analogous to CCS, such as SO_2 and NOx scrubbers, see CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

[50] DOE, National Energy Technology Laboratory, CCS Demonstrations, CCPI Initiative, http://netl.doe.gov/research/proj?k=FC26-06NT42391.

[51] For more information on IGCC power plants and CCS, see CRS Report R41325, *Carbon Capture: A Technology Assessment*, by Peter Folger.

emissions released from the plant.[52] According to DOE, this would make the CO_2 emissions from the Kemper Project comparable to a natural gas-fired combined cycle power plant, and would therefore emit less than the 1,100 pounds per megawatt-hour limit as required by the new EPA proposed rule. The estimated 3 million tons of CO_2 captured each year from the plant would be transported via newly constructed pipeline for use in enhanced oil recovery operations at nearby depleted oil fields in Mississippi.

Commercial operation of the Kemper County Project has been delayed several times since construction began in 2010.[53] According to a Mississippi Power timeline for the project, commercial operation will begin sometime in 2016.[54] The project also has cost far more than the original estimate. The $270 million award under Round 2 of the CCPI program represented approximately 10% of what DOE had reported as the overall cost to build the plant, approximately $2.67 billion.[55] However, in April 2013 the company announced that capital costs would be closer to $3.4 billion, approximately $1 billion higher than original cost estimates for the plant.[56] In early April 2014, Mississippi Power released documents indicating that the project was on schedule to begin operations in the last quarter of 2014 but that the total cost for the plant, including the lignite mine, CO_2 pipeline, land purchase, and all the other components of the full project, had risen to approximately $5.2 billion.[57] In late April 2014, Mississippi Power again modified its cost and schedule estimates, adjusting costs upward by $61 million related to construction issues and $135 million related to the extension of the start-up date into 2015.[58] According to some reports, the overall cost of the plant may now exceed $6 billion when complete and ready for commercial operation,[59] and the schedule for start-up of commercial operations has been pushed to 2016.[60]

It is likely that the plant will attract increased scrutiny in the wake of the EPA proposed rule on CO_2 emissions, and its cost and schedule overruns evaluated against the promised environmental benefits due to CCS technology.[61] As **Figure 1** shows, costs for technologies tend to peak for projects in the demonstration phase of development, such as the Kemper County Project. What

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[52] DOE, National Energy Technology Laboratory, CCS Demonstrations, CCPI Initiative, http://netl.doe.gov/research/proj?k=FC26-06NT42391.

[53] MIT Carbon Capture and Sequestration Technologies, CCS Project Database, *Kemper County IGCC Fact Sheet: Carbon Capture and Storage Project*, http://sequestration.mit.edu/tools/projects/kemper.html.

[54] See Mississippi Power, Kemper County IGCC Project, Facts-Project Timeline, http://www.mississippipower.com/about-energy/plants/kemper-county-energy-facility/facts. Site accessed March 19, 2015.

[55] DOE Office of Fossil Energy, CCPI Round 2 Selections, http://energy.gov/fe/ccpi-round-2-selections.

[56] Tamar Hallerman, "Miss. Power to Absorb $540M in Cost Increases from Kemper Plant," *GHG Reduction Technologies Monitor*, April 26, 2013, http://ghgnews.com/index.cfm/miss-power-to-absorb-540m-in-cost-increases-from-kemper-plant/. Other reports cite the total costs for the plant.

[57] See Mississippi Power, Kemper County IGCC Project, Monthly Status Report Through February 2014, http://www.eenews.net/assets/2014/04/03/document_cw_01.pdf.

[58] See Mississippi Power, Kemper County IGCC Project, Monthly Status Report Through March 2014, http://www.eenews.net/assets/2014/04/30/document_cw_01.pdf.

[59] Daniel Cusack, "Kemper Plant Reaches Key Gasification Milestone, Despite Ballooning Costs," *Climate Wire*, March 13, 2015, http://www.eenews.net/climatewire/stories/1060014974/search?keyword=kemper.

[60] Mississippi Power, Kemper County Energy Facility, "Facts," *Project Timeline*, http://www.mississippipower.com/about-energy/plants/kemper-county-energy-facility/facts, as of April 4, 2015.

[61] See, for example, Mark Drajem, "Mississippi's Kemper Coal Plant Overruns Show Risk of EPA Carbon Rule," *Bloomberg News, SunHerald.com*, September 19, 2013, http://www.sunherald.com/2013/09/19/4964367/kemper-county-coal-plant-overruns.html.

the cost curve will look like, namely, how fast costs will decline and over what time period, is an open question and will likely depend on if and how quickly CCS technology is deployed on new and existing power plants.

Canada's Boundary Dam Project: The World's First Commercial-Scale CCS Project

The Boundary Dam Project, operated by SaskPower, is a Canadian venture, and it is the only commercial-scale power plant with CCS operating in the world. Some of its published cost and schedule data may be helpful to those trying to understand the financing and time requirements for other commercial-scale CCS projects. The cost for the project was approximately $1.3 billion, according to one source, of which $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.[62] 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 plant may have cost as much as $3.8 billion. The larger-scale project was discontinued because of the escalating costs.[63]

Like the Kemper Plant discussed above, Boundary Dam is a project that sells CO_2 for enhanced oil recovery, shipping 90% of the captured CO_2 via a 41-mile pipeline to the Weyburn Field. Unused CO_2 will be stored in a deep saline aquifer about 2.1 miles underground. The now-operating 110 megawatt (net) plant plans to capture at least 1 million tons of CO_2 per year.

