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FOSTERING LOW CARBON ENERGY

Next Generation Policy to Commercialize CCS in the United States

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Acronyms and Abbreviations

2DS: 2 Degree Scenario
ACCTION: Advanced Clean Coal Technology Investment in our Nation Act of 2015
AEP: American Electric Power
AIEC: American Energy Innovation Council
ARRA: American Reinvestment and Recovery Act of 2009
BECCS: Bio-energy with carbon capture and storage
BTU: British thermal unit
C2ES: Center for Climate and Energy Solutions
CAA: Clean Air Act
CCS: Carbon capture and storage
CCUS: Carbon capture, utilization, and storage
CEDA: Clean Energy Deployment Administration
CERC: Clean Energy Research Center
CES: Clean Energy Standard
CfD: Contract for differences
CO_2: Carbon dioxide
COE: Cost of energy
CPP: Clean Power Plant
CPPI: Clean Power Plant Initiative
CRS: Congressional Research Service
CSLF: Carbon Sequestration Leadership Forum
CURC: Coal Utilization Research Council
DECC: U.K. Department of Energy and Climate Change
DOE: U.S. Department of Energy
EESA: Energy Improvement and Extension Act of 2008
EISA: Energy Independence and Security Act of 2007
EIA: U.S. Environmental Information Agency
EOR: Enhanced oil recovery
EPA: U.S. Environmental Protection Agency
EPACT: Energy Policy Act of 2005
EPRI: Electric Power Research Institute
FEED: Front end engineering and design
GAO: U.S. Government Accountability Office
GHGs: Greenhouse gases

GW: Gigawatt
GWh: Gigawatt-hour
HECA: Hydrogen Energy California Project
HELE: High efficiency, low emissions
IEA: International Energy Agency
IEEE: Institute of Electrical and Electronics Engineers
IGCC: Integrated gasification combined cycle
IPCC: Intergovernmental Panel on Climate Change
IRC: Internal revenue code
ITC: Investment Tax Credit
JCT: Joint Committee on Taxation
KWh: Kilowatt-hour
MLP: Master limited partnership
MW: Megawatt
MWe: Megawatt electrical
MWh: Megawatt-hour
NACSA: National Carbon Sequestration Atlas
NEORI: National Enhanced Oil Recovery Initiative
NEPA: National Environmental Policy Act
NETL: National Energy Technology Laboratory
NGCC: Natural gas combined cycle
NO_x: Nitric oxide/nitrogen dioxide
OECD: Organization of Economic Co-operation and Development
PC: Pulverized coal
RD&D: Research, development, and demonstration
R&D: Research and development
RGGI: Regional Greenhouse Gas Initiative
RPS: Renewable portfolio standards
SC: Super-critical
SO_2: Sulfur dioxide
SPR: Strategic Petroleum Reserve
TECP: Texas Clean Energy Project
T&S: Transportation and storage
USC: Ultra super-critical
USEA: U.S. Energy Association

Summary for Policymakers

Carbon capture and storage (CCS) is the integrated process of capturing carbon dioxide (CO_2) from power generation or industrial activities, then storing (sequestering) it to prevent its release into the atmosphere. Storage is typically achieved by transporting and injecting CO_2 into a suitable geological formation. In some cases CO_2 can also be utilized while achieving long-term storage—most notably for enhanced oil recovery (EOR).

Most low or zero carbon technologies do not come entirely without controversy, but CCS may well be the most contentious, with critics opposed because it will take pressure off scaling back use of fossil fuels, especially coal, has high costs, and because of concern that CO_2 cannot be safely stored long-term underground. Despite these challenges, CCS has undisputed potential to serve as a key component of a carbon mitigation portfolio for the electricity, petrochemical, and other industries. Moreover, there are numerous studies that have concluded that in the long-term CCS can be a cost effective measure to reduce global CO_2 emissions.

However, with the exception of one plant in Canada, integrated CCS projects have not been commercially deployed to date in the power sector, and there is fairly wide skepticism that it will happen any time soon. Indeed, CCS seems to be caught in a classic policy dilemma: while some governments view CCS as a low carbon option, without a government requirement or strong incentive to significantly reduce CO_2 emissions there is little or no incentive for the private sector to develop and deploy CCS technology.[1]

The objective of this policy brief is to provide policymakers with a high-level qualitative review of what policies are needed to commercialize CCS based on the status of the technology, its commercial risks, and its political realities if it is to be a viable component of a low carbon portfolio. We hope this policy brief helps re-ignite a substantive dialogue on the role of CCS.

Conclusions

CCS can meet environmental, economic, and national security objectives. First, it is a carbon disposal approach that can be deployed on new or existing coal- and natural gas-fired power plants to meet the environmental goal of reducing or eliminating CO_2 emissions. Second, supporting innovation and commercialization of CCS technologies provides various economic benefits, in particular offering a pathway to transitioning existing fossil-fuel assets to a low carbon economy. Positioning the United States at the forefront of CCS technology development also potentially fosters export markets for U.S. companies. This is particularly relevant since most of the growth in coal use in the coming decades will be in emerging market countries with large projected increases in coal-fired electricity generation. Perhaps most importantly from an economic perspective, several reputable analyses, for example from the International Energy Agency, World Bank, and the United Nations, indicate that with CCS as part of a technology portfolio, overall costs of transitioning to a low carbon economy will be lower. Third, CCS can meet national security goals by providing a way to take advantage of abundant domestic fossil fuel resources, including increased oil production by using captured CO_2 for EOR, in which CO_2 is ultimately sequestered in depleted oil reservoirs. This can simultaneously reconcile national security goals with the goal of reducing greenhouse gases (GHGs).

Current policy does not adequately address CCS technology status and risks. The U.S. government has supported CCS since 1997, and in the last

[1] Edward S. Rubin, "Will Cutting Carbon Kill Coal?" Pittsburgh Post-Gazette, Section E, November 2014.

Current policy is not fostering CCS commercialization or creating markets for CCS technology

decade, the Department of Energy has implemented a robust, world-leading program with policy support focused on carbon capture technologies, and storage. Specifically, CCS policy mainly comprises early stage financial support for R&D and demonstration projects to help nurture various technologies along with financial incentives implemented through the tax code to facilitate deployment. Despite this support, integrated CCS projects in the power sector are proceeding slowly along the innovation and commercialization pathway: In the United States CCS is currently in the demonstration stage with only two facilities under construction at power plants. Commercializing CCS is not a technology challenge—rather, policies are needed that spur further development of *integrated* projects at scale. Specifically, disadvantages of the current policy approach are:

- Insufficient support for large-scale demonstrations
- Inadequate financial incentives
- Lack of policies that establish sizeable markets for CCS technology

Fundamentally, current policy is not fostering CCS technology commercialization or creating markets for CCS technology.

A portfolio of "next generation" polices is required. The range of risks along the innovation spectrum involved in commercializing CCS means that a portfolio of multiple policies is required, encompassing front-end (helping technology launch) to back-end (helping technology commercialize) approaches. In other words, multiple policies are required to meet multiple risks. This approach requires government action or intervention not only to improve existing policy tools but also to implement new mechanisms. In particular, since CCS is a technology that reduces CO_2 emissions, there is an immediate need to establish a more robust back-end policy approach that requires emissions reductions or directly establishes a carbon price signal in order to create a market for CCS technology. A policy portfolio that addresses the current lack of climate (regulatory) policy will be required to pull the deployment of large-scale integrated CCS projects beyond their current demonstration phase and into the early commercialization stages.

"Next generation" CCS policy

A portfolio of policies that address existing risks and is politically feasible.

In addition, a "next generation" policy portfolio for CCS will need to reflect evolving political realities, addressing concerns over the extent of the government's role in the market, whether policies are voluntary or mandatory, and in particular the impact on the federal budget and taxpayers. The policies requiring more direct government action and expense will require clear "off-ramps" for decreasing or phasing out support as the technology becomes more commercialized and/or costs come down. Such voluntary policy incentives will require approaches to reduce government/taxpayer exposure/liability, for example "revenue neutrality" provisions or ways to ensure that government monies are provided in a "competitive" process. Perhaps most importantly, the policy portfolio will need to be able to stand the test of time. A multi-policy approach to address multiple challenges must be in place for multiple years to succeed: this means spanning political cycles and leadership changes.

This policy approach requires government financial support. Although increasing financial support certainly poses a political challenge, it is vital to continue to lower costs of existing technologies, as well as to find and demonstrate new and cheaper technologies. Although the exact level of funding, the number of projects, or the GWs of large-scale demonstration plants operating are arguably viable metrics to frame the discussion and help forge a reasonable commercialization pathway, it is equally important to implement efficient and politically feasible mechanisms to fund it.

Off-ramps for technologies in R&D pipeline should be considered. There is increasing support for modifying existing front end policy to streamline the R&D technology pipeline, i.e. instituting a process for deciding if and when to drop R&D for certain technologies if they do not show promise in performance or cost reduction. This approach requires that an agreed process—and likely a supporting institutional structure—be established to govern how decisions would be made to drop certain technologies.

EOR is a transitional stepping stone for CCS commercialization. The ability to sell CO_2 for EOR will certainly help reduce the cost of CCS, but it lowers the cost for a technology that still has no market in the electric power sector. The major promise and potential of CCS is deployment for mitigating climate change. This in turn means widespread deployment on power plants and long-term geologic storage of billions of tons of CO_2 per year, well beyond the demands of the EOR market (especially in the current situation of relatively low oil prices). In short, as noted by a CCS expert we interviewed, "we should not lose focus on what we are really trying to accomplish" and treat CO_2-EOR as a transitional step in CCS commercialization.

Recommendations

Serious consideration of developing CCS as low carbon technology requires a "next generation" policy framework that recognizes the range of risks and policy mechanisms needed to address them, as well as political challenges. This is a complex public policy issue: A CCS policy approach needs to accomplish multiple strategic national and international objectives and address existing risks and goals in a timely and comprehensive manner.

Below we highlight specific mechanisms that we believe should form the basis of a thoughtful discussion on what is required to support commercialization of CCS. These policy tools are geared toward what best addresses existing risks and are politically feasible. Our specific recommendations (details of which are discussed in the full report) are summarized as follows:

Addressing technology risk

To move CCS commercialization forward, it is important to consider some off-budget funding mechanism that generates sufficient financial resources in support of large-scale demonstration projects, while limiting or reducing the impact on the federal budget.

1. ***Dedicated CCS trust fund supported by a wires or public good surcharge.*** A CCS trust fund could support R&D and large-scale demonstrations, and possibly other policy incentives and mechanisms. A process and structure (a new entity, board, or organization) for program oversight and management that is targeted specifically to CCS should be created.

Addressing financial risk

There is little disagreement that high capital and operating costs present barriers for CCS projects. The following steps to revise *existing* policy could improve access to financing.

2. ***Modifications to loan guarantee program.*** To improve access to government loan guarantees, several revisions should be considered: eliminate the requirement for an appropriation to pay the credit subsidy cost, allow entities that have received

other financial support also to be eligible for a loan guarantee, and consider sourcing loan guarantee monies from a separate fund, not the Treasury.

3. ***Modifications to tax credits***. The Obama administration's proposal to make investment tax credits refundable should be adopted to increase available support and reduce the cost of accessing the credits. The President also proposed a sequestration tax credit, which includes $10/tonne for CO_2 stored as a result of EOR. Consideration should be given to increasing this to more closely approximate the per MWh value of other forms of low carbon energy. Other proposals to modify 45Q tax credits for CO_2-EOR, reflecting the detailed recommendations of the National Enhanced Oil Recovery Initiative, should also be considered.

While improving the design and implementation of existing policy tools is appropriate, the magnitude of the financing challenges requires consideration of *new* approaches.

4. ***CCS projects eligible for master limited partnerships.*** MLPs are a well understood, existing mechanism that has been employed successfully for decades that would broaden access to financing for CCS projects.

5. ***CCS projects eligible for private activity bonds.*** PABs are also a familiar tool that would increase the ability of developers and utilities to raise capital at little cost to taxpayers.

6. ***Financial support for front end engineering and design work***. Providing funding for early stage project due diligence will reduce the financial burden on project developers while facilitating borrowing from commercial lenders. This approach has been used effectively in the United Kingdom for its two CCS projects.

Addressing climate policy uncertainty: Creating markets for CCS technology

7. ***A federal carbon policy***. Carbon policy, such as a requirement to reduce CO_2 emissions or a sufficiently high CO_2 price, is needed in order to create a market for CCS technology. There are a variety of policy tools available but it seems that a combination of approaches is needed. As a carbon price alone is not likely to be set high enough, and given the uncertainty of whether and at what level an implicit CO_2 price might emerge from EPA's carbon regulations, the implication is that *in isolation* these may not be effective policy mechanisms. However, performance standards and a price on carbon work to offset their individual drawbacks. Moreover, low natural gas prices also impact the competitiveness of CCS in the United States, suggesting the need for multiple, complementary policy tools to support deployment of the technology.

8. ***An electricity price stabilization framework.*** In markets that are not currently subject to a CO_2 reduction requirement or climate change policy, a mechanism that ensures the purchase of low carbon (CCS-based) power or a stable price of such power would help offset operating costs and address policy uncertainty, although this approach may still need to be complemented with grants and other incentives to deal with high capital costs. Similar to the Contract for Differences approach proposed in the United Kingdom, the level of support would vary according to a market based benchmark or index, and should be allocated on a competitive basis, with a path for phase-out over the life of the project.

In sum, CCS can be a viable technology to meet U.S. environmental goals, as well as yielding related economic and national security benefits. However, policymakers and the general public must be aware of what is required from a policy standpoint. Our hope is that the approach outlined here fosters the kind of substantive conversation on CCS that has been missing in recent years, but is much needed as part of developing a comprehensive energy-climate policy.

1. Introduction

As global leaders and interest groups prepare for the United Nations Conference on Climate Change in Paris at the end of 2015, it is timely to re-evaluate key instruments to reduce and manage the risks of climate change. The stakes seem fairly straightforward: Anthropogenic GHG emissions have increased since the pre-industrial era, and their effects are "extremely likely" to have been the main cause for observed global warming since the 1950s.[2] In debates about future pathways for dealing with the anticipated effects of climate change, adaptation and mitigation are considered to be complementary.[3] In discussions about mitigation strategies, and because carbon dioxide is considered to be the principal GHG linked to climate change, for many years CCS technologies have featured prominently as part of a broader portfolio.

Defining CCS

Carbon capture and storage is the integrated process of capturing carbon dioxide from power generation or industrial activities and storing it permanently via processing or injection into suitable geologic formations. CCS is considered a climate mitigation tool since it captures manmade CO_2 from large, stationary, single-point sources for the purpose of isolating the carbon dioxide from the atmosphere.[4] In fact, several studies have suggested that unless CCS becomes a viable mitigation technology, it is increasingly likely that energy-system carbon emissions will not be reduced to levels that limit global warming to 2 degrees Celsius.[5] Further background information on the various components of the CCS value chain is presented in **Annex A**.

Why CCS is Important

CCS is a low-carbon technology that can form part of a balanced portfolio approach to address climate change, as well as economic and national security goals. Given that coal and natural gas will continue to play a significant role in the power and industrial sectors globally for a number of decades, moving to a low carbon economy will take time. CCS is the only technology that can achieve significant emissions reductions from existing fossil fuel infrastructure (e.g., 90 percent capture or higher), offering a pathway to transition

[2] Intergovernmental Panel on Climate Change (IPCC) Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)], *Climate Change 2014: Synthesis Report*, IPCC, Geneva, Switzerland, 2014, http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.

[3] Ibid., p.17.

[4] IPCC Working Group III [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)], *IPCC Special Report on Carbon Dioxide Capture and Storage*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2005, https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf.

[5] For example, see: International Energy Agency (IEA), *IEA 2015 Energy Technology Perspectives*, Paris: OECD/IEA, 2015, p. 208.

fossil-fuel assets to a low carbon economy and responsibly use the large existing resource base in coal and natural gas. Most critically, many analyses indicate that in the long run, with CCS as part of the technology portfolio, overall costs of this transition will be lower. We elaborate on the chief reasons why CCS is important below.

Climate change is a serious global challenge

Climate change is one of the most critical issues facing policymakers today. The United Nations Intergovernmental Panel on Climate Change (IPCC) has established with "high-confidence" that climate change will have a wide range of negative effects around the globe, with varying degrees of intensity. According to the International Energy Agency (IEA), in order to mitigate the impacts of climate change, global temperatures should not rise above 2°C (often referred to as the "2°C Scenario," or 2DS).[6] Furthermore, it has been well documented that the continued increase in global carbon emissions is fueled predominantly by fossil fuel usage—in particular coal, and to a lesser extent oil and natural gas.[7] Currently, the world is not on track to meet the 2DS target as CO_2 emissions are expected to increase to 38.0 Gt in 2040, nearly 20 percent above 2012 levels.[8]

Fossil fuels will continue to be a major part of the energy mix

According to the IEA, coal will continue to represent a significant portion of the global power mix to 2040.[9] In OECD countries, coal continues to play a prominent role in the fuel mix but is increasingly under pressure from market forces, policy support for renewables, and environmental regulation.[10] As a result coal demand is projected to fall in OECD countries by 2040. In sharp contrast, in the developing word coal usage is projected to increase by one third in regions as diverse as Africa, India, China, Indonesia, Brazil, and Southeast Asia.[11] It is important to note that burning natural gas also results in substantial amounts of CO_2 emissions. Given that the IEA's projection that the share of natural gas in the global energy mix will increase to 24 percent by 2040 from 21 percent currently means that CCS for natural gas will, over time, also become a serious political and environmental issue.[12]

The rise in fossil fuel demand in emerging markets is driven by population growth, urbanization, an expanding middle class, and energy subsidies.[13] Many countries are also faced with meeting the challenge of electricity access: Nearly 1.3 billion people still lack access to electricity and another 2.7 billion rely on biomass for cooking.[14] For many emerging market governments, providing citizens with basic access to electricity at the lowest possible cost is currently a priority, more so than concerns about climate change. That often leads to investments in coal-fired electricity generation because the feedstock is abundant and competitive.

China plays a particularly critical role in projected global coal use. The IEA estimates that China will consume more coal than the rest of the world combined for the next two decades.[15] China has

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[6] "Publications: Scenarios and Projections," International Energy Agency, accessed 29 September 2015, http://www.iea.org/publications/scenariosandprojections/.

[7] Dieter Helm, *The Carbon Crunch,* Yale University Press; Second edition, revised and updated edition, August 2015.

[8] IEA, *World Energy Outlook 2014 (WEO 2014),* (Paris: OECA/IEA, 2014,) p. 87, www.worldenergyoutlook.org/publications/weo-2014/.

[9] The IEA anticipates the share of coal to be 31 percent of the global power mix by 2040, IEA, *WEO 2014*, p. 216.

[10] According to the Energy Information Administration (EIA), *Annual Energy Outlook 2014(AEO 2014) with projections to 2040*, DOE/EIA, April 2014, p. MT-26, in the reference case coal is expected to comprise 34 percent of electricity generation in 2040.

[11] IEA *WEO 2014,* p. 177.

[12] Ibid., p. 136.

[13] John P. Banks, et al., *Coal Markets in Motion*, Energy Security and Climate Initiative Coal in the 21st Century Issue Brief #1, The Brookings Institution, March 2015, p. 4, http://www.brookings.edu/research/papers/2015/03/coal-markets-in-motion.

[14] IEA, *WEO 2014*, p. 73.

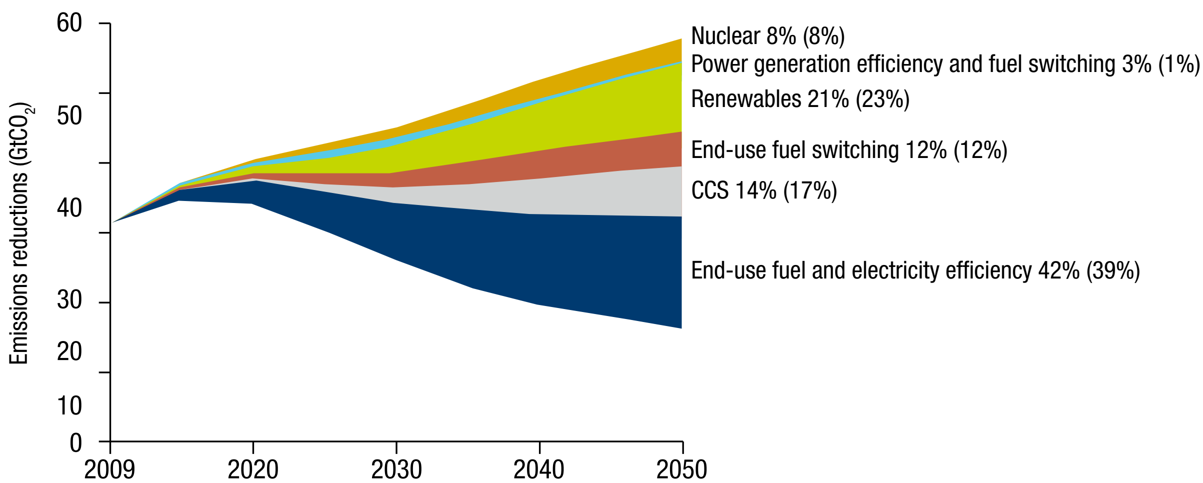
[15] Ibid., See also Helm, *The Carbon Crunch*, p. 44.

pledged that it will reach its maximum amount of CO_2 emissions "around" 2030.[16] In order to achieve that, authorities recently announced that it will cap coal consumption in 2020, with several market analysts predicting that Chinese peak coal consumption will be reached as early as 2016.[17]

CCS can play a crucial role in addressing climate change

As noted, there are currently uncertainties about whether the 2DS scenario can be reached, based on continued global growth in fossil fuel use. Many observers have suggested increased policy support for, and investment in, renewable energy in order to shift away from reliance on fossil fuels.[18] However, it is highly uncertain whether this approach alone would achieve the emissions reductions of the 2DS, owing to the inability of renewables to mitigate CO_2 emissions from existing (and future) electricity plants and industrial facilities.[19] As part of the 2DS, the IEA has indicated that CCS, along with renewables and low-emission alternatives, is a "vital" technology to meet long-term global goals for carbon emissions reduction.[20] Specifically, the IEA calls for CCS to account for 14 percent of cumulative emissions reductions by 2050 (see **Exhibit 1**).

EXHIBIT 1: CCS can contribute to 14 percent of total emission reductions through 2050 in 2DS compared to 6DS



Note: Numbers in brackets are shares in 2050. For examples, 14% is the share of CCS in cumulative emission reductions through 2050, and 17% is the share of CCS in emission reductions in 2050, compared with the 6DS.
Source: IEA, "Technology Roadmap: Carbon Capture and Storage," 2013, p 24.

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[16] "U.S.-China Joint Announcement on Climate Change," The White House: Office of the Press Secretary, 11 November 2014, https://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change.
[17] Several major institutions including Citibank, National Resource Defense Council, and Bernstein Research all expect China coal to peak prior to 2020, Robin Webster, "Peak Coal in China: Unimaginable or Achievable," *Road to Paris*, 30 January 2015, http://roadtoparis.info/2015/01/30/peak-coal-china-unimaginable-achievable/.
[18] Kyle Ash, "Carbon Capture SCAM," Greenpeace, Washington, D.C., 2015, http://www.greenpeace.org/usa/wp-content/uploads/legacy/Global/usa/planet3/PDFs/Carbon-Capture-Scam.pdf.
[19] IEA, *Technology Roadmap Carbon capture and storage*, p. 49.
[20] IEA, *IEA 2015 Energy Technology Perspectives*, Paris: OECD/IEA, 2015, p. 20.

The IPPC has determined that without either CCS and/or CCS with bio-energy, the 2°C threshold cannot be met.[21] Several other major studies have come to similar conclusions; the UN Economic and Social Council, for example, has stated that CCS must contribute at least one-sixth of emissions reductions by 2050 in order to keep temperatures below the 2°C rise.[22] Google, through its Renewable Energy Cheaper than Coal (RE<C) initiative—which was originally designed to develop renewable energy sources that could generate electricity at a lower cost than coal-fired capacity—has concluded that there is already far too much CO_2 in the atmosphere and that in order to keep global temperatures from rising, it must be removed by utilizing carbon negative technologies such as bioenergy with CCS.[23]

Reducing GHG emissions will be more expensive without CCS

Most importantly, many scenarios illustrate that over the long-run deploying CCS reduces the cost of combatting climate change. The World Bank believes "that the cost of reaching the 2°C target more than doubles if CCS is not available (for technological, economical, or social acceptability reasons)" and noted that this may be an underestimate given that other models have been unable to reach the target without CCS.[24] According to the IPCC, "the inclusion of CCS in a mitigation portfolio is found to reduce the costs of stabilizing CO_2 concentrations by 30 percent or more."[25] The IEA estimates that without CCS the cost of achieving the 2DS would increase investment in electricity by 40 percent, an estimated $2 trillion over 40 years.[26] CCS may currently be a high cost, energy intensive technology, but with expanded use over time it is expected that costs will decrease: In the IEA's 2DS, capital costs decline 20 percent between 2020 and 2050.[27]

In sum, large-scale investment in non-fossil energy and new technologies are surely one way forward to help mitigate carbon emissions, but such expenditures do not address the emissions associated with existing industrial and fossil fuel-based electricity capacity, as well as the new capacity that is expected to come online in the coming decades, especially in the developing world. CCS could be a cost-effective long-term investment to help address this gap.

Status of CCS in the Electricity Sector

Despite the fact that CCS has been discussed for over a decade as a serious policy option in the power sector for combatting climate change, it is not widely deployed on a commercial basis. More accurately stated, while there are mature markets for some individual technologies or processes comprising CCS, these components are not commercially operating

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[21] IPCC Working Group III, *IPCC Special Report on Carbon Dioxide Capture and Storage*, Summary for Policymakers, p. 3.

[22] Economic Commission for Europe Committee on Sustainable Energy, *Revised recommendations of the United Nations Economic Commission for Europe to the United Nations Framework Convention on Climate Change on how carbon capture and storage in cleaner electricity production and through enhanced oil recovery could be used in reducing greenhouse gas emissions*, Prepared by the Group of Experts on Cleaner Electricity Production from Fossil Fuels, United Nations, Geneva, 19-21 November 2014, http://www.unece.org/fileadmin/DAM/energy/se/pdfs/clep/ge10/ECE.ENERGY.2014.5.Rev.1.pdf.

[23] Ross Koningstein and David Fork, "What It Would Really Take to Reverse Climate Change," *IEEE Spectrum*, 18 November 2014, http://spectrum.ieee.org/energy/renewables/what-it-would-really-take-to-reverse-climate-change.

[24] Marianne Fay, et al., "Decarbonizing Development Three Steps to a Zero-Carbon Future," Washington, DC: International Bank for Reconstruction and Development/The World Bank 2015, p. 36, http://www.worldbank.org/content/dam/Worldbank/document/Climate/dd/decarbonizing-development-report.pdf.

[25] IPCC, 2014: Summary for Policymakers, in: IPCC Working Group III (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S.Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel and J.C.Minx, eds.), Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to theFifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 12.

[26] International Energy Agency, *IEA 2012 Energy Technology Perspectives*, p. 10.

[27] Ibid., p. 219.

in an integrated manner in the power sector at scale. Globally, there is one fully operational electricity plant with CCS, two additional projects under construction, and eight other projects that are expected to become operational prior to 2020.[28] For more details on the operational and planned projects, we refer to **Annex B**.

Indeed, over the course of the last decade the pace of CCS deployment has been very modest, largely owing to the inadequacy of government support and the lack of carbon policy.[29] Absent the requirement to reduce emissions, the hesitance of electricity producers to apply CCS technology centers on its significant costs. In particular, capturing carbon is an energy intensive process, and without a market for carbon it makes no commercial sense to use this technology. Moreover, in order to achieve significant cost reductions, next to R&D a substantial amount of commercial deployment is essential to bring costs down, and in turn for that to happen a market for carbon capture technologies must be developed.[30]

The opening of SaskPower's Boundary Dam facility in 2014 in Saskatchewan, Canada—the first commercial power plant with CCS—was a major milestone, and it is likely that a number of other plants will become operational in the coming years. Importantly, what these projects all demonstrate is that the specific context is highly relevant, and determines whether projects are eventually financed and built. At this point in time, in certain niche situations where there is a market for the captured carbon (e.g. for EOR) and possibly other captured gases along with significant policy support, CCS at power plants can be feasible. A key question is whether policy will evolve requiring emissions reductions, fostering CCS as part of a least-cost decarbonization strategy.

However, it is important to note that a market for captured carbon in itself will not be sufficient to incentivize the large-scale deployment of CCS. For example, even if the United States were to adopt policies that put a significant price on carbon, electricity producers would most likely continue to do what is already happening, which is build gas-fired electricity plants. Instead of focusing solely on a price for carbon, there is growing consensus that a broad policy framework is required that spurs technological refinement and addresses various uncertainties and risks regarding all three components of CCS that are currently prohibiting commercial deployment. This includes investment in transportation and geologic storage infrastructure and development of the requisite supporting legal and regulatory framework.[31]

The question remains: How can CCS be incentivized in several dozens of projects worldwide, in order to learn from different contexts and significantly reduce costs? A comprehensive and long-term policy framework seems essential, arguably making the goal of carbon emissions reduction with CCS more a political challenge than a technical one. Yet what should this policy framework entail?

Methodology

This policy brief assesses the risks and barriers related to CCS at electricity plants, and the existing

[28] For a detailed listing of these projects refer to the Global CCS Institute project database: "Large-Scale CCS Projects," Global CCS Institute, http://www.globalccsinstitute.com/projects/large-scale-ccs-projects#map. Additionally these other 8 projects are categorized under the execute stage, meaning their final investment decision has been confirmed, and commissioning and construction has been undertaken, according to the Global CCS Institute.

[29] Max Krahé, et al., "From demonstration to deployment: An economic analysis of support policies for carbon capture and storage," Energy Policy 60, 2013, p. 753-763.

[30] Edward S. Rubin, et al., "The Outlook for Improved Carbon Capture Technology," Progress in Energy and Combustion Science 38 (2012).