Recovery Act Funding for CCS Projects: A Lynchpin for Success?

The bulk of Recovery Act funds for CCS ($3.32 billion, or 98%) was directed to three subprograms organized under the CCS Demonstrations Programs: the Clean Coal Power Initiative (CCPI), Industrial Carbon Capture and Storage projects (ICCS), and FutureGen (**Table 1**). Under the 2010 *CCS Roadmap*, and with the large infusion of funding from the Recovery Act, DOE's goal is to develop the technologies to allow for commercial-scale demonstration in both new and retrofitted power plants and industrial facilities by 2020. The DOE 2011 *Strategic Plan* sets a more specific target: to bring at least five commercial-scale CCS demonstration projects online by 2016.[64]

[62] MIT Carbon Capture & Sequestration Technologies, CCS Project Database, *Boundary Dam Fact Sheet: Carbon Capture and Storage Project*, http://sequestration.mit.edu/tools/projects/boundary_dam.html. A SaskPower fact sheet describes it as a $1.4 billion partnership between the government of Canada and SaskPower, http://saskpowerccs.com/ccs-projects/boundary-dam-carbon-capture-project/7913%20CSS%20Factsheet-Boundary%20Dam-newtense.pdf.

[63] MIT Carbon Capture & Sequestration Technologies, CCS Project Database, *Boundary Dam Fact Sheet: Carbon Capture and Storage Project*.

[64] U.S. Department of Energy, *Strategic Plan*, May 2011, p. 18, http://energy.gov/sites/prod/files/2011_DOE_Strategic_Plan_.pdf.

It could be argued that in its allocation of Recovery Act funding, DOE was heeding the recommendations of some experts[65] who identified commercial-scale demonstration projects as the most important component, the lynchpin, for future development and deployment of CCS in the United States. It could also be argued that much of the future success of CCS is riding on these three programs. Accordingly, the following section provides a snapshot of the CCPI, ICCS, and FutureGen programs, and a brief discussion of some of their accomplishments and challenges.

CCS Demonstrations: Clean Coal Power Initiative and Industrial Carbon Capture and Storage

Clean Coal Power Initiative

The Clean Coal Power Initiative was an ongoing program prior to the $800 million funding increase from the Recovery Act. This funding now is being used to expand activities in this program area for CCPI Round 3 beyond developing technologies to reduce sulfur, nitrogen, and mercury pollutants from power plants.[66] After enactment of the Recovery Act, DOE did not request additional funding for CCPI under its Fossil Energy program in the annual appropriations process (**Table 1** shows zero dollars for FY2012-FY2015). Rather, in the FY2010 DOE budget justification, DOE stated that funding for the these projects in CCPI Round 3 would be supported through the Recovery Act, and as a result "DOE will make dramatic progress in demonstrating CCS at commercial scale using these funds without the need for additional resources for demonstration in 2010."[67]

According to the 2010 DOE *CCS Roadmap*, Recovery Act funds have been used for these demonstration projects to "allow researchers broader CCS commercial-scale experience by expanding the range of technologies, applications, fuels, and geologic formations that are being tested."[68] DOE selected six projects under CCPI Round 3 through two separate solicitations.[69] The total DOE share of funding would have been $1.75 billion for the six projects in five states: Alabama, California, North Dakota, Texas, and West Virginia (**Table 2**). However, the projects in Alabama, North Dakota, and West Virginia withdrew from the program, and currently the DOE share for the remaining three projects is approximately $1.03 billion (of a total of over $6 billion

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[65] See, for example, the presentations given by Edward Rubin of Carnegie Mellon University, Howard Herzog of the Massachusetts Institute of Technology, and Jeff Phillips of the Electric Power Research Institute, at the CRS seminar *Capturing Carbon for Climate Control: What's in the Toolbox and What's Missing*, November 18, 2009. (Presentations available from Peter Folger at 7-1517.) Rubin stated that at least 10 full-scale demonstration projects would be needed to establish the reliability and true cost of CCS in power plant applications. Herzog also called for at least 10 demonstration plants worldwide that capture and sequester a million metric tons of CO_2 per year. In his presentation, Phillips stated that large-scale demonstrations are critical to building confidence among power plant owners.

[66] DOE had solicited and awarded funding for CCPI projects in two previous rounds of funding: CCPI Round 1 and Round 2. The Recovery Act funds were to be allocated in CCPI Round 3, focusing on projects that utilize CCS technology and/or the beneficial reuse of CO_2. For more details, see http://www.fossil.energy.gov/programs/powersystems/cleancoal/.

[67] U.S. Department of Energy, *Detailed Budget Justifications FY2010*, volume 7, Fossil Energy Research and Development, p. 35, http://www.cfo.doe.gov/budget/10budget/Content/Volumes/Volume7.pdf.

[68] DOE 2010 *CCS Roadmap*, p. 15.

[69] The first solicitation closing date was January 20, 2009; the second solicitation closing date was August 24, 2009. Thus the first set of project proposals were submitted prior to enactment of the Recovery Act. See http://www.fossil.energy.gov/programs/powersystems/cleancoal/.

for total expected costs). With the withdrawal of three CCPI Round 3 projects, DOE's share of the total program costs shrank from over 21% to approximately 15%.

Table 2. DOE CCPI Demonstration Round 3 Projects

Round 3 Project	Location	DOE Share of Funding ($ millions)	Total Project Cost ($ millions)	Percent DOE Share	Metric Tons of CO_2 Captured Annually (millions)	Project Status
Texas Clean Energy Project	Penwell, TX	450	1,727	26%	2.2[b]	Active
Hydrogen Energy California Project	Kern County, CA	408	4,028	10%	2.6	Active
Petra Nova Energy Project	Thompsons, TX	167	1,000	17%	1.4	Active
AEP Mountaineer Project	New Haven, WV	334	668	50%	1.5	Withdrawn July 2011
Southern Company Project	Mobile, AL	295	665	44%	1	Withdrawn February 2010
Basin Electric Power Project	Beulah, ND	100	387	26%	0.9	Withdrawn December 2010
Total		**1,754**	**8,475**	**21.0%**	**9.6**	
Total, Active Projects[a]		**1,025**	**6,755**	**15.2%**	**6.2**	

Sources: DOE Fossil Energy Techline; Environment News Service (March 12, 2010), http://www.ens-newswire.com/ens/mar2010/2010-03-12-093.html; National Energy Technology Laboratory (NETL) Clean Coal Power Initiative (CCPI) website, http://www.netl.doe.gov/technologies/coalpower/cctc/ccpi/index.html; NETL Factsheet: Summit Texas Clean Energy, LLC, November 2014, http://www.netl.doe.gov/research/coal/major-demonstrations/clean-coal-power-initiative/ccpi-summit; NETL Factsheet Hydrogen Energy California Project, November 2014, http://www.netl.doe.gov/research/coal/major-demonstrations/clean-coal-power-initiative/ccpi-heca; NETL Factsheet Petra Nova Parish Holdings: W.A. Parish Post Combustion CO_2 Capture and Sequestration Project, November 2014, http://www.netl.doe.gov/research/coal/major-demonstrations/clean-coal-power-initiative/ccpi-petra-nova.

Notes: DOE funding for the Petra Nova (formerly NRG) Energy Project was initially announced as up to $154 million (see March 9, 2009, DOE Techline, http://www.fossil.energy.gov/news/techlines/2010/10005-NRG_Energy_Selected_to_Receive_DOE.html). A May 2010 DOE fact sheet indicated that funding was $167 million (http://www.netl.doe.gov/publications/factsheets/project/FE0003311.pdf). A November 2014 DOE fact sheet noted that the scale of the project was increased to $1.0 billion because the original 60 megawatt project was too small to produce enough CO_2 for significant enhanced oil production from CO_2 injection.

a. Totals include amounts that were reallocated from withdrawn projects to active projects.

b. According to NETL, this amount would be a maximum amount per year. About 1.74 million metric tons would be stored geologically annually; the remaining amount of captured CO_2 would be used for urea production.

Reasons for Withdrawal from the CCPI Program

Commercial sector partners identified a number of reasons for withdrawing from the CCPI program, including finances, uncertainty regarding future regulations, and uncertainty regarding the future national climate policy.

Southern Company—Plant Barry 160 Megawatt Project: Southern Company withdrew its Alabama Plant Barry project from the CCPI program on February 22, 2010, slightly more than two months after DOE Secretary Chu announced $295 million in DOE funding for the 11-year, $665 million project that would have captured up to 1 million tons of CO_2 per year from a 160 megawatt coal-fired generation unit.[70] According to some sources, Southern Company's decision was based on concern about the size of the company's needed commitment (approximately $350 million) to the project, and its need for more time to perform due diligence on its financial commitment, among other reasons.[71] Southern Company continues work on a much smaller CCS project that would capture CO_2 from a 25 megawatt unit at Plant Barry.

Basin Electric Power—Antelope Valley 120 Megawatt Project: On July 1, 2009, Secretary Chu announced $100 million in DOE funding for a project that would capture approximately 1 million tons of CO_2 per year from a 120 megawatt electric-equivalent gas stream from the Antelope Valley power station near Beulah, ND.[72] In December 2010, the Basin Electric Power Cooperative withdrew its project from the CCPI program, citing regulatory uncertainty with regard to capturing CO_2, uncertainty about the project's cost (one source indicates that the company estimated $500 million total cost; DOE estimated $387 million—see **Table 2**),[73] uncertainty of environmental legislation, and lack of a long-term energy strategy for the country.[74] The project would have supplied the captured CO_2 to an existing pipeline that transports CO_2 from the Great Plains Synfuels Plant near Beulah for enhanced oil recovery in Canada's Weyburn field approximately 200 miles north in Saskatchewan.