[31] See, for example: Samuel Bassi, et al., *Bridging the gap: improving the economic and policy framework for carbon capture and storage in the European Union,* Policy Brief, Grantham Institute, 2015; Advisory Council of the European Technology Platform for the Zero Emission Fossil Fuel Power Plants, *CO_2 Capture and Storage (CCS) Recommendations for transitional measures to drive deployment in Europe,* Zero Emissions Platform (ZEP), 17 November 2013, http://www.zeroemissionsplatform.eu/library/publication/240-me2.html.

policy framework to support its application. The focus is on the United States, though we consider several other key parts of the world. This study aims to identify what the main bottlenecks are with regard to the integrated usage of the three components of CCS. We focus in particular on policies that are meant to spur technological innovation and to effect further cost reductions.

The analysis builds on an extensive literature review. In addition, we interviewed over fifty experts from various backgrounds including industry, academia, government, and NGOs. Finally, in-depth discussions in our Coal Task Force, a diverse working group of experts, helped inform our research over the course of 2015.

Assumptions and Definitions

This policy brief does not assess the models that form the foundation of recent reports from the IPCC, IEA, and others, but rather takes those as a given starting point. We feel confident in doing so, because there is an overwhelming amount of literature which reaches conclusions along similar lines, even though substantial uncertainties remain about the extent and exact effects of climate change.[32]

Though we acknowledge that CCS may be applied in various settings in the future, in this policy brief we focus on the use of CCS in electricity generation because that is where the amount of carbon emissions is highest. It is worth noting that in this context a number of studies also refer to the combination of biomass energy with CCS, referred to as Bio-Energy with Carbon Capture and Storage (BECCS).[33] In theory, this technology allows the amount of carbon in the atmosphere to be reduced instead of merely avoided. This assumes that the amount of carbon seized during the growing of biomass, combined with the underground storage of captured carbon is larger than the carbon emissions associated with the life cycle processing and use of biomass. Even though the potential of BECCS is significant, this policy brief focuses on CCS technology, given the substantial hurdles that have to be overcome before large-scale application of BECCS becomes feasible.

In addition, while we recognize that CCS can also be applied in the industrial sector, which accounts for roughly 15 percent of global carbon emissions, this falls outside the scope of this paper.[34] Nevertheless, CCS is currently the only viable technology with the ability to reduce emissions from cement factories, chemical plants, and steel processing plants by over 50 percent, providing it with a potentially critical role in climate change mitigation.[35]

This study does not examine substantial challenges related to the development of a CO_2 transportation and geologic storage infrastructure, nor do we examine the complexities of the supporting legal and regulatory framework needed to deploy that infrastructure on a large scale.

We do acknowledge that addressing these issues is important in order to achieve large-scale application of integrated CCS projects. Indeed, some believe these issues have to be addressed as urgently as challenges on the capture side. For example, in the European Union evidence from work to date points to clustering of common transport and storage networks as a significant source of cost reductions in the shortest timeframe. As one of our interviewees noted: "Reducing costs (of CCS) is as much dependent on engineering learning as it is on risk mitigation that feeds through to cost of capital, counterparty performance, guarantees, and other commercial learning that will reduce costs when individual projects are followed by

[32] For example, Helm, *The Carbon Crunch*.
[33] For example, Bassi, et al., *Bridging the gap: improving the economic and policy framework for carbon capture and storage in the European Union*.
[34] Soren Anderson and Richard Newel, "Prospects for Carbon Capture and Storage Technologies: Discussion Paper," Resources for the Future, January 2003, http://www.rff.org/documents/RFF-DP-02-68.pdf.
[35] IEA, *IEA 2015 Energy Technology Perspectives*.

large chain projects and networks." During the course of our research, several respondents in the U.S. emphasized the importance of addressing transportation and storage challenges. For example, one CCS project developer noted: "If the country wants coal to be a part of the mix, we need to solve the issue of CO_2 transportation infrastructure." A CCS expert stated that "There's no point in capturing carbon if you have nowhere to put it." In addition, the U.S. government has acknowledged these challenges for years, and the U.S. Department of Energy's recent Quadrennial Energy Review concluded that "given the upfront capital costs associated with pipeline construction and the absence of policy incentives for reducing industrial carbon pollution, financial support would likely be needed to spur private investments in some regions."[36] There are others who, particularly in the United States, while recognizing that transportation and storage challenges need to be addressed, do not think that they are "showstoppers" for large-scale development of integrated CCS projects given the existing CO_2 pipeline network, large potential storage capacity, and the opportunity to use captured CO_2 for EOR.

Regardless of one's particular perspective on these questions, we do agree that policies addressing transportation and storage need to be part of an overall policy mix supporting CCS.[37] Nevertheless, in this analysis, we focus on the capture side because that continues to be a major part of the current policy discussion in the United States.

Finally, a word about terminology. CCS and CCUS (carbon capture, utilization and storage) are both used in industry and academia. We have elected to use "CCS" given the emphasis on long-term storage as a way to remove carbon from the atmosphere and the widely accepted view that industrial uses of carbon are too small to be a meaningful carbon mitigation tool, or do not result in permanent removal. Similarly, "storage" and "sequestration" are used interchangeably, but in this brief we use "storage" largely because we believe it is the more commonly recognized term among policymakers and the general public.

This policy brief is organized as follows:

- **Section 2: Risks and barriers for CCS commercialization** – Explains factors affecting the pace of CCS technology innovation and deployment.
- **Section 3: Policies supporting CCS in the United States** – Describes the principal policy instruments promoting CCS and how they work.
- **Section 4**: **Gaps and weaknesses in current CCS policy** – Assesses how existing policies have fared in addressing risks confronting CCS.
- **Section 5: Available policy options for promoting CCS** – Examines various policy options, measuring them against two basic criteria: how they can be effective in addressing the identified gaps and whether they are politically feasible.
- **Section 6: Conclusions and recommendations** – Provides policy priorities for consideration in supporting commercialization of CCS.

[36] *The Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure*, Department of Energy, April 2015, p. 7-24.

[37] In particular, there is a need to address gaps in the legal and regulatory framework. The specific issues have been known for many years, and there have been serious proposals and other efforts to design effective approaches. For example, the World Resources Institute published guidelines for CCS projects in 2008 (see, World Resources Institute, "CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage," Washington, D.C., 2008); and the CCSReg Project has developed detailed recommendations for federal legislation to regulate carbon storage, available at http://www.ccsreg.org/model_legislation.html. Another detailed assessment of these issues is found in M. Granger Morgan and Sean T. McCoy, "Carbon capture and sequestration: removing the legal and regulatory barriers," RFF Press, 2012.

2. Risks and Barriers for CCS Commercialization

While there are mature markets for some individual technologies or processes comprising CCS, these components are not commercially operating in an integrated manner in the power sector at scale. Specifically, there are three main inter-related factors that explain the slow pace of commercial deployment and technology innovation: (1) financial risk; (2) technology risk, and (3) climate (regulatory) policy uncertainty.

Financial Risk

One barrier to deploying CCS is the **high capital cost** compared to an unabated project (one not capturing or storing CO_2). The capture process accounts for about 80 percent of the additional cost of an integrated CCS project owing to the need to add capture equipment (CO_2 absorber, regenerator, and compressor). In addition to higher capital costs for a power plant with a capture system, there are **higher operating costs** owing to the need for more fuel to offset the diversion of some output to operate the capture system, as well as additional operations and maintenance (O&M) costs. The capture equipment requires energy from the power plant, thus effectively reducing the net electricity output of the plant per unit of coal fuel input (lower plant efficiency). This energy penalty (added fuel input required per net kWh output) has an impact on a project's economics given the combination of higher costs and lower output. Estimates of the energy penalty vary, but tend to range between 10-50 percent depending on whether pre-combustion, oxy-fuel combustion, or post-combustion capture technology is used.[38]

Table 1 summarizes the impacts of adding a capture system on capital costs, the levelized cost of electricity, and CO_2 avoided costs for different capture routes. Integrated gasification combined cycle (IGCC) plants present some unique considerations. They are more expensive to build without capture systems than pulverized coal (PC) plants, but pre-combustion capture with IGCC is easier given higher pressures and concentration of CO_2 in the flue gas stream, lowering the incremental cost compared to adding capture to PC plants. In addition, IGCC does provide flexibility in terms of the end uses of the gas produced. However, as with PC plants, there are efficiency disadvantages from adding CO_2 capture owing to the energy penalty. **Text Box 1** describes key issues related to CCS with natural gas-fired plants.

Technology Risk

Another important factor is the risk entailed in operating a facility with new technology. Fundamentally

[38] See for example: Mikael Hook, et al., "Carbon Capture and coal consumption: Implications of energy penalties and large scale deployment," Energy Strategy Reviews, 7 (2015) p. 18-28; and also Peter Folger, "Carbon Capture: A Technology Assessment," Congressional Research Service, November 2013.

TABLE 1: Cost summary by capture route (NETL, July 2015)

Parameter	PC Supercritical		IGCC		NGCC	
	No capture	With capture	No capture	With capture	No capture	With capture
Total Plant Cost (2011$/kW)	2,026	3,524	2,372	3,540	685	1,481
COE ($/MWh) – excluding T&S	82.3	133.2	99.8	141.9	57.6	83.3
COE ($/MWh) – including T&S	82.3	142.8	99.8	151.8	57.6	87.3
CO_2 Captured Cost ($/tonne CO_2) – excluding T&S	n/a	58.2	n/a	66.5	n/a	71.1
CO_2 Captured Cost ($/tonne CO_2) – including T&S	n/a	89.4	n/a	102.9	n/a	93.8

Sources: "Cost and Performance Baseline for Fossil Energy Plants – Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity," Revision 3, U.S. Department of Energy, National Energy Technology Laboratory, 6 July 2015; also "Cost and Performance Baseline for Fossil Energy Plants – Volume 1b: Bituminous Coal (IGCC) to Electricity," Revision 2b – Year Dollar Update, U.S. Department of Energy, National Energy Technology Laboratory, 31 July 2015. Figures assume 90 percent capture rate. NGCC is natural gas combined cycle; IGCC is integrated gasification combined cycle; PC is pulverized coal. COE is cost of electricity. T&S is transportation and storage. IGCC technology shown is Chicago Bridge & Iron E-Gas system.

this revolves around the fact that—unlike other environmental technologies such as SO_2 scrubbers and SCRs for NOx—a carbon capture system is integral to the plant's operation, and needs to function in order to generate revenue for commercial operation. With limited experience to date, there are questions concerning how CCS will function on a full-scale power plant over a period of years with a high dispatch rate. Issues may include how well the technology lives up to this standard and other subsidiary issues such as the impact of a system shut-down, maintenance requirements, and workforce training needs.

The technology risk is not inconsequential. For example, in the course of our research we heard that some vendors of conventional power plant equipment (turbines, boilers, etc.) are reluctant to provide performance guarantees for their equipment because there is so little operational and performance data available for their use in an integrated CCS project. For a utility responsible for grid reliability, this is a major risk.

A related issue raised by a few participants in our research is reconciling current trends in the electric utility industry with CCS. Specifically, CCS represents a traditional approach relying on large, centralized baseload plants at a time when the sector is moving toward greater decentralization and use of smaller, distributed resources. Specific issues include whether, with the deployment of more intermittent generation, CCS plants will be able to load follow or cycle more frequently. In addition, questions were posed regarding whether and how low carbon, dispatchable baseload generation such as CCS-coal or CCS-natural gas should be rewarded in order to avoid path dependency on one or a limited number of fuels, helping to achieve the lowest possible CO_2 avoided cost.

Climate (Regulatory) Policy Uncertainty

Currently there is limited rationale for spending money to add a capture system to an existing coal-fired power plant, or to build a new plant with capture equipment. There is little opportunity to make money by deploying CCS technology since there is no market for the captured CO_2, and there is no market because there is no price or value placed on CO_2. In other words, the cost of installing a capture system on a coal-fired plant is substantially greater than the price/value of CO_2. As shown in **Table 1**, a CO_2 price of between $60-70/tonne is required to spur the deployment of CCS technology across different capture routes (excluding transportation and storage). In short, there is no market for CCS technology in the absence of a policy requirement to reduce CO_2 emissions, constituting a major risk for CCS.

In addition, there are other dynamics at play in the United States that contribute to poor market conditions for CCS. Historically low natural gas prices in the last 5 to 7 years owing to the shale gas boom, decreasing or flattening demand for electricity, and more stringent environmental regulations have contributed to the declining competitiveness of coal, further weakening the viability of deploying CCS technology. Relatively low natural gas prices are a particularly critical factor: As one participant in our discussions noted, "With low gas prices, no one will build CCS. Gas prices have to rise above $10/MBtu to incentivize building a PC plant with partial capture."

It is important to note that CCS is not just a low carbon technology applicable for coal-fired power plants. The shale gas boom is expected to keep natural gas prices low and drive increasing additions of natural gas fired power generation. The U.S. Energy Information Administration (EIA) projects in its reference case that natural gas will account for 73 percent of all capacity additions from 2013 to 2040. Some analyses indicate that for deep decarbonization, i.e., to achieve an 80 percent reduction in CO_2 levels beyond 2050, CCS will be required for natural gas generation.[39] Several experts we interviewed cited the need to avoid natural gas "path dependency": not to let low gas prices lead to a myopic, steady, incremental dependency on natural gas, effectively locking-in a natural gas infrastructure making carbon reductions difficult in the long-run. The key issue is how to incentivize commercialization of CCS for both coal and natural gas in the long-run within an environment of relatively low natural gas prices and no requirement to reduce CO_2 emissions to the levels achievable with CCS.[40]

It is illustrative that those projects that have progressed the furthest toward deployment in North America are using captured CO_2 in EOR: This provides a revenue stream to help offset the operating costs of deploying the technology. However, CO_2 EOR projects present their own challenge since the price of CO_2 fluctuates along with changes in the price of oil, affecting the economics of a capture project. CO_2 is typically priced and sold based on oil indices with lenders (banks) running scenarios with oil at $40 per barrel, lowering how

TEXT BOX 1: Is coal-CCS the same as natural gas-CCS?

From a technology perspective, the same capture approach using amine systems can be applied to natural gas-fired plants. In fact this has been done, e.g. with the 250 MW gas-fired cogeneration plant in Bellingham, Massachusetts that operated from 1991 to 2005. There are, however, tradeoffs based on economics and different flue gases. It's easier to capture CO_2 from natural gas because the flue gas stream has a lower concentration of CO_2 (5 percent) compared with coal (15 percent), but in general "the lower the concentration of CO_2 the more costly it will be to remove."* Natural gas also produces a flue stream with a higher concentration of oxygen which can interact with the amines, and there is also a need to ensure that pressure is maintained to avoid tripping out the turbines. These issues can be addressed but add cost, although with cheap gas it is possible to more than make up the expense of adding the capture system while addressing these issues. There are also added costs particular to coal-fired CO_2 capture such as the need to treat prior to the flue gas prior to entering the amine capture system owing to the presence of impurities.

* Victoria R. Clark and Howard J. Herzog, "Assessment of the US EPA's Determination of the Role for CO2 Capture and Storage in New Fossil Fuel-Fired Power Plants," Environmental Science and Technology, 24 June 2014.

[39] For example, see "The Future of Natural Gas," Massachusetts Institute of Technology, 2011, p. 69.
[40] The new EPA carbon regulations require only 20 to 30 percent reductions (see section 5).

much project developers can borrow and requiring that more equity be raised.