American Electric Power—Mountaineer 235 Megawatt Project: In July 2011 American Electric Power (AEP) decided to halt its plans to build a carbon capture plant for a 235 megawatt generation unit at its 1.3 gigawatt Mountaineer power plant in New Haven, WV. The project represented Phase 2 of an ongoing CCPI project. Secretary Chu had earlier announced a $334 million award for the project on December 4, 2009.[75] According to some sources, AEP dropped the project because the company was not certain that state regulators would allow it to recover the additional costs for the CCS project through rate increases charged to its customers.[76] In addition, company officials cited broader economic and policy conditions as reasons for cancelling the project.[77] Some commentators suggested that congressional inaction on setting limits on GHG

[70] MIT Carbon Capture & Sequestration Technologies, *Plant Barry Fact Sheet: Carbon Dioxide Capture and Storage Project*, http://sequestration.mit.edu/tools/projects/plant_barry.html.

[71] Ibid.

[72] U.S. DOE, Fossil Energy Techline, *Secretary Chu Announces Two New Projects to Reduce Emissions from Coal Plants*, July 1, 2009, http://www.fossil.energy.gov/news/techlines/2009/09043-DOE_Announces_CCPI_Projects.html.

[73] Lauren Donovan, "Basin Shelves Lignite's First Carbon Capture Project," *Bismarck Tribune*, December 17, 2010, http://bismarcktribune.com/news/local/a5fb7ed8-0a1b-11e0-b0ea-001cc4c03286.html.

[74] Daryl Hill and Tracie Bettenhausen, "Fresh Tech, Difficult Decisions: Basin Electric has a History of Trying New Technology," Basin Electric Power Cooperative newsletter, January-February 2011, http://www.basinelectric.com/Miscellaneous/pdf/FeatureArticles/Fresh_Tech,_difficul.pdf.

[75] U.S. DOE, Fossil Energy Techline, *Secretary Chu Announces $3 Billion Investment for Carbon Capture and Sequestration*, December 4, 2009, http://www.fossil.energy.gov/news/techlines/2009/09081-Secretary_Chu_Announces_CCS_Invest.html.

[76] Matthew L. Wald and John M. Broder, "Utility Shelves Ambitious Plan to Limit Carbon," *New York Times*, July 13, 2011, http://www.nytimes.com/2011/07/14/business/energy-environment/utility-shelves-plan-to-capture-carbon-dioxide.html?_r=1.

[77] Michael G. Morris, chairman of AEP, quoted in Matthew L. Wald and John M. Broder, "Utility Shelves Ambitious Plan to Limit Carbon," *The New York Times*, July 13, 2011.

emissions, as well as the weak economy, may have diminished the incentives for a company like AEP to invest in CCS.[78] One source concluded that "Phase 2 has been cancelled due to unknown climate policy."[79]

Reshuffling of Funding for CCPI

According to DOE, $140 million of the $295 million previously allotted to the Southern Company Plant Barry project was redistributed to the Texas Clean Energy project and the Hydrogen Energy California project. DOE provided additional funding, resulting in each project receiving an additional $100 million above its initial award.[80] The remaining funding from the canceled Plant Barry project (up to $154 million) was allotted to the NRG Energy project in Texas (now the Petra Nova Energy Project; see **Table 2**).[81]

According to a DOE source, selection of the Basin Electric Power project was announced but a cooperative agreement was never awarded by DOE.[82] Funds that were to be obligated for the Basin project could therefore have been reallocated within the department, but were rescinded by Congress in FY2011 appropriations.

Some of the funding for the AEP Mountaineer project was rescinded by Congress in FY2012 appropriations legislation (P.L. 112-74). In the report accompanying P.L. 112-74, Congress rescinded a total of $187 million of prior-year balances from the Fossil Energy Research and Development account.[83] The rescission did not apply to amounts previously appropriated under P.L. 111-5; however, funding for the AEP Mountaineer project that was provided by the Recovery Act and not spent was returned to the Treasury and not made available to the CCPI program.[84]

Industrial Carbon Capture and Storage Projects

The original DOE ICCS program was divided into two main areas: Area 1, consisting of large industrial demonstration projects; and Area 2, consisting of projects to test innovative concepts for the beneficial reuse of CO_2.[85] Under Area 1, the first phase of the program consisted of 12 projects cost-shared with private industry, intended to increase investment in clean industrial technologies and sequestration projects. Phase 1 projects averaged approximately seven months in duration. Following Phase 1, DOE selected three projects for Phase 2 for design, construction,

[78] Wald and Broder, *New York Times*, July 13, 2011.

[79] MIT Carbon Capture & Sequestration Technologies, *AEP Mountaineer Fact Sheet: Carbon Dioxide Capture and Storage Project*, http://sequestration.mit.edu/tools/projects/aep_alstom_mountaineer.html.

[80] Telephone conversation with Joseph Giove, DOE Office of Fossil Energy, March 19, 2012.

[81] U.S. DOE Fossil Energy Techline, "Secretary Chu Announces Up To $154 Million for NRG Energy's Carbon Capture and Storage Project in Texas," March 9, 2010, http://www.fossil.energy.gov/news/techlines/2010/10005-NRG_Energy_Selected_to_Receive_DOE.html.

[82] Telephone conversation with Joseph Giove, DOE Office of Fossil Energy, April 11, 2011.

[83] U.S. Congress, House Committee on Appropriations, Subcommittee on Military Construction, Veterans Affairs, and Related Agencies, *Military Construction and Veterans Affairs and Related Agencies Appropriations Act, 2012*, conference report to accompany H.R. 2055, 112th Cong., 1st sess., December 15, 2011, H.Rept. 112-331 (Washington: GPO, 2011), p. 851.

[84] Telephone conversation with Joseph Giove, DOE Office of Fossil Energy, March 19, 2012.

[85] Email from Regis K. Conrad, Director, Division of Cross-Cutting Research, DOE, March 20, 2012.

and operation.[86] The three Phase 2 projects are listed as large-scale demonstration projects in **Table 3**. The total share of DOE funding for the three projects, provided by the Recovery Act, is $686 million, or approximately 64% of the sum total Area 1 program cost of $1.075 billion.

Under Area 2, the initial phase consisted of $17.4 million in Recovery Act funding and $7.7 million in private-sector funding for 12 projects to engage in feasibility studies to examine the beneficial reuse of CO_2.[87] In July 2010, DOE selected six projects from the original 12 projects for a second phase of funding to find ways of converting captured CO_2 into useful products such as fuel, plastics, cement, and fertilizer. The six projects are listed under "Innovative Concepts/Beneficial Use" in **Table 3**. The total share of DOE funding for the six projects, provided by the Recovery Act, is $141.5 million, or approximately 71% of the sum total cost of $198.2 million.

Since its original conception, the DOE ICCS program has expanded with an additional 22 projects, funded under the Recovery Act, to accelerate promising technologies for CCS.[88] In its listing of the 22 projects, DOE groups them into four general categories: (1) Large-Scale Testing of Advanced Gasification Technologies; (2) Advanced Turbo-Machinery to Lower Emissions from Industrial Sources; (3) Post-Combustion CO_2 Capture with Increased Efficiencies and Decreased Costs; and (4) Geologic Storage Site Characterization.[89] The total share of DOE funding for the 22 projects, provided by the Recovery Act, is $594.9 million, or approximately 78% of the sum total cost of $765.2 million.

Overall, the total share of federal funding for all the ICCS projects combined is $1.422 billion, or approximately 70% of the sum total cost of $2.038 billion.

Table 3. DOE Industrial Carbon Capture and Storage (ICCS) Projects

(showing DOE share of funding and total project cost)

ICCS Project Name	Location	Type of Project	DOE Share of Funding ($ millions)	Total Project Cost ($ millions)	Percent DOE Share
Air Products & Chemicals, Inc.	Port Arthur, TX	Large-Scale Demonstration	284	431	66%
Archer Daniels Midland Co.	Decatur, IL	Large-Scale Demonstration	141	208	68%
Leucadia Energy, LLC	Lake Charles, LA	Large-Scale Demonstration	261	436	60%
Alcoa, Inc.	Alcoa Center, PA	Innovative Concepts/Beneficial Use	13.5	16.9	80%

[86] U.S. DOE, National Energy Technology Laboratory, *Industrial Carbon Capture and Storage (ICCS): Area 1*, http://www.netl.doe.gov/research/coal/major-demonstrations/industrial-carbon-capture-and-storage.

[87] U.S. DOE, *Recovery Act, Innovative Concepts for Beneficial Reuse of Carbon Dioxide*, http://energy.gov/fe/innovative-concepts-beneficial-reuse-carbon-dioxide-0.

[88] Email from Regis K. Conrad, Director, Division of Cross-Cutting Research, DOE, March 20, 2012.

[89] U.S. DOE, Carbon Capture and Storage from Industrial Sources, Industrial Carbon Capture Project Selections, http://fossil.energy.gov/recovery/projects/iccs_projects_0907101.pdf.

ICCS Project Name	Location	Type of Project	DOE Share of Funding ($ millions)	Total Project Cost ($ millions)	Percent DOE Share
Novomer, Inc.	Ithaca, NY	Innovative Concepts/Beneficial Use	20.5	25.6	80%
Touchstone Research Lab, Ltd.	Triadelphia, PA	Innovative Concepts/Beneficial Use	6.7	8.4	80%
Phycal, LLC	Highland Heights, OH	Innovative Concepts/Beneficial Use	51.4	65	80%
Skyonic Corp.	Austin, TX	Innovative Concepts/Beneficial Use	28	39.6	70%
Calera Corp.	Los Gatos, CA	Innovative Concepts/Beneficial Use	21.4	42.7	50%
Air Products & Chemicals, Inc.	Allentown, PA	Advanced Gasification Technologies	71.7	75	96%
Eltron Research & Development, Inc.	Boulder, CO	Advanced Gasification Technologies	71.4	73.7	97%
Research Triangle Institute	Research Triangle Park, NC	Advanced Gasification Technologies	168.8	174	97%
GE Energy	Schenectady, NY	Advanced Turbo-Machinery	31.3	62.6	50%
Siemens Energy	Orlando, FL	Advanced Turbo-Machinery	32.3	64.7	50%
Clean Energy Systems, Inc.	Rancho Cordova, CA	Advanced Turbo-Machinery	30	42.9	70%
Ramgen Power Systems	Bellevue, WA	Advanced Turbo-Machinery	50	79.7	63%
ADA-ES, Inc.	Littleton, CO	Post-Combustion Capture	15	18.8	80%
Alstom Power	Windsor, CT	Post-Combustion Capture	10	12.5	80%
Membrane Technology & Research, Inc.	Menlo Park, CA	Post-Combustion Capture	15	18.8	80%
Praxair	Tonawanda, NY	Post-Combustion Capture	35	55.6	63%
Siemens Energy, Inc.	Pittsburgh, PA	Post-Combustion Capture	15	18.8	80%
Board of Trustees U. of IL	Champaign, IL	Geologic Site Characterization	5	6.5	77%
N. American Power Group, Ltd.	Greenwood Village, CO	Geologic Site Characterization	5	7.85	64%