The risk of investing in CCS is also enhanced by the inability of utilities to recover costs in most state regulatory proceedings. State utility regulators are reluctant to allow ratepayers to shoulder the burden for expensive projects without climate policy that prioritizes and values low carbon options. Indeed, at least one utility has specifically cited lack of cost recovery as the reason for terminating a CCS project.[41] Even with cost recovery, the regulatory process can be fraught with political and economic complexity. For example, the Mississippi Public Service Commission approved a two-year 18 percent rate increase for customers of Mississippi Power to help pay for the Kemper project, but in February 2015 the state Supreme Court ruled that the Commission did not properly assess the utility's costs, and ordered the utility to refund $350 million to customers.[42]

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[41] "AEP places carbon capture commercialization on hold, citing uncertain status of climate policy, weak economy," AEP Press Release, 14 July 2011, http://www.aep.com/newsroom/newsreleases/?id=1704.

[42] Kristi E. Swartz, "Mississippi Power details refund hurdles for Kemper CCS project," EnergyWire, 23 July 2015; and Kristi E. Swartz, "Mississippi Power files sweeping rate plan to pay for Kemper's cost overruns," EnergyWire, 18 May 2015.

3. Policies to Support CCS in the United States

U.S. government CCS policy mainly consists of financial support for R&D and demonstration projects, and loan guarantees and tax credits.[43] At the state level, more than a dozen states have established a variety of financial incentives for CCS projects.

Federal Policies

The U.S. government, principally through the Department of Energy, has supported CCS since 1997, and since then several major pieces of legislation have increased the level of support (see **Text Box 2**).

Research, development, and demonstration

According the Congressional Research Service, Congress has appropriated $6.4 billion from FY2008 to FY2014 for CCS research, development, and demonstration (RD&D) for DOE's Office of Fossil Energy: $3 billion in total annual appropriations, and $3.4 billion from the ARRA 2009.[44]

TEXT BOX 2: Key federal CCS legislation

- Regional Carbon Sequestration Partnerships (2003) – created seven RCSPs to evaluate and test large-scale carbon storage sites across the country
- Energy Policy Act of 2005 (EPACT 2005) – provided a 10-year authorization for DOE's basic R&D program, and enacted loan guarantees and tax incentives
- Energy Independence and Security Act of 2007 (EISA 2007) – increased support for large-scale demonstration projects
- American Recovery and Reinvestment Act of 2009 (ARRA 2009) – expanded support for CCS R&D and demonstration projects.

* Peter Folger, "Carbon Capture and Sequestration: Research and Development, and Demonstration at the U.S. Department of Energy," Congressional Research Service, 10 February 2014.

Fossil Energy Research and Development (within the Office of Fossil Energy) is organized around two areas related to carbon capture and storage: CCS and Power Systems, and Demonstrations (see

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[43] DOE also supports transportation and storage efforts as part of its CCS portfolio, but as noted this policy brief does not encompass these programs.

[44] Peter Folger, "Carbon Capture and Sequestration: Research and Development, and Demonstration at the U.S. Department of Energy," Congressional Research Service, 10 February 2014.

Annex C for details). The focus of these programs is increasingly dominated by CCS; and CCS policy is centered on supporting carbon capture and carbon sequestration, specifically R&D, pilot testing, and commercial scale demonstration for each of these areas, both individual components and integrated systems.[45] For example, in the DOE's FY2016 budget request, carbon capture and carbon storage account for 40 percent of total fossil energy research and development, and 61 percent of all coal-related research.[46]

Capture research, development, and demonstration (RD&D)

DOE's carbon capture RD&D program's goals are summarized below:

- Demonstration of 1st generation technologies;
- Development of 2nd generation technologies ready for demonstration in 2020 to 2025, and commercial deployment beginning in 2025; cost around $40/tonne of CO_2 captured for retrofits and new plants;
- Development of transformational technologies ready for demonstration in the 2030-2035 timeframe, and commercial deployment beginning in 2035; cost less than $40/tonne of carbon captured.[47]

According to NETL's recent technology readiness review, there are 58 active carbon capture R&D projects encompassing the laboratory/bench scale through pilot stages (most of these are post-combustion projects).[48]

Large-scale demonstrations

Since 2007, the U.S. government's emphasis has been on integrated demonstration projects in an attempt to accelerate commercial deployment while reducing technology costs. Two of the main efforts in CCS demonstrations are the *Clean Coal Power Initiative (CPPI),* and *FutureGen.* These are briefly described below and summarized in **Exhibit 2**.[49]

No large-scale CCS demonstration project is operating in the U.S. power sector; two are under construction using 1st generation capture technology.

- *Clean Coal Power Initiative (CPPI)* – Initiated in 2002, the CPPI is designed to foster clean coal demonstration projects by providing cash grants to qualifying projects, with cost co-sharing between the DOE and private sector. In three rounds of solicitations between 2003-2009, seven CCS projects in the power sector were awarded funding, four of which are still active.
- *FutureGen* – This project was developed in 2003 as a 10 year proposal to build a zero-emission coal-fired power plant with CCS. FutureGen Alliance, a non-profit company comprising several major

[45] Carl Bozzutto, et al, "Fossil Forward" - Revitalizing CCS: Bringing Scale and Speed to CCS Deployment," National Coal Council, January 2015, p. 50, http://www.nationalcoalcouncil.org/newsletter/Bridging_the_CCS_Chasm.pdf.

[46] *Department of Energy FY 2016 Congressional Budget Request: Budget in Brief*, Office of Chief Financial Officer, February 2014, p. 35, http://www.energy.gov/sites/prod/files/2015/02/f19/FY2016BudgetinBrief.pdf. Other CCS activities may be included in other line items.

[47] According to the DOE: 1st Generation Technologies include components that are being demonstrated or are commercially available; 2nd Generation Technologies include components in the R&D phase that should be ready for demonstration by 2020-2025; and, Transformational Technologies include components that are in early stages of development or that offer the potential for improvements in cost and performance beyond 2nd Generation (*Carbon Capture Technology Program Plan*, DOE Office of Fossil Energy, December 2014, Figure 1-2, and CCS Technology Category Definitions, p. 10, https://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/Program-Plan-Carbon-Capture-2013.pdf).

[48] 2014 Technology Readiness Assessment—Overview, DOE/NETL, January 2015, table 4, http://www.netl.doe.gov/File%20Library/Research/Coal/Reference%20Shelf/DOE-NETL-20151711-2014-Technology-Readiness-Assessment-Overview.pdf.

[49] In addition to the two programs described below, DOE also funds an Industrial Carbon Capture and Storage (ICCS) program, designed to support a variety of large-scale industrial demonstration projects. Active ICCS projects are depicted in Exhibit 2.

EXHIBIT 2: Active CCS/CCUS Demonstration Projects

	Plant Type		Sequestration			Feedstock
	Power	Industrial	Saline	EOR	Rate*	
Pre-combustion						
HECA (IGCC-Polygen)	x	x		x	2.55	NM Sub-bituminous Coal/Petcoke Blend
Southern-Kemper Co. (IGCC)	x			x	3.0	MS Lignite
Summit Texas (IGCC-Polygen)	x	x		x	2.2	WY sub-bituminous Coal
Leucadia, Lake Charles (Methanol & Hydrogen)		x		x	4.5	Petroleum Coke
Air Products and Chemicals, Inc. (SMR)		x		x	0.925	Natural Gas
ADM (Ethanol Production)		x	x		0.900	Corn Fermentation
Post-combustion						
NRG Energy	x			x	1.4	WY Sub-bituminous Coal
Oxy-combustion						
FutureGen 2.0	x		x		1.0	Il. Bituminous / PRE Coal Blend

CCPI ICCS Area 1 FutureGen 2.0

*Rate in million metric tons per year

Source: Carl Bozzutto, et al, "Fossil Forward," p. 60 from DOE/FE-0565, Major Demonstration Programs: Program Update 2013, http://www.netl.doe.gov/research/coal/major-demonstrations.

international coal and utility companies, was formed to partner with the DOE to develop the project, with DOE covering 74 percent of the project costs. However, in 2008, the DOE discontinued funding FutureGen largely owing to increasing costs (to $1.8 billion from the initial projection of $950 million.). By 2010 the Obama administration announced a new FutureGen 2.0 facility using money from the ARRA to retrofit an obsolete 200 MW power plant in Illinois and to develop a pipeline and storage reservoir. However, the project encountered rising costs and legal challenges leading to its cancellation in February 2015.[50]

Financial Incentives

In addition to policy support for research, development and demonstration, the U.S. government provides two forms of financial incentives for CCS: loan guarantees and tax credits. These are summarized in **Exhibit 3.** It is estimated that since 2006 these incentives have totaled $3 to $4 billion.

Loan guarantees

A loan guarantee provides assurance that the government will assume the debt obligations of a borrower (project developer) in case of default. It is designed to facilitate financing of a project with perceived high levels of risk.

[50] Information derived from: Peter Folger, "The FutureGen Carbon Capture and Sequestration Project: A Brief History and Issues for Congress," Congressional Research Service, 10 February 2014, http://fas.org/sgp/crs/misc/R43028.pdf; and Christa Marshall, "DOE kills FutureGen Project," E&E News, 4 February 2015, http://www.eenews.net/climatewire/stories/1060012843/search?keyword=futuregen+2.0.

EXHIBIT 3: U.S. government financial incentives for CCS

Energy Policy Act of 2005		Energy Improvement and Extension Act of 2008
Loan Guarantees	**Tax Credits***	**Tax Credits**
• $8 bilion available • Authorizes DOE to guarantee up to 80 percent of total project costs. • Borrowers pay "credit subsidy cost" • Two separate solicitations held in 2008 and 2013 • No projects have received a loan guarantee	• IRC §48A – $2.55 billion available for IGCC and other advanced coal projects • Projects must capture & sequester 65 percent of CO_2 emissions, and be in service within 5 years • IRC §48B – $600 million available for gasification projects • Projects must capture & sequester 75 percent of CO_2 emissions, and be in service within 7 years • Tax credit rate of 30 percent of total project cost available for §48A and §48B • Since 2006, USG has awarded $2.3 billion in tax credits under IRC §48A and §48B	• IRC §45Q provides: • $20/metric ton of CO_2 captured and sequestered • $10/metric ton for CO_2 used in oil or gas EOR and stored • Credit available up to 75 million metric captured and stored • As of mid-2014, 27 million metric tons have been stored as a result of 45Q • 45Q tax credits will total $700 million in the period 2014 to 2018

*Some of the original terms of the tax credits under EPACT 2005 were supplemented and revised by the Energy Improvement and Extension Act of 2008.
Source: Peter Folger and Molly F. Sherlock, "Clean Coal Loan Guarantees and Tax Incentives: Issues in Brief," Congressional Research Service, 19 August 2014.

Section 1703 of the Energy Policy Act (EPACT) 2005 created the loan guarantee program to support technologies that "avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases, and employ new or significantly improved technologies." The categories of eligible technologies include CCS and advanced fossil energy systems, including gasification. The law authorizes DOE to guarantee up to 80 percent of total project costs.[51]

The government must receive a "credit subsidy cost" payment that covers the long-term costs of implementing and managing the loan guarantee, either from a government appropriation or from the borrower. Under Section 1703, the government has not appropriated funds to cover the credit subsidy cost, so borrowers are responsible for this cost.

Congress has authorized $8 billion for fossil energy under the EPACT 2005 (Section 1703) loan guarantee program, with an emphasis on projects that incorporate CCS. Two separate solicitations have been held, in 2008 and 2013, but no projects have received a loan guarantee.

Tax incentives

Investment tax credits allow a project developer to reduce tax liability up to a certain percentage of total project cost, thus reducing the project's up front financial risk. Section 1703 of EPACT 2005 created two investment tax credits under

[51] Further information on EPACT 2005 Section 1703 can be found at, "Section 1703 Loan Program," Department of Energy, Loan Programs Office, http://energy.gov/lpo/services/section-1703-loan-program; also see: Energy Policy Act of 2005, Public Law 109-58, U.S. Statutes at Large 119, 2005, 1117-1122, http://energy.gov/sites/prod/files/2014/03/f11/EPA2005TitleXVII.pdf.

TABLE 2: Clean coal tax credit allocations (2009-2013)

Code Section	Project Name		Credit Awarded
2009-2010 Allocation Round			
IRC §48A	Christian County Generation, LLC		$417,000,000
	Summit Texas Clean Energy, LLC		$313,436,000
	Mississippi Power Company		$279,000,000
		Total	*$1,009,436,000*
IRC §48B	Faustina Hydrogen Products		$121,660,000
	Lake Charles Gasification, LLC		$128,340,000
		Total	*$250,000,000*
2011-2012 Allocation Round			
IRC §48A	Hydrogen Energy California LLC		$103,564,000
		Total	*$103,564,000*
2012-2013 Allocation Round			
IRC §48A	STCE Holdings, LLC		$324,000,000
	SCS Energy California, LLC		$334,500,000
		Total	*$658,500,000*

Source: Data from IRS presented in Peter Folger, "The FutureGen Carbon Capture and Sequestration Project: A Brief History and Issues for Congress," Congressional Research Service, 10 February 2014, http://fas.org/sgp/crs/misc/R43028.pdf, pp 6-7.

the Internal Revenue Code (IRC), which were subsequently updated under the Energy Improvement and Extension Act of 2008 (EESA 2008).[52] Tax credits are competitive: The DOE and Department of Treasury jointly review applications from project developers. In the first round of solicitations in 2006, the government awarded nine projects totaling $1 billion in tax credits.[53] **Table 2** summarizes the award rounds from 2009 to 2013. In sum, since 2006, the federal government has awarded $2.3 billion in tax credits under IRC §48A and §48B.

EESA 2008 also created a new tax credit for CO_2 sequestration under IRC §45Q, with the following basic terms:

- $20/metric ton of CO_2 captured and sequestered

[52] Originally under EPACT 2005, IRC §48A addressed advanced coal projects: $800 million for IGCC projects (up to 20 percent of project costs), and $500 million for other advanced coal-fired generation projects (up to 15 percent of project costs). Projects must be in service within five years. IRC §48B supported gasification projects: $350 million (up to 20 percent of project costs). EESA 2008 made several changes to the existing tax credit system under EPACT 2005: (a) for §48A authorized additional $1.25 billion; (b) for §48B authorized additional $250 million; (c) projects must be in service in seven years; (d) Tax credit rate increased to 30 percent of total cost for all projects; (e) DOE must identify those receiving the tax credit and amounts; (f) for §48A projects must capture and sequester 65 percent of CO2 emissions; and (g) for §48B projects must capture and sequester 75 percent of CO2 emissions. Based on information in Peter Folger and Molly F. Sherlock, "Clean Coal Loan Guarantees and Tax Incentives: Issues in Brief," Congressional Research Service, 19 August 2014, pp 6-7.