ICCS Project Name	Location	Type of Project	DOE Share of Funding ($ millions)	Total Project Cost ($ millions)	Percent DOE Share
Sandia Technologies, LLC	Houston, TX	Geologic Site Characterization	4.38	5.63	78%
S. Carolina Research Foundation	Columbia, SC	Geologic Site Characterization	5	6.25	80%
Terralog Technologies USA, Inc.	Arcadia, CA	Geologic Site Characterization	5	6.25	80%
U. of Alabama	Tuscaloosa, AL	Geologic Site Characterization	5	10.8	46%
U. of Kansas Center for Research, Inc.	Lawrence, KS	Geologic Site Characterization	5	6.29	80%
U. of Texas at Austin	Austin, TX	Geologic Site Characterization	5	6.25	80%
U. of Utah	Salt Lake City, UT	Geologic Site Characterization	5	7.23	69%
U. of Wyoming	Laramie, WY	Geologic Site Characterization	5	5	100%
		Totals	**1,422.4**	**2,038.4**	**70%**

Source: Emails from Regis K. Conrad, Director, Division of Cross-Cutting Research, DOE, March 20 and March 27, 2012; U.S. DOE, National Energy Technology Laboratory, *Major Demonstrations, Industrial Capture and Storage (ICCS): Area 1*, http://energy.gov/fe/articles/new-recovery-act-funding-boosts-industrial-carbon-capture-and; U.S. DOE, *Carbon Capture and Storage from Industrial Sources, Industrial Carbon Capture Project Selections,* http://fossil.energy.gov/recovery/projects/iccs_projects_0907101.pdf.

Notes: Table is ordered from top to bottom by type of project: Large-Scale Demonstration; Innovative Concepts/Beneficial Use; Advanced Gasification Technologies; Advanced Turbo-Machinery; Post-Combustion Capture; and Geologic Site Characterization. Totals may not add due to rounding.

Geologic Sequestration/Storage: DOE RD&D for the Last Step in CCS

DOE allocated $112 million in FY2012, $107 million in FY2013, $109 million in FY2014, $100 million in FY2015, and is requesting $109 million in FY2016 for its carbon sequestration and storage activities. (See **Table 1**.) In contrast with the carbon capture technology RD&D, which received nearly all of the $3.4 billion from Recovery Act funding, carbon sequestration/carbon storage activities received approximately $50 million in Recovery Act funds. Recovery Act funds were awarded for 10 projects to conduct site characterization of promising geologic formations for CO_2 storage.[90]

[90] The total DOE share for the 10 projects is $49.4 million. See **Table 3**.

Brief History of DOE Geological Sequestration/Storage Activities

DOE has devoted the bulk of its funding for geological sequestration/storage activities to RD&D efforts for injecting CO_2 into subsurface geological reservoirs. Injection and storage is the third step in the CCS process, following the CO_2 capture step and CO_2 transport step. One part of the RD&D effort is characterizing geologic reservoirs (which received a $50 million boost from Recovery Act funds, as noted above); however, the overall program is much broader than just characterization, and has now reached the beginning of the phase of large-volume CO_2 injection demonstration projects across the country. According to DOE, these large-volume tests are needed to validate long-term storage in a variety of different storage formations of different depositional environments, including deep saline reservoirs, depleted oil and gas reservoirs, low permeability reservoirs, coal seams, shale, and basalt.[91] The large-volume tests can be considered injection experiments conducted at a commercial scale (i.e., approximately 1 million tons of CO_2 injected per year) that should provide crucial information on the suitability of different geologic reservoirs; monitoring, verification, and accounting of injected CO_2; risk assessment protocols for long-term injection and storage; and other critical challenges.

In 2003 DOE created seven regional carbon sequestration partnerships (RCSPs), essentially consortia of public and private sector organizations grouped by geographic region across the United States and parts of Canada.[92] The geographic representation was intended to match regional differences in fossil fuel use and geologic reservoir potential for CO_2 storage.[93] The RCSPs cover 43 states and 4 Canadian provinces and include over 400 organizations, according to the DOE 2011 *Strategic Plan*. **Table 4** shows the seven partnerships, the lead organization for each, and the states and provinces included.[94] Several states belong to more than one RCSP.

Table 4. Regional Carbon Sequestration Partnerships

Regional Carbon Sequestration Partnership (RCSP)	Lead Organization	States and Provinces in the Partnership
Big Sky Carbon Sequestration Partnership (BSCSP)	Montana State University-Bozeman	MT, WY, ID, SD, eastern WA, eastern OR
Midwest Geological Sequestration Consortium (MGSC)	Illinois State Geological Survey	IL, IN, KY
Midwest Regional Carbon Sequestration Partnership (MRCSP)	Battelle Memorial Institute	IN, KY, MD, MI, NJ, NY, OH, PA, WV,

[91] DOE 2010 *CCS Roadmap*, p. 55.

[92] Four Canadian provinces are partners with DOE in two of the regional partnerships, and are members with other participating organizations that are contributing funding and other support to the partnerships.

[93] DOE National Energy Technology Laboratory, Carbon Sequestration Regional Carbon Sequestration Partnerships, http://www.netl.doe.gov/technologies/carbon_seq/infrastructure/rcsp.html.

[94] In its FY2016 budget justification, DOE renamed the RCSPs subactivity the Storage Infrastructure subactivity. See U.S. Department of Energy, FY2016 Congressional Budget Request, volume 3, *Fossil Energy Research and Development*, p. 572.

Regional Carbon Sequestration Partnership (RCSP)	Lead Organization	States and Provinces in the Partnership
Plains CO_2 Reduction Partnership (PCOR)	University of North Dakota Energy and Environmental Research Center	MT, northeast WY, ND, SD, NE, MN, IA, MO, WI, Manitoba, Alberta, Saskatchewan, British Columbia (Canada)
Southeast Regional Carbon Sequestration Partnership (SECARB)	Southern States Energy Board	AL, AS, FL, GA, LA, MS, NC, SC, TN, TX, VA, portions of KY and WV
Southwest Regional Partnership on Carbon Sequestration (SWP)	New Mexico Institute of Mining and Technology	AZ, CO, OK, NM, UT, KS, NV, TX, WY
West Coast Regional Carbon Sequestration Partnership (WESTCARB)	California Energy Commission	AK, AZ, CA, HI, OR, NV, WA, British Columbia (Canada)

Source: DOE National Energy Technology Laboratory, *Carbon Sequestration Regional Carbon Sequestration Partnerships*, http://www.netl.doe.gov/research/coal/carbon-storage/carbon-storage-infrastructure.

The RCSPs have pursued their objectives through three phases beginning in 2003: (1) Characterization Phase (2003 to 2005), an initial examination of the region's potential for geological sequestration of CO_2; (2) Validation Phase (2005 to 2011), small-scale injection field tests (less than 500,000 tons of CO_2) to develop a better understanding of how different geologic formations would handle large amounts of injected CO_2; and (3) Development Phase (2008 to 2018 and beyond), injection tests of at least 1 million tons of CO_2 to simulate commercial-scale quantities of injected CO_2.[95] The last phase is intended also to collect enough information to help understand the regulatory, economic, liability, ownership, and public outreach requirements for commercial deployment of CCS.

There are RD&D activities funded by DOE under its carbon sequestration/carbon storage program activities other than the RCSPs, such as geological storage technologies; monitoring, verification, and assessment; carbon use and reuse; and others. However, the RCSPs were allocated approximately 66% of annual spending on carbon sequestration/carbon storage in FY2015, and comprised 58% of that account in the FY2016 budget request. The RCSPs provide the framework and infrastructure for a wide variety of DOE geologic sequestration/storage activities.

Current Status and Challenges to Carbon Sequestration/Storage

The third phase—Development—is currently underway for all the RCSPs, and large-scale CO_2 injection has begun for the SECARB and MGSC projects.[96] The Development Phase large-scale injection projects are arguably akin to the large-scale carbon capture demonstration projects discussed above (see **Table 2**). They are needed to understand what actually happens to CO_2

[95] DOE National Energy Technology Laboratory, Carbon Sequestration Regional Carbon Sequestration Partnerships, http://www.netl.doe.gov/research/coal/carbon-storage/carbon-storage-infrastructure.

[96] For details on the two large-scale injection experiments by SECARB, see http://www.secarbon.org/; for details on the large-scale injection experiment by MGSC, see http://sequestration.org/.

underground when commercial-scale volumes are injected in the same or similar geologic reservoirs as would be used if CCS were deployed nationally.

In addition to understanding the technical challenges to storing CO_2 underground without leakage over hundreds of years, DOE also expects that the Development Phase projects will provide a better understanding of regulatory, liability, and ownership issues associated with commercial-scale CCS.[97] These nontechnical issues are not trivial, and could pose serious challenges to widespread deployment of CCS even if the technical challenges of injecting CO_2 safely and in perpetuity are resolved. For example, a complete regulatory framework for managing the underground injection of CO_2 has not been developed in the United States. However, EPA promulgated a rule under the authority of the Safe Drinking Water Act (SDWA) that creates a new class of injection wells under the existing Underground Injection Control Program. The new class of wells (Class VI) establishes national requirements specifically for injecting CO_2 and protecting underground sources of drinking water. EPA's stated purpose in proposing the rule was to ensure that CCS can occur in a safe and effective manner in order to enable commercial-scale CCS to move forward.[98]