[53] Of those projects, the following seven agreed to publically acknowledge receipt of the tax credit: (a) Duke Energy – Edwardsport IGCC Project, Edwardsport, IN; (b) Tampa Electric Company, Polk County, FL; (c) Southern Company—Mississippi Power Company, Kemper County, MS; (d) Duke Energy Cliffside Modernization Projects, Cleveland and Rutherford County, NC; (e) E.ON U.S., Louisville Gas and Electric and Kentucky Utilities Co., Bedford, KY; (f) Carson Hydrogen Power, LLC: Carson Hydrogen Power Project, Carson, CA; and (g) TX Energy, LLC: Longview Gasification and Refueling Project, Longview, TX. See "Energy Secretary and Secretary of the Treasury Announce the Award of $1 Billion in Tax Credits to Promote Clean Coal Power Generation and Gasification Technologies," Department of Energy, Washington, D.C., 30 November 2006, http://2001-2009.state.gov/g/oes/rls/or/2006/77195.htm.

- \$10/metric ton for CO_2 used in oil or gas EOR and stored
- Credit available up to 75 million metric captured and stored

As of mid-2014, it is estimated that 27 million metric tons have been stored as a result of 45Q and the Department of Treasury indicates that 45Q tax credits will total \$700 million in the period 2014 to 2018.[54]

International efforts

The United States has played a leadership role in spurring CCS development globally by supporting and participating in a variety of efforts and programs.

Research and information sharing

One of the more prominent international activities the United States supports is the Carbon Sequestration Leadership Forum (CSLF). The CSLF is a ministerial-level organization created to help bring together governments, NGOs, and the private sector on research projects to understand the challenges of CCS better and to expand information sharing. The United States leads several CSLF efforts involving capturing carbon at hydrogen production plants and monitoring and performance of saline aquifer storage projects.[55]

The Global CCS Institute, established in 2009 with funding from the Australian government, is an international membership organization designed to advance the deployment of CCS globally through development and demonstration projects.[56] The Institute also collaborates with significant multilateral bodies that specially focus on CCS global development, including the IEA, the CSLF, and the Clean Energy Ministerial (an international forum promoting a transition to a clean energy economy).[57] In 2010, the Global CCS Institute received \$500,000 from the U.S. Department of State—the first time the institute has received funding from any source besides the Australian government. The funding granted by the U.S. Department of State supports mapping CO_2 storage capacities in developing nations, sharing best practices and policies, as well as developing case studies for enabling CCS deployment.[58]

Additionally, the United States through the DOE, helps provide access to technical expertise and R&D.[59] The National Carbon Sequestration Atlas (NACSA) is an international effort carried out by Canada, Mexico, and the United States to better assess and identify the North American potential of geological formations for the storage of CO_2.[60]

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[54] Folger and Sherlock, "Clean Coal Loan Guarantees and Tax Incentives," pp 8-9 and Rubin, et al., "The Outlook for Improved Carbon Capture Technology." It is worth noting that other studies are more optimistic and conclude that the costs of electricity with CCS can be halved and become cost competitive with other low carbon technologies with the installation of around 2.5 GW. See CCS Sector Development Scenarios in the UK, Element Energy Limited, Cambridge, April 2015, http://www.eti.co.uk/wp-content/uploads/2015/05/2015-04-30-ETI-CCS-sector-development-scenarios-Final-Report.pdf.

[55] For details of all U.S. led CSLF recognized projects refer to: Carbon Sequestration and Leadership Forum, "Active and Completed CSLF Recognized Projects (as of October 2013)" in Washington: Ministerial Meeting, Washington D.C., 4-7 November 2013, p. 93, http://www.cslforum.org/publications/documents/Washington2013/MeetingDocumentsBook-Washington1113.pdf.

[56] "Who We Are," Global CCS Institute, accessed 29 July 2015, http://www.globalccsinstitute.com/content/who-we-are.

[57] For more information on the Global CCS Institute's work plan see: Global CCS Institute, "Accelerating CCS: 2013-2017—Five Year Strategic Plan: June 2015 Update," Global CCS Institute, 2015, http://www.globalccsinstitute.com/files/content/page/316/files/Business%20Stategy_June%202015%20update.pdf.

[58] "U.S. Department of State Funds the Global CCS Institute for Capacity Development and Knowledge Sharing Targeting Developing Countries," Global CCS Institute press release, 28 September 2010, http://www.globalccsinstitute.com/institute/media-centre/media-releases/us-department-state-funds-global-ccs-institute-capacity-deve-0.

[59] IEA, *Carbon Capture and Storage: Legal and Regulatory Review*, Paris: OECD/IEA, 2010, p. 45, https://www.iea.org/publications/freepublications/publication/191010IEA_CCS_Legal_and_Regulatory_Review_Edition1.pdf.

[60] North American Carbon Atlas Partnership, "The North American Carbon Storage Atlas 2012," Natural Resources Canada, Mexican Ministry of Energy, U.S. Department of Energy, May 2012, https://www.netl.doe.gov/File%20Library/Research/Carbon-Storage/NACSA2012.pdf.

Supporting CCS in developing countries

DOE's Office of Fossil Energy has lead major initiatives to research and expand the knowledge base of CCS in emerging economies (see also **Text Box 3**).[61] Outlined below are two of these key bilateral relationships.[62]

India

In 2005, the DOE, in collaboration with India's Ministry of Coal, formed a Coal Working Group with the aim of promoting policy, technology, and research on the efficient and environmentally friendly use of coal as a result of the U.S.-India Energy Dialogue.[63] This working group has a particular emphasis on emerging clean coal technologies, including CCS, and encourages India's involvement in the CSLF which provides Indian specialists an invaluable opportunity to engage with industry experts.

China

Similarly, in 2000 the United States and China signed the Fossil Energy Protocol, an initiative to promote technological cooperation on fossil fuels. Currently the protocol is exposing Chinese

TEXT BOX 3: What is the role of advanced PC combustion technologies?

Some observers have made the argument that deploying more advanced, efficient pulverized coal (PC) combustion technology–super-critical (SC), ultra-super-critical (USC)–would be a more cost effective and timely way to reduce emissions: For every 1 percent increase in coal-fired generating efficiency, there is a 2 to 3 percent reduction in CO_2 emissions. The IEA has recommended that high efficiency, low emissions (HELE) technologies be deployed until such time as CCS technology is more mature.*

In the course of our discussions, we heard skepticism of this "capture ready" approach. It was generally acknowledged that, as long as new plants are being built, they should be using the most efficient combustion technologies (in addition to lowering CO_2 emissions, cooling needs and coal supply requirements are reduced). Moreover, there is no doubt that the more efficient the power plant, the cheaper the capture process because there's less CO_2 to deal with. This approach is also viewed by many as particularly applicable to emerging markets: With many developing countries adding coal-fired capacity and CCS out of reach on cost, SC and USC could be built to reduce emissions in the near-term with the ability to add CCS later.**

However, building USC without CCS but with the intent to add capture later, has its challenges. Unless the plant is converted fairly quickly, it may not make sense to spend a significant amount of extra capital to make it capture ready. One estimate mentioned in our discussions suggested that if a payback period is longer than 5 to 6 years, there's no reason not to build the plant with CCS. In addition, retrofitting a plant with a capture system later has barriers (e.g., design changes in emissions control systems and re-configuring the steam system if adding post combustion capture). Thus, in the long-run it may be better to build a new, more efficient plant with capture.

* International Energy Agency, *Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation*, Paris: OECD/IEA, 2012.

** Robert Bryce, "Not Beyond Coal," Manhattan Institute, 14 October 2014.

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[61] Of the members of the Global CCS Institute only Australia, Canada, the EU, Norway, the U.K. and the United States have contributed funding to CCS in developing countries; see "Making the Case for Funding Carbon Capture and Storage in Developing Countries 2013," Global CCS Institute, p. 9.

[62] U.S. Department of Energy, "International Cooperation," Office of Fossil Energy, accessed 10 August 2015, http://energy.gov/fe/services/international-cooperation.

[63] U.S. Department of Energy, "US-India Energy Dialogue: Coal Working Group," Office of Fossil Energy, accessed 11 August 2015, http://energy.gov/fe/services/international-cooperation/us-india-energy-dialogue-coal-working-group.

companies and research organizations to advanced U.S. technologies, including those for carbon capture in the power sector.[64] As a result of the protocol's U.S.-China Strategic Economic Dialogue in 2009, the Clean Energy Research Center (CERC) was established to focus on joint research endeavors including clean coal and CCS technologies. Funding for CERC was extended through 2020 with an explicit focus for cooperation between the United States and China on advancing a CCS demonstration project in China.[65] This public-private initiative will provide China the opportunity to engage directly in research and monitoring of the utilization of CO_2 for fresh water production from aquifers.[66] CERC continues to facilitate cooperative research efforts between U.S. and Chinese scientists and engineers on CCS technologies in order to create a more diverse energy portfolio and to mitigate climate change.

State Policies

More than a dozen states have implemented CCS-related policies with funding often coming from the issuance of general obligation bonds. Many state policies are linked to specific job creation goals and requiring use of resources from the state. Only a few states offer financial support for R&D, including Kentucky, Minnesota, and Illinois. Specific policy instruments include:

- *Cost recovery*: Some states allow cost recovery, particularly for IGCC facilities. For example, Colorado allows public utilities to apply for cost recovery for an IGCC plant that captures and stores carbon dioxide and is considered a public convenience and necessity for Colorado. Such a designation allows utilities to be eligible to recover costs incurred from planning, developing, constructing, and operating an IGCC plant through rate adjustments from Colorado's retail customers.[67] Florida, Indiana, Mississippi, New Mexico, and Virginia also allow some form of cost recovery.
- *Financial incentives*: Most state financial incentives supporting CCS are tax exemptions/reductions, investment tax credits, and EOR-specific support, while a few involve grants and loans. Many of the tax exemptions and reductions apply to property or excise taxes, and the EOR incentives typically reduce severance or taxes on oil extracted using CO_2.
- *Portfolio standards*: Several states have implemented portfolio mandates for clean coal and/or CCS. For example, West Virginia, Pennsylvania, Michigan, Massachusetts, and Ohio have "alternative energy" portfolio standards, which define technology eligibility in a variety of ways that reduce or prevent emissions, including deployment of higher efficiency plants such as IGCC and CCS.[68] Illinois is the one state that has created a specific "clean coal" portfolio requirement: In 2009, the Clean Coal Portfolio Standard Law established a target of 25 percent for all electricity sold in the state to be from "clean coal facilities" by 2025. Under the mandate, a plant in the program must be "an electric generating facility that uses primarily coal as a feedstock and that captures and sequesters carbon emissions."[69]

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[64] Department of Energy, "Bilateral Agreements with China," Office of Fossil Energy, accessed 11 August 2015, http://energy.gov/fe/services/international-cooperation/bilateral-agreements-china.
[65] U.S.-China Joint Announcement on Climate Change, 12 November 2014, http://www.us-china-cerc.org/pdfs/US-China-Joint-Announcement-on-Climate-Change--12-Nov-2014.pdf.
[66] Ibid.
[67] House Bill 06-1281, Public Utilities, Chapter 300, 1 June 2006, 1413-1418, http://tornado.state.co.us/gov_dir/leg_dir/olls/sl2006a/sl_300.pdf.
[68] "Renewable & Alternative Energy Portfolio Standards," Center for Climate and Energy Solutions, 20 May 2013, http://www.c2es.org/sites/default/modules/usmap/pdf.php?file=5907.
[69] Clean Coal Portfolio Standard Law, Public Act 095-1027, The State of Illinois represented in the General Assembly, SB 1987, http://www.ilga.gov/legislation/publicacts/95/PDF/095-1027.pdf.

4. Gaps and Weaknesses in Current CCS Policy

CCS presents a wide array of risks along the technology innovation path that current policy does not address. There is insufficient support for large-scale demonstration projects that are widely accepted as being critical to driving down costs. Financial incentives are inadequate for market needs, suffering from design flaws or insufficient funding. There is also a lack of back-end policies to create markets for CCS technology.

CCS is a particularly challenging technology for policymakers. As noted, it is actually comprised of several technological components, each of which is at different levels of maturity in different sectors. There is extensive literature explaining the life cycle of technology innovation, from concept to market maturity. **Exhibit 4** depicts the commercialization status of integrated CCS projects in the power sector using a standard depiction of innovation stages, highlighting the major current policies supporting CCS in the United States.

It is important to note several caveats and definitions. First, the technology innovation process is not completely linear.[70] For example, the learning that takes place in early adoption and diffusion of a technology feeds back into R&D and demonstration, and ongoing innovation continues to support technology in the marketplace. Second, policies need to be tailored to the stage of technology development.[71] As such, front-end policies are geared toward helping to launch—or nurture—a technology. It is generally accepted that government will have a strong role at this stage, and thus there is less political sensitivity in supporting government funding for a technology's launch. Back-end policies are needed as a technology moves through demonstration to initial deployment to diffusion in the market—or to help mature the technology. The costs of supporting a technology increase and thus the political ease of implementation decreases (the role of government support becomes more controversial). Moreover, as technology commercialization proceeds, there is greater scope and need for private sector financing and collaboration with the government.

The federal government's policy focus for CCS broadly has been appropriate given the risks and status of CCS technology commercialization: The high costs of capture and the lack of knowledge about storage capacity and performance have led the DOE to focus on these areas. Specifically, CCS policy in the United States has primarily involved the front end policy tools of financial support for RD&D and the back-end voluntary measures of

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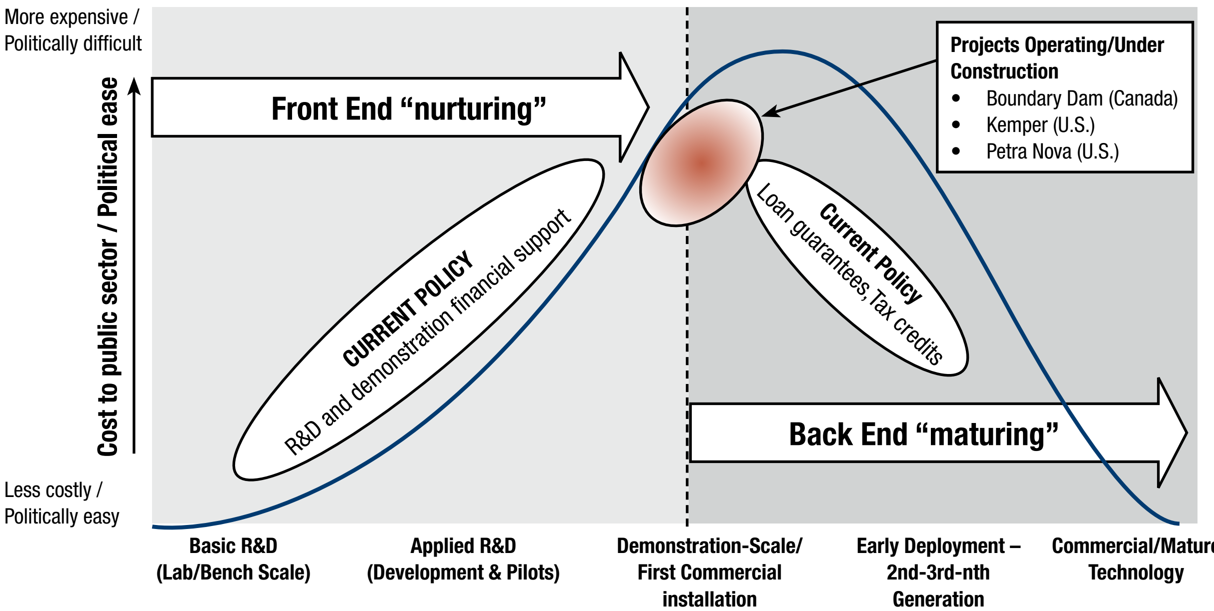
[70] E.S. Rubin, "The Government Role in Technology Innovation: Lessons for the Climate Change Policy Agenda," Proc. of 10th Biennial Conference on Transportation Energy and Environmental Policy,, Institute of Transportation Studies, University of California, Davis, August 2005.