The development of the regulation for Class VI wells highlighted that EPA's authority under the SDWA is limited to protecting underground sources of drinking water but does not address other major issues. Some of these include the long-term liability for injected CO_2, regulation of potential emissions to the atmosphere, legal issues if the CO_2 plume migrates underground across state boundaries, private property rights of owners of the surface lands above the injected CO_2 plume, and ownership of the subsurface reservoirs (also referred to as pore space).[99] Because of these issues and others, there are some indications that broad community acceptance of CCS may be a challenge. The large-scale injection tests may help identify the key factors that lead to community concerns over CCS, and help guide DOE, EPA, other agencies, and the private sector towards strategies leading to the widespread deployment of CCS. Currently, however, the general public is largely unfamiliar with the details of CCS and these challenges have yet to be resolved.[100]

Outlook

Testimony from Scott Klara of the National Energy Technology Laboratory sums up a crucial metric for the success of the federal CCS RD&D program, namely, whether CCS technologies are deployed in the commercial marketplace:

> The success of the Clean Coal Program will ultimately be judged by the extent to which emerging technologies get deployed in domestic and international marketplaces. Both technical and financial challenges associated with the deployment of new "high risk" coal technologies must be overcome in order to be capable of achieving success in the marketplace. Commercial scale

[97] DOE National Energy Technology Laboratory, *Carbon Sequestration Regional Partnership Development Phase (Phase III) Projects*, http://www.netl.doe.gov/technologies/carbon_seq/infrastructure/rcspiii.html.

[98] For more information on the EPA Class VI wells in particular, and the Safe Drinking Water Act generally, see CRS Report RL34201, *Safe Drinking Water Act (SDWA): Selected Regulatory and Legislative Issues*, by Mary Tiemann.

[99] For a discussion of several of these legal issues, see CRS Report RL34307, *Legal Issues Associated with the Development of Carbon Dioxide Sequestration Technology*, by Adam Vann and Paul W. Parfomak.

[100] For more information on the different issues regarding community acceptance of CCS, see CRS Report RL34601, *Community Acceptance of Carbon Capture and Sequestration Infrastructure: Siting Challenges*, by Paul W. Parfomak.

> demonstrations help the industry understand and overcome startup issues, address component integration issues, and gain the early learning commercial experience necessary to reduce risk and secure private financing and investment for future plants.[101]

To date, there are no commercial ventures in the United States that capture, transport, and inject large quantities of CO_2 (e.g., 1 million tons per year or more) solely for the purposes of carbon sequestration. The Kemper County Energy project likely will be the first to do so, although the majority of the injected CO_2 will be for purposes of enhanced oil recovery. The Boundary Dam Project in Canada, which began operations in 2014, is the first commercial-scale power plant with CCS in operation in the world. Boundary Dam also sends most of its captured CO_2 to a nearby oilfield for enhanced oil recovery.

The DOE CCS RD&D program has embarked on commercial-scale demonstration projects for CO_2 capture, injection, and storage. The success of these demonstration projects will likely bear heavily on the future outlook for widespread deployment of CCS technologies as a strategy for preventing large quantities of CO_2 from reaching the atmosphere while plants continue to burn fossil fuels, mainly coal. The proposed EPA standard to limit CO_2 emissions from new coal-fired power plants has invited renewed scrutiny of CCS technology and its prospects for commercial deployment. Congress may wish to carefully review the CCS R&D program and particularly the results from the demonstration projects as they progress. Such a review could help Congress evaluate whether DOE is on track to meet its goal of allowing for an advanced CCS technology portfolio to be ready by 2020 for large-scale demonstration and deployment in the United States.

In addition to the issues and programs discussed above, other factors might affect the demonstration and deployment of CCS in the United States. The use of hydraulic fracturing techniques to extract unconventional natural gas deposits recently has drawn national attention to the possible negative consequences of deep well injection of large volumes of fluids. Hydraulic fracturing involves the high-pressure injection of fluids into the target formation to fracture the rock and release natural gas or oil. The injected fluids, together with naturally occurring fluids in the shale, are referred to as produced water. Produced waters are pumped out of the well and disposed of. Often the produced waters are disposed of by re-injecting them at a different site in a different well. These practices have raised concerns about possible leakage as fluids are pumped into and out of the ground, and about deep-well injection causing earthquakes.[102] Public concerns over hydraulic fracturing and deep-well injection of produced waters may spill over into concerns about deep-well injection of CO_2. How successfully DOE is able to address these types of concerns as the large-scale demonstration projects move forward into their injection phases could affect the future of CCS deployment.

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[101] Testimony of Scott Klara, Deputy Laboratory Director, National Energy Technology Laboratory, U.S. Department of Energy, in U.S. Congress, Senate Energy and Natural Resources Committee, *Carbon Capture and Sequestration Legislation*, hearing to receive testimony on carbon capture and sequestration legislation, including S. 699 and S. 757, 112th Cong., 1st sess., May 12, 2011, S.Hrg. 112-22.

[102] See, for example, CRS Report R43836, *Human-Induced Earthquakes from Deep-Well Injection: A Brief Overview*, by Peter Folger and Mary Tiemann.

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