[71] This section draws on policy characterization and stages in Charles Weiss and William B. Bonvillian, "Structuring an Energy Technology Revolution," Massachusetts Institute of Technology Press, 2009.

EXHIBIT 4: Current policy framework for commercializing integrated CCS projects in the power sector



Sources: Carl Bozzutto, et al., "Fossil Forward"; and Charles Weiss and William B. Bonvillian, "Structuring an Energy Technology Revolution."

loan guarantees and tax credits. The focus of these policies has been to demonstrate CCS technology while driving down costs. This is not an unusual approach given the technology's status, high costs, and engineering challenges typically confronting the deployment of first-of-a-kind facilities.

Despite this policy support, CCS commercialization has not progressed quickly, with no fully integrated large-scale plants in operation in the power sector in the United States, and only two under construction. In addition, none of the DOE's CCS programs have progressed beyond the pilot-scale level in the 10 to 50 MW facility size.[72] Many analysts and experts point out the lack of CCS deployment and progress in lowering costs. [73] Indeed one expert we interviewed observed that, in terms of cost trajectory, CCS is about where wind and solar were 10 years ago.

What are the problems?

Insufficient Support for Large-Scale Demonstrations

It is widely agreed that large-scale demonstration projects are vital for addressing technology risk and commercializing CCS. The theory is straightforward: Operating a CCS project at scale allows operators to learn more about performance, make improvements, and ultimately lower costs. There is also evidence that this theory works in practice, based on the deployment experience with other technologies

> "All demonstration projects will cost more than you think, and will be a hassle to get up and running, but long-term costs will come down"
>
> —Technology company official

[72] Carl Bozzutto, et al., "Fossil Forward," p. 51.
[73] See for example, Howard Herzog, "Pumping CO2 underground can help fight climate change. Why is it stuck in second gear?" MIT Energy Initiative, 12 March 2015.

in the power sector. A study led by Ed Rubin at Carnegie Mellon University has documented that capital costs of SO_2 and NOx capture systems declined 13 percent for each doubling of installed capacity, and this experience suggests that the cost of electricity from plants with CO_2 capture could fall 30 percent after 100,000 MW of capture plant capacity has been added globally.[74]

This "learning by doing" is especially critical at scale: Given the large volume of CO_2 in the flue gas stream from a coal-fired power plant—and the need to store large volumes permanently in order to be an effective climate change mitigation tool—projects must move from small-scale pilots (1 to 50 MW size) to large-scale demonstration (greater than 100 MW size) with capture systems applied to the complete flue gas stream.[75] This learning process is taking place at Boundary Dam (see **Annex B**).

For these reasons, numerous institutions and experts have emphasized the need for more demonstration projects to bring down CCS costs. For example, in its 2007 "Future of Coal" report, the Massachusetts Institute of Technology stated that "the priority objective with respect to coal should be the successful large-scale demonstration of the technical, economic, and environmental performance of the technologies that make up all of the major components of a large-scale integrated CCS system."[76] It went on to call for three to five "first-of-a-kind" coal utilization demonstration power plants with carbon capture, on the scale of 250 to 500 MWe, and three to four large-scale sequestration demonstration projects of 1 million tonnes CO_2/year.[77] In 2009, the National Research Council called for 10 GW of demonstration plants by 2020, and in 2010, the president's *Interagency Task Force on Carbon Capture and Storage* called for five to ten commercial-scale demonstrations by 2016 to foster the early success of CCS projects."[78] As noted, since 2007 federal policy has emphasized large-scale demonstration projects, as especially evidenced by the $3.4 billion allocated under the ARRA 2009.

Nevertheless, there are few active large scale CCS demonstration projects. In three application rounds under the CPPI, 18 projects have been awarded funding, of which seven are integrated CCS projects in the power sector. Of these, three have been withdrawn.

The main explanation for this limited progress is that demonstration projects are expensive and policy support to address this challenge has been inadequate. As shown in **Table 3,** the total project costs of each of the four active large-scale demonstration projects range from $1 billion to $6 billon. More importantly, all of the projects un-

TABLE 3: Cost breakdown of CCPI demonstration projects

Project	Total Federal Funding	Total Project Cost	Federal Cost Share (%)
HECA	$408M	$4B	10
TCEP	$450M	$2.5B	18
Petra Nova	$167M	$1B	17
Kemper	$293M	$6.1B	5
TOTALS	**$1.752B**	**$13.6B**	**13**

Source: Carl Bozzutto, et al., "Fossil Forward," p. 80.

[74] E.S. Rubin, et al., "Use of Experience Curves to Estimate the Future Cost of Power Plants with CO_2 Capture," International Journal of Greenhouse Gas Control, vol. 11, no. 2, 2007, pp 188-197.

[75] This size breakdown is from "Carbon Storage Technology Program Plan," NETL, December 2014, p. 17, figure 1-7, http://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/Program-Plan-Carbon-Storage.pdf and Carl Bozzutto, et al., "Fossil Forward," p. 51. While there have been CO2 capture systems on power plants for several decades, these have only been applied to a part of the flue gas stream, and have not been a part of an integrated project transporting and placing the CO2 in long-term geologic storage.

[76] *Future of Coal: options for a carbon-constrained world,* Massachusetts Institute of Technology, 2007, p. xi, http://web.mit.edu/coal/The_Future_of_Coal.pdf.

[77] Ibid.

[78] "Report of the Interagency Task Force on Carbon Capture and Storage August 2010," U.S. Department of Energy and Environmental Protection Agency, August 2010, p. 11; and "America's Energy Future: Technology and Transformation," National Research Council, 2009, p.106. Other analysts and experts have also called for 10 large-scale demonstration projects.

derestimated project costs at the beginning owing to factors common to deploying first-of-a-kind technologies, such as engineering design and permitting changes.[79] In addition, the DOE's financial support is limited to 50 percent of total project costs, but in reality the federal government's cost share ranges between five to 18 percent of total project costs for the four demonstration projects. This means that private sector project developers need to raise the vast majority of financing for a project.

While there are federal incentives to address this financial challenge, they have drawbacks. For example, the money made available under the CPPI is significant, but the grants are underweighted to the highly risky development phase of projects: Little of the grant money is available at the front end engineering phase, where $50 million to undertake due diligence may be required to get a project to market. Commercial lenders are unwilling to fund this early stage since the technology is relatively new. Finally, as noted by the NCC, *annual funding* has supported R&D but not larger demonstrations; there have been no further appropriations for large-scale demonstrations since the ARRA 2009.[80]

Inadequate Financial Incentives

Loan guarantees and tax credits are helpful to the private sector, but do not address the range of risks involved in building and operating a CCS project.

Though loan guarantees help secure financing for up-front capital costs, they do not ensure a revenue stream to recover the operating costs of capturing and compressing the carbon, and do not directly assist in creating a market for CCS technology.

Moreover, the design of the loan guarantee program has also been cited as a barrier. In particular, the requirement that the project developer pay the credit subsidy cost is a disincentive that adds to the overall financial burden of the project.[81] In addition, as one developer noted in our research, if a project receives a cash grant from the federal government, for example under the CPPI, it is not eligible to receive a loan guarantee.[82] This is why some projects bring in foreign partners, as they can then go to their governments' export credit agencies and acquire loans. High administration and due diligence fees have also been cited as problems.[83]

> "The debt issue is a mess–we need to fix access to long term loans and figure out how to stabilize the CO_2 price."
>
> —Senior executive, Project Developer

These reasons may help explain why no loan guarantees have been issued for an advanced fossil fuel project.

Existing tax credits are acknowledged to help project returns, however they suffer from design challenges.[84] First, non-taxpaying entities cannot take advantage of tax credits, in effect leaving many types of potential investors on the side-lines, including pension funds, foreign companies, sovereign wealth funds, and non-profits.

[79] Carl Bozzutto, et al., "Fossil Forward," p. 110.
[80] Carl Bozzutto, et al., "Fossil Forward," p. 129. The NCC's Fossil Forward report also that while the DOE is targeting 2nd generation capture technologies to be ready for demonstration in the 2020 to 2025 timeframe, thus far the budget does not reflect the scale of financial resources required for demonstration, rather focusing on the initial R&D stages.
[81] As noted in section 6, the credit subsidy cost is a payment that covers the long-term cost of implementing and managing the loan guarantee. For the only two projects that have received loan guarantees under the 1705 program the government appropriated money to pay the credit subsidy cost.
[82] See: U.S. Department of Energy, Loan Programs Office, "Loan Guarantee Solicitation for Applications for Advanced Fossil Energy Projects," Solicitation Number: DE-SOL-0006303, 22 April 2015.
[83] See, for example: "Comment Listing, U.S. Department of Energy Loan Programs Office, Draft Advanced Fossil Energy Projects Solicitation," September 2013.
[84] This section draws on: Sasha Mackler, "Reassessing Renewable Energy Subsidies: Issue Brief," Bipartisan Policy Center (BPC), 22 March 2011.

Importantly, in the U.S. power industry, municipal and cooperative electric utilities are unable to take advantage of tax credits. As of 2013, 43 percent of the generation portfolio of cooperatives was coal-fired, while for publicly owned utilities it was 29 percent.[85]

Furthermore, if a company or project developer does not have taxable income, has tax losses, or cannot forecast tax liabilities over the period of eligibility of the tax credit, it may partner with a "tax equity investor" that can take advantage of the tax credit, as has happened with renewable energy projects.[86] However, this approach is expensive: In the renewable energy sector, the "friction cost" of partnering with a tax equity investor is estimated to increase the cost of project debt 3 to 8 percent.[87]

These structural challenges in tax credits are exacerbated for CCS projects, reducing their attractiveness vis-à-vis renewable energy. First, unlike renewable energy, there is more risk confronting potential investors in CCS projects. There is uncertainty regarding whether the technology will work, and renewable energy technologies being deployed at scale are largely similar in design and operation, while CCS technologies are not. Finally, there is an existing deep market in tax equity for renewable energy so transactions in this space are able to monetize the value of the tax credits in a timelier manner than CCS projects.

The 45Q tax credit for CO_2-EOR is designed to provide a revenue stream for project developers to help offset the operating costs of a capture project. However, this incentive mechanism has drawbacks. First, some critics have stated that 45Q was too broadly designed, resulting in a situation where "who gets the incentive is not really who needs it." Specifically, some industries and projects such as gas processors got the bulk of the monies available under 45Q, prompting a comment that "if we are trying to stimulate CCS on power projects by giving tax credits for CO_2 -EOR, then policy should be focused on power projects." There have also been concerns over the effectiveness of 45Q if oil prices decline significantly, reducing the demand for CO_2 for EOR, thus threatening a project's revenue stream.

In sum, project developers and utilities are faced with the complex process of trying to compile all of these financial incentives into a viable project, but even with these policy mechanisms in place, it is not enough to address all of the risks involved.

Lack of Policies that Establish Sizeable Markets for CCS Technology

CCS policy in the United States is weighted toward front-end mechanisms to support early R&D, with less emphasis on back-end policy tools that help move technology from demonstration to early deployment and ultimately market maturity. R&D alone will not suffice and financial incentives in their current incarnation are not sufficient for CCS commercialization.

In the course of our research discussions we consistently heard from a wide variety of stakeholders that markets spur development—and that a lack of a market discourages industry from continuing technology development. Some form of economy wide push to value carbon reductions is needed to demonstrate that there is a market for CCS technology.

Without a CO_2 reduction requirement or climate change policy, some form of support is required to assist plant owners in addressing the gap between the cost of deploying CCS and revenues earned

[85] "U.S. Electric Generating Capacity and Generation by Fuel Type, 2013," 2015-2016 Annual Directory & Statistical Report, American Public Power Association, http://www.publicpower.org/files/PDFs/USElectricGeneratingCapacityandGenerationbyFuelType.pdf.
[86] Mackler, "Reassessing Renewable Energy Subsidies: Issue Brief."
[87] This cost estimate is from Hudson Clean Energy Partners via BPC, 22 March 2011, p. 11.

from selling electricity or the CO_2 captured. Policies can help stabilize or limit this gap, and/or achieve a higher—or an additional—revenue stream for the electricity produced, the carbon captured, other products resulting from the capture process, or all of these together. Price stabilization schemes include feed-in-tariffs, contracts for differences (CfDs), and mechanisms to guarantee CO_2 price levels.[88]

Another facet of this risk is the offtake of CO_2. There is only a certain amount of CO_2 an end-user can take, so utilities have to have contingency plans (e.g. a backup storage option perhaps for each facility, in the event there is a disruption in CO_2 offtake). This risk has clear financial implications and could become a major liability if CO_2 is regulated in the future: If utilities can't sell the carbon for industrial use or some form of storage, then they have to incur the cost of emitting CO_2 or the cost of storing it themselves, or both.

This risk raises the important "large volume" caveat to CO_2 EOR. The ability to sell carbon dioxide for EOR certainly will help reduce the cost of CCS, as well as the financing of capture projects, but in the view of many experts this business model will not incentivize large-volume storage (gigatonnes of CO_2) permanently underground. Rather, EOR should be viewed as a stepping stone.

There are others, however, who believe that more effort should be made to explore additional carbon utilization options—for example in industrial uses such as urea in fertilizer—to ensure the establishment of markets for the use of captured CO_2. Nevertheless, the overriding assessment among experts is that these industrial uses for CO_2 would not address climate change in a meaningful way. The IPCC stated that "In view of the low fraction of CO_2 retained, the small volumes used and the possibility that substitution may lead to increases in CO_2 emissions, it can be concluded that the contribution of industrial uses of captured CO_2 to climate change mitigation is expected to be small."[89]

At the state level, the lack of widespread ability to recover costs of a CCS project or, where it does exist, the complex political environment surrounding cost recovery serves as a disincentive and limits another avenue to generate a revenue stream.

A review of the three CCS projects that withdrew from the CPPI illustrates the risk that a lack of a market for CCS technology entails. Southern Company, American Electric Power, and Basin Electric Power cited the lack of ability to recover costs and uncertain market and regulatory conditions as key factors in their decisions (along with size of the financial commitment).[90]

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[88] Christoph von Stechow, Jim Watson, and Barbara Praetorius, "Policy incentives for carbon capture and storage technologies in Europe: A qualitative multi-criteria analysis," *Global Environmental Change*, vol. 21, no. 2, 2011, pp 346-357.
[89] IPCC Working Group III, *IPCC Special Report on Carbon Dioxide Capture and Storage*, p. 41.
[90] Folger, "Carbon Capture and Sequestration: Research and Development, and Demonstration at the U.S. Department of Energy," p. 14.

5. Available Policy Options to Promote CCS

Many policy options are available to address gaps and weaknesses in the current CCS policy framework. These tools span front-end and back-end approaches for technology innovation, and include increasing the level of financial support for existing policy mechanisms, modifying how policies in place are implemented, and instituting new policies. They incorporate voluntary incentives and mandatory requirements, market based as well as command and control instruments, and the creation of new institutions or processes for implementing policy.

Any proposed policy framework will have to meet two key, basic criteria: effectiveness and feasibility. Effectiveness measures how well policies address the range of risks confronting CCS. Feasibility describes the extent to which a policy approach limits costs for ratepayers and taxpayers. In addition, feasibility incorporates the ease of implementation of the policy, addressing the level of acceptance across a range of stakeholders, as well as the complexity of legislative and bureaucratic steps required. No individual policy will perfectly address all risks, and will have advantages and disadvantages impacting the ability to meet these criteria. In addition, choosing policy options should not be considered an "either-or" dynamic; rather there may be optimal ways to combine policies to achieve the desired objectives, and policy mixes will change over time.

This discussion is limited to selected, leading policy options that emerged during our research and/or have been raised in recent years, in particular as part of the legislative process in the U.S. Congress. Our analysis provides comments on their advantages and disadvantages relative to these criteria (see **Exhibit 5** for a summary). The balance of our discussion is weighted toward back-end policies since in our view they represent the largest current gap in the policy framework.

Front-End Policy

As noted, front-end policy is characterized by government financial support for R&D and demonstration projects, specifically financial support for two priorities identified by DOE: 2nd generation and transformational capture technologies, and ensuring sufficient funding for demonstration projects with 1st generation capture technology.[95] This approach seems eminently reasonable: Government support for basic and applied research is a sound and long-standing approach that resonates across the political spectrum and civil society. Demonstration projects are more problematic: By definition, support at this technology

[91] This is closely linked with a need to support the movement of projects from the demonstration stage to more commercial deployment of 2nd, 3rd and 4th generation facilities. We characterize the policy requirements for this process in our following discussion of back-end policy.

innovation stage is more expensive as projects increase in scale and complexity.

Nevertheless, as discussed in section 4, there is broad consensus—and real world experience illustrating—that demonstration projects are essential for gaining operational experience and driving down costs in the long run. As such, for at least a decade or more, various institutions have argued that increased financial support is required for CCS, especially in R&D and demonstration. In 2009, Senator Byron Dorgan (D-ND) created a "CCS Pathways Initiative" designed to bring a wide array of stakeholders together to assess the needs for moving CCS forward. That group largely agreed that a significant increase in government financial support is required. While it is difficult to compare proposals, and there were many diverse views on how much of the incremental cost the federal government should fund, there was consensus both "that with a sufficient level of funding to cover the incremental costs, CCS plants can begin planning, development, and construction today, and that a significant amount of CCS capacity can be in operation by 2025 to 2030 and beyond."[92] Although cost estimates produced by the stakeholders in the "CCS Pathways Initiative" varied, the ranges were illustrative: $475 million to $600 million per year for 10 years for R&D, and $800 million to $2.1 billion per year for 10 years for demonstrations.[93] More recently, CURC and EPRI released an update to their joint roadmap for advanced coal technology in which they estimated that the federal share of required funding to "average approximately $570 million to $940 million per year in the early years, and $495 million per year from 2026-2035."[94] The major drawback of any proposals to increase funding is that they will be viewed as large increases in government spending and further burdening taxpayers.

Funding approaches

While there may be widespread agreement that increased levels of funding are required to support the front-end launch phase for CCS technology innovation, the real challenge is finding ways to pay for it. In an era where government expenditures, especially proposals for new funding, are highly scrutinized, it is critical that politically feasible, long-term funding mechanisms are designed to support CCS commercialization. While increased funding is likely to be required from annual appropriations, there have been several types of off-budget proposals for funding mechanisms over the last several years, some combined with suggestions for institutional structures to implement them. Below we highlight the main concepts and some specific legislative examples.

CCS trust fund, supported by wires charge or public good surcharge

Under this policy, a separate fund would be established explicitly for the purpose of promoting CCS (or clean energy generally, including CCS). Revenues for the fund would be generated through a newly-established fee. One approach is a "wires charge," or a fee collected on each kWh of electricity sold with the revenues managed by the fund. Typically the surcharge would be applied to coal-fired generation, but could also be levied on all fossil-fuel electricity. This concept was proposed by Rubin in early 2008,[95] and was followed later that year by Representative Rick Boucher's (D-VA) Carbon Capture and Storage Early Deployment Act.[96]

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[92] "Clean Coal/CCS Technology Development Pathways: A process initiated by Senator Byron Dorgan (D-ND) to develop a cohesive strategic pathway for clean coal and CCS," Fall 2009.

[93] Ibid. These proposals were for the period 2010-2020.

[94] "The CURC-EPRI Advanced Coal Technology Roadmap," Coal Utilization Research Council and the Electric Power Research Institute, July 2015. This estimate includes advanced technologies beyond CCS.

[95] Naomi Peña and Edward S. Rubin, "A Trust Fund Approach to Accelerating Deployment of CCS: Options and Considerations," White Paper Series, Pew Center on Global Climate Change, January 2008, http://www.c2es.org/docUploads/Trust-Fund-FINAL.pdf.

[96] Carbon Capture and Storage Early Development Act, 110th Congress, 2nd session, H.R. 625812, Washington, D.C., 2008, https://www.congress.gov/bill/110th-congress/house-bill/6258/text.

EXHIBIT 5: Summary assessment of policy options for CCS technology innovation

POLICY TOOLS	CRITERIA	
	Effectiveness	**Feasibility**
FRONT-END POLICY		
Funding & Institutional Approaches		
CCS Trust Fund – Supported by wires charge, or public good surcharge	• Addresses technology risk by raising funds for large-scale demonstration projects (and possibly other stages of technology deployment) • Key issues in design are what to apply the charge to and for how long, how much to be assessed, who should oversee, and how money will be used • Public good surcharge on fossil fuels could provide long-term funding source owing to large existing resource base	• Trust funds are a well-known mechanism • Provides off-budget source of revenue • Requires enabling legislation, time to set up • Wires charge could be viewed as burden on ratepayers, especially in states with high coal and gas fired generation • Surcharge on oil and gas activities may be challenged as harming growth in that sector, also revenues generated subject to oil price fluctuations
BACK-END POLICY		
Voluntary Incentives - Existing		
Tax Credits Investment tax credit (ITC) – IRC48a, IRC 48b Sequestration (Production) Tax Credit (45Q)	**ITC** • Helps address financial risk (high capital costs) and encourage further investments, but does not directly help create market for CCS technology or offset operating costs • Generally considered insufficient alone to spur more investment; not applicable to non-tax paying entities • Refundable ITC would make more resources available on a dollar for dollar basis **Sequestration (Production) Tax Credit–45Q** • Helps put value on and stabilize CO2 price, helping create a market for CCS technology; does not address high capital costs	• Tax credits negatively impact government budget by reducing tax revenue • Modifications to 45Q—more market-based and competitively implemented—make it more politically feasible • Incentives through tax code are familiar policy approach in the energy sector; changes proposed for ITC and 45Q could be made by modifying existing legislation or tax code
Loan guarantee	• Helps with up-front capital costs—increases probability developers will secure a loan to finance project; but does not directly address operating costs or help create a market for CCS technology • Some design aspects limit attractiveness (credit subsidy cost, restrictions on accessing other government support), as well as complexity in application and negotiation process	• Requires government outlay • Over a range of projects, probability of default is low, which allows government to support many projects while minimizing own burden
Direct loans and federal cost sharing grants	• Direct funding reduces capital costs • Most repayment conditions are soft terms, reducing the cost to developers	• Expensive to government • Requirements for projects to find private funding could reduce burden on government
Voluntary Incentives – New		
Bonds Clean Coal Bonds Private Activity Bonds (PABs)	• Additional tool to helps investors access funding • PABs considered cheaper, with longer repayment periods	• Well known instruments in private sector—used for other environmental control technologies • Market-based mechanisms • PABs low cost to taxpayers • Would require legislation

POLICY TOOLS	CRITERIA	
	Effectiveness	**Feasibility**
Master Limited Partnerships	• Additional tool to helps investors access funding • Could add to financing complexity	• Well known instrument in private sector • Market based mechanism • Requires modifying existing legislation/ tax code
Price stabilization Contract for Differences (CfDs)	• Helps create market, reduces gap between costs of CCS and revenues earned from selling electricity and/or carbon • Volatility of market prices impacts effectiveness/attractiveness for investors	• Can be structured as a competitive, market-based tool that reduces impact on government expenditure • Requires new enabling legislation and careful design • Financial risk of volatile prices could be transferred to government
Mandatory Approaches		
Market-based – **cap and trade (C&T)** Market-based – **carbon tax**	• Price on carbon creates market for carbon • In C&T price volatility of allowances can increase uncertainty of return on capital • C&T sets clear emission reduction goals • Carbon tax establishes clearer and more predictable price signal	• Both require legislation to establish • C&T viewed as more complex; tax challenging in determining level • Both provide revenues for government, and/or for CCS support, or taxpayer relief • Compared to command and control, carbon pricing applies to all activities & achieves reductions with lower cost • Experience with C&T for carbon in RGGI, and for SO_2 • Both viewed as raising costs for carbon-intensive firms, and for ratepayers
Command & control **– Portfolio standards**	• Can drive the creation of a market for the technology • If quotas are traded in certificates, operators are exposed to financial risks through the volatility of certificates • Flexible approach allows electricity producers to choose energy sources to meet the standards • If portfolio standards are sufficiently long-term, investors will be encouraged to make long-term commitments to technology	• Trading of certificates can provide revenue to companies and government • Practices can be transferable from renewables sector • Compliance costs are recovered from charges to taxpayers' electricity bills. • Varying effects on electricity prices of consumers • Viewed as favoring certain technologies
Command & control **– Performance standards**	• Emission standards can spur deployment of the technology–addresses need to create a market for CCS • Emissions levels are known, emerging implicit price on carbon is not • Limited incentive to improve beyond set targets	• Known policy tool, used for other environmental control technologies in utility sector • Same standards across all emissions could increase costs for plants with older and less efficient technologies • Difficult to set the level needed to reach goals • Viewed as raising costs for industry and ratepayers

Information derived from: International Energy Agency, "A policy strategy for carbon capture and storage," January 2012; Christoph von Stechow, Jim Watson, and Barbara Praetorius, "Policy incentives for carbon capture and storage technologies in Europe: A qualitative multi-criteria analysis," pp 346-357; Max Krahe, et al., "From demonstration to deploymnet: An economic analysis of support policies for carbon capture and storage," Energy Policy 60, 2013, p. 753-763; and Mohammed A. Al-Juaied, "Analysis of Financial Incentives for Early CCS Deployment," Discussion Paper 2010-14, Cambridge, M.A.: Belfer Center for Science and International Affairs, October 2010.

This proposed legislation called for the creation of a carbon storage research corporation that would collect an assessment on fossil fuel-based electricity "to accelerate the development and early deployment of systems for the capture and storage of carbon dioxide emissions from fossil fuel electric generation facilities."[97] The assessment would vary by the carbon content of the fuel, be adjustable based on levels of production from each fuel, be subject to state utility regulatory approval, and be set at a level that would generate between $1 billion and $1.1 billion annually. The wires charge concept was later incorporated in the Waxman-Markey legislation in 2009, and the Carbon Capture and Storage Deployment Act (S. 3591) introduced by Senator John D. Rockefeller (D-WV).

Public good surcharges are assessments applied to a broader range of activities outside of the electricity sector but the revenues generated are similarly applied to promoting CCS and perhaps other low carbon options. Several recent proposals include:

- *Surcharge on fossil fuel production:* In January 2013, scholars at the Brookings Institution called for taxing the production of hydrocarbons, either on a volumetric or carbon-content basis, specifically to promote CCS (along with battery technologies), as a condition for other policies designed to promote and take advantage of the surge in domestically available oil and gas supplies.[98]
- *Surcharge on fossil fuel exports:* Project Third Way expanded on this concept in March 2014 proposing an assessment, either on a BTU or carbon content basis, on exports of oil and gas to fund clean energy innovation.[99]

There have been other approaches suggested recently for the creation of funds dedicated to the development of clean energy including, but in some cases not exclusively, to CCS. These have targeted existing oil and gas operations and related infrastructure as the funding sources, such as using funds from the Strategic Petroleum Reserve or revenues generated from offshore oil and gas production.[100]

Wires charges and public good surcharges have been used to establish funds for a variety of activities throughout the US economy. They can be valuable mechanisms in providing much-needed off-budget funding to meet key objectives. The critical questions to address in designing such policy tools are: What is the assessment applied to? How much is the assessment expected to generate and for how long? How are the funds used, and how is the program managed institutionally? Assessing a fee on coal and natural gas-fired electricity generation and in turn using that revenue to support the development and deployment of CCS seems to be the soundest approach since the benefits of the fee flow back to the targeted sector. Applying a public good surcharge on fossil fuel production or exports has its own set of pros and cons. Given the projections for increased oil and gas production, any fee on the increasing volumes of output could provide a solid base of revenues for a CCS trust fund. However, this is likely to be politically challenged on the grounds of threatening the growth and economic benefits emanating from a booming oil and gas sector. Moreover, the amount of revenue generated would be susceptible

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[97] Ibid.

[98] Foreign Policy Scholars, "Big Bets, Black Swans: A Presidential Briefing Book," The Brookings Institution, January 2013.

[99] Melissa Carey and Josh Freed, "How a Fee on Fossil Exports Can Make the U.S. a Clean Energy Superpower," Third Way, 11 March 2014, http://www.thirdway.org/memo/how-a-fee-on-fossil-exports-can-make-the-us-a-clean-energy-superpower.

[100] With the surge in domestic oil production, there have been calls using the SPR for other purposes. The American Energy Opportunity Act of 2014 proposed an "Energy Independence and Security Fund," with funds transferred from the SPR Petroleum Account. These funds are meant to be distributed for research projects into various existing funds, such as the "Fossil Energy Research and Development" account, which supports R&D in various technologies, including carbon capture and storage. The American Conservation and Clean Energy Independence Act of 2009 proposed establishing a 'Clean Coal Technology Deployment and Carbon Capture and Sequestration Reserve' which would fund research, development, and construction of emission prevention technologies. This Reserve would be funded by revenues collected from commercial leasing of federal oil and gas on the outer Continental Shelf.

to oil price fluctuations, and any fee on fossil fuel exports would need to be compatible with commitments under global trade agreements.

Back-End Policy

There is a clear need to implement more robust back-end policies to support CCS deployment. While several financial incentives are in place, there are options available to re-tool or improve them. Beyond the existing loan guarantee program and tax incentives, however, there is a gap in policy mechanisms to address the lack of a market for CCS technology. Back-end policies are designed to "pull" a technology into the market, helping to mature it to the point of widespread commercial deployment. These policies may require increasing government expenditure and greater government intervention and thus are politically more challenging to institute and maintain.

There are two broad categories of back-end policies: voluntary incentives and mandatory approaches.[101] Voluntary incentives are policies that market actors may take advantage of at various stages of technology innovation. Within this category, there are options for improving existing financial incentives, as well as establishing new mechanisms to address the range of risks confronting investors in a CCS project.

Voluntary incentives: Existing mechanisms

Modifications to 45Q

Designed primarily to support the use of CO_2 for EOR, major revisions have been considered to this tax incentive, addressing the cap on carbon sequestered, the amount of the tax credit, and other aspects.[102] However, the National Enhanced Oil Recovery Initiative, run by C2ES and the Great Plains Institute, has proposed perhaps the most detailed changes which have gained some traction: They were supported in legislation introduced by Senators Rockefeller (D-WV) and Heitkamp (D-ND) in 2014.[103] These include:

- *Competitive bidding*: A CO_2 capture project will bid for a certain level of credit; the lowest bid will win. Bids reflect the difference between the cost to capture and transport CO_2 and revenue from selling the CO_2 for use in EOR.
- *Separate tranches*: To ensure that credits are available for the range of potential man-made sources of CO_2, there will be separate tranches for electric power, lower-cost industrial, and higher-cost industrial projects. Power plant projects would be eligible for up to \$45/tonne and would represent the biggest tranche of eligible projects.

[101] This draws on policy categorizations contained in Alic, J.A., D.S. Mowery, and E.S. Rubin, "U.S. Technology and Innovation Policies: Lessons for Climate Change," Pew Center on Global Climate Change, Arlington, VA, 2003; Also in Weiss and Bonvillian, "Structuring an Energy Technology Revolution."

[102] See for example: The No More Excuses Energy Act of 2011 which would have repealed the 500,000 metric tons of carbon dioxide minimum for a facility to qualify for the credit, No More Excuses Energy Act of 2011, 112th Congress, 1st session, H.R. 1023, Washington, D.C., 2011, https://www.congress.gov/bill/112th-congress/house-bill/1023. Also the The American Energy Innovation Act proposed increasing the cap on the amount of CO2 stored from 75,000,000 to 225,000,000 metric tons, as well as the amount of tax credit to \$50 per tonne for captured and stored CO2, and \$40 per tonne for CO2 used in EOR, American Energy Innovation Act, 111th Congress, 1st session, H.R. 2828, Washington, D.C., 2009, https://www.congress.gov/bill/111th-congress/house-bill/2828. In recent years, several other pieces of legislation have proposed new provisions to the tax code to promote CO2 EOR. These center around expanding the financial incentive based on the source of the carbon captured, distance the carbon is transported, stabilizing the price of CO2 for EOR by some form of linkage with oil prices, and other changes. For example, the Practical Energy Act of 2011 proposed a 70 percent investment tax credit for any power or industrial project capturing CO2 and using a trunkline of at least 300 miles, as well as an associated deployment and production tax credit, Practical Energy Plan Act of 2011, 112th Congress, S. 1321, 1st session, Washington, D.C., 2011, https://www.congress.gov/bill/112th-congress/senate-bill/1321.

[103] Recommended Modifications to the 45Q Tax Credit for Carbon Dioxide Sequestration, National Enhanced Oil Recovery Initiative (NEORI), February 2012, http://neori.org/publications/neori-45q/; also "NEORI Calls for Continued Efforts to Advance CO2-EOR in the New Congress," NEORI, 13 January 2015, http://neori.org/neori-calls-for-continued-efforts-to-advance-co2-eor-in-the-new-congress/.

- *Benchmarked to oil prices*: Tax credit will vary with the international price of oil—the price of oil would be locked in for year one of the tax credit, but thereafter the credit will vary based on price of oil.
- *Allocation and certification changes*: To increase certainty for CO_2 capture project developers, the bill also would introduce certain reforms for allocating new 45Q credits. A certification process would allow CO_2 capture projects to reserve newly-allocated 45Q tax credits and ensure that projects move forward toward construction and completion in a timely manner.

These proposals appear to improve the effectiveness of 45Q by strengthening its ability to provide a revenue stream for captured CO_2, and focusing more on the incentive for the power sector. Specifically, by functioning as a *variable production tax credit* for CO_2-EOR, with the government as a counterparty, the cost gap—the difference between the suppliers' cost to capture and transport CO_2 and the EOR operators' willingness to pay for CO_2—determines the expected level of the tax credit in a proposed competitive bidding process. In addition, the tax credit is revenue neutral or revenue-positive: the federal government will bear the cost of a CO_2-EOR tax credit program, yet it will enjoy increased revenues from the expansion of CO_2-EOR oil production when taxes are collected on the additional production. One critique is that this takes time, i.e. there is a lag between when the tax revenue is collected on the additional oil production from EOR, and thus a lag in several years when the revenue is available to support CCS. Moreover, despite these design features, it is unclear how an extended period of unusually low oil prices such as exists currently could negate the attractiveness of such a tax credit mechanism. Nevertheless, the market-based and competitive design elements potentially make 45Q more politically feasible.

Expanded or new tax credit approaches

There have been many legislative proposals to expand the use of tax credits (amount of credit available) or to reform how they are implemented.[104] Most recently, President Obama's FY2016 budget submission proposed $2 billion in refundable investment tax credits available for both new and retrofitted power plants with carbon capture technology.[105] Both types of plants must capture more than 75 percent of CO_2 emissions, and the credit would be for 30 percent of the cost, including for CO_2 capture, transportation, and storage infrastructure. This proposal also calls for refundable sequestration tax credits for up to 20 years of $50 per metric ton of CO_2 "permanently sequestered and not beneficially reused and $10 per metric ton for CO_2 that is permanently sequestered and beneficially reused."

The private sector generally has reacted favorably to the administration's tax credit proposal, indicating that it is directionally a good step. The investment tax credit and sequestration tax credit are viewed as complementary and making the tax credits refundable is a major improvement since this allows the IRS to treat the credit as a payment thus functioning like the cash grant program for renewable energy under the American Recovery and Reinvestment Tax Act of 2009 (Sec. 1603).

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[104] One of the more interesting proposals was an energy tax reform bill introduced by Sen. Max Baucus (D-MT) in 2013 proposing to eliminate all separate tax credits for individual fuels and technologies and institute instead two tax credits for transportation and electricity. The electricity tax credit would be available for any facility that produces electricity that is 25 percent cleaner than the average for all electricity production facilities (defined by an agreed greenhouse gas ratio), and operators can choose between a production tax credit of up to $0.023 per kilowatt for a maximum of 10 years, and a maximum investment tax credit of 20 percent. CCS would be eligible under this proposal. See Chairman Max Baucus, "Summary of Staff Discussion Draft: Energy Tax Reform," U.S. Senate Committee on Finance, 18 December 2013, http://www.washingtonpost.com/blogs/wonkblog/files/2013/12/Baucus.energy.bill_.draft_.DEc_.2013.pdf.

[105] "Investing in Coal Communities, Workers, and Technology: The POWER+ Plan," The President's Budget, White House, Fiscal Year 2016, https://www.whitehouse.gov/sites/default/files/omb/budget/fy2016/assets/fact_sheets/investing-in-coal-communities-workers-and-technology-the-power-plan.pdf.

Nevertheless, the tax credits are still considered insufficient to support CCS project development. In addition, the proposal imposes restrictions on the total amount of tax credits available for new or retrofitted plants, as well as for any single technology, thus potentially diluting the funding available for promising deployment pathways. As one private sector developer pointed out, this supports many different technologies "but we need a clearer signal that allows us to go with one, and drop what doesn't work."

Modifications to the loan guarantee program

There are proposals to address the structural issues with the existing loan guarantee program, in particular the credit subsidy cost and restrictions on accessing the loan guarantees. For example, the Energy Loan Program Improvement Act of 2015 would repeal the condition that an appropriation for the cost of the guarantee is required, and the ACCTION (Advanced Clean Coal Technology Investment in our Nation) Act of 2015 would eliminate the restriction that loan guarantees could not be provided to entities receiving other government support such as grants. The American Clean Energy Leadership Act of 2009 introduced by Senator Jeff Bingaman (D-NM) established a revolving Clean Energy Investment Fund that would be the source for loan guarantees instead of the Treasury, thus reducing the government's risk (and the borrowers credit subsidy payment would be deposited in the new fund, not the Treasury).

Loan guarantees can play a positive role in helping to secure a loan, and thus address up front financing risks. However, even with the changes described above, they do not address other risks, are complex to negotiate and implement, and the unknown credit subsidy cost can be a disincentive. In addition, the large amounts and high profile awards to individual companies make this a politically charged instrument.

Direct loans and grants

Instead of loan guarantees, an alternative is for the federal government to provide loans directly to eligible projects. There have been legislative proposals recommending the establishment of such a mechanism for CCS. For example, the American Energy, American Innovation Act of 2008 would have established a Coal Innovation Direct Loan Program, providing loans of up to $10 billion for projects that store at least 75 percent of captured CO_2, and allowing loans to meet 100 percent of capital costs but not exceeding 50 percent of total costs.[106]

The United Kingdom has developed a financing mechanism specifically to address costs in front end engineering and design (FEED): Under the CCS Commercialization Program, the government has allocated 100 million pounds to support FEED costs, and has already met 75 percent of the FEED costs for the White Rose and Peterhead CCS projects.[107] The 2013/2014 FEED contracts contain detailed reporting requirements designed to share information about delivering large scale commercial CCS projects, including "commercial and financing arrangements; program and risk management; consents and permitting; technical design, engineering and integration; health and safety; and lessons learnt."[108]

Direct loans reflect some of the same advantages and disadvantages as loan guarantees, although they may be more flexible in targeting specific technologies or stages of project implementation, such as FEED support in the United Kingdom.

[106] American Energy, American Innovation Act of 2008, 110th Congress, 2nd session, H.R. 7239, Washington, D.C., 2008, https://www.congress.gov/bill/110th-congress/house-bill/7239/text#toc-H8E22BF8B7D5443E08F00A152FBCE794B.

[107] "Next Steps in CCS: Policy Scoping Document," U.K. Department of Energy and Climate Change, August 2014, p. 22, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/341995/Final_Version_Policy_Scoping_Document_PSD.pdf.

[108] "Carbon Capture and Storage knowledge sharing," U.K. Department of Energy & Climate Change, 11 June 2015, https://www.gov.uk/government/collections/carbon-capture-and-storage-knowledge-sharing.

Voluntary incentives: New mechanisms

There are also a variety of new policy tools that have been proposed to provide a wider range of options to help with the financial challenges and risks involved in CCS projects.

Clean coal bonds

The existing tax code allows for the use of bonds for renewable energy and energy conservation, but carbon capture and storage projects are not currently eligible.[109] Many bills have been proposed for the creation of a *clean energy coal bond,* under which proceeds from the sale of bonds can be used for "capital expenditures" for "qualified projects."[110] Under these laws, a coal-based electric generation unit that includes carbon dioxide capture, transport, and storage property and captures and stores a certain amount of CO_2 would qualify for issuing a bond. Qualified issuers would include cooperative electric companies along with municipal and public power entities. Some bills also propose a credit for holders of a clean energy coal bond: Taxpayers holding the bond would be eligible for a credit equal to the product of a credit rate determined by the secretary of energy and the outstanding face amount of the bond.[111]

Private activity bonds

According to IRS Publication 4078, private activity bonds (PABs) are "tax-exempt bonds issued by a state or local government, the proceeds of which are used for a defined qualified purpose by an entity other than the government issuing the bonds."[112] Several groups recently have argued publicly for expanding the use of PABs for CCS projects, especially since this instrument was used by utilities in financing the deployment of other environmental technologies such as SO_2 scrubbers prior to its repeal in 1986.[113]

Although bonds may be subject to market volatility through interest rate fluctuation, they are familiar instruments and help address financing needs. They could also be used to help fund natural gas-CCS projects in addition to coal projects. In addition, they provide cheaper interest rates, have longer repayment periods, and cost taxpayers less since states cap PABs.[114]

Master limited partnerships

A master limited partnership (MLP) is a type of business structure "that is taxed as a partnership, but whose ownership interests are traded on financial markets like corporate stock."[115] The

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[109] Under 26 U.S. Code Part IV, Subpart I-Qualified Tax Credit Bonds, bonds can be used for clean renewable energy and energy conservation. The renewable energy bonds apply to wind, biomass, geothermal, solar, hydropower, refined coal, and hydrokinetic energy facilities.

[110] For example see Carbon Reduction Technology Bridge Act of 2008 at https://www.congress.gov/bill/110th-congress/house-bill/6756/text. Others with similar provisions include the ACCTION Act of 2015, Fulfilling US Energy Leadership Act of 2011, Coal Energy Bridge Act of 2010, Future Fuels Act of 2008, Eight Steps to Energy Sufficiency Act of 2008, BOLD Energy Act of 2006, Breaking Our Long-Term Dependence Energy Act of 2006, and Clean EDGE Act of 2006.

[111] The credit allowance works much like present-law tax credit bond and entitles the holder to a tax credit. The amount of the tax credit is calculated by multiplying the bond's credit rate by the face amount on the holder's bond. This rate, determined by the secretary, permits issuance of the bond without discount and interest cost to the issuer. Credit accrues quarterly and can be included in gross income. Additionally it can be claimed against regular income tax liability and alternative minimum tax liability. See reference: Joint Committee on Taxation, Description of the "Energy Advancement and Investment Act of 2007," (JCX-31-07), 14 June 2007, p. 16. Also see for example BOLD Energy Act of 2006, Breaking Our Long-Term Dependence Energy Act of 2006, and Clean EDGE Act of 2006.

[112] Tax-Exempt Private Activity Bonds, Internal Revenue Service (IRS), Office of Tax Exempt Bonds, 2005, http://www.irs.gov/pub/irs-pdf/p4078.pdf.

[113] Stanford University and Summit Power have been at the forefront of developing this concept–see reference in C2ES presentation, Patrick Falwell, "Opportunities for Financing CCS Projects & the Impact of Oil Prices on CO2-EOR," National Coal Council 2015 Annual Spring Meeting, C2ES, 8 April 2015, http://www.nationalcoalcouncil.org/Presentations/2015/Spring-Meeting-2015/7-Patrick-Falwell-C2ES-NCC-Spring-2015.pdf.

[114] These benefits are highlighted in a presentation by Sasha Mackler, "Financing CCUS: How targeted policies can drive the industry," USEA Energy Briefing, Summit Power, May 2015, http://www.usea.org/sites/default/files/event-/CCUS%20Finance_0528.pdf.

[115] Molly F. Sherlock and Mark P. Keightley, "Master Limited Partnerships: A Policy Option for the Renewable Energy Industry," Congressional Research Service, 28 June 2011. This summary was provided in John P. Banks, et al., "Assessing the Role of Distributed Power Systems in the U.S. Power Sector," The Brookings Institution and Hoover Institution, October 2011.

difference is that, for tax purposes, partnerships are "generally subject to one layer of taxation in contrast to publically-traded… corporations, which are subject to two layers of taxation."[116] At the same time, however, having access to equity markets like a corporation provides MLPs with larger amounts of capital. As a result, combining benefits of two types of business structures means that MLPs can secure capital at lower costs because they have access both to more capital as well as favorable tax treatment.[117]

MLPs have long been used in the oil and gas industry, but there has been increasing interest in recent years in expanding the use of MLPs for a broader array of energy projects. Interestingly, MLPs are available for EOR and for CO_2 pipelines, but not capture projects.

The Master Limited Partnership Parity Act of 2013 (S. 795) sponsored by Senator Chris Coons (D-DE) included provisions for CCS. It is notable that the Joint Committee on Taxation, which reviews proposed legislation for its impact on the federal budget, scored the CCS components of the bill as having insignificant budget impact compared to other sections.[118] A new bill to promote expansion of the MLP mechanism–S. 1656–also supports CCS: "To qualify for the MLP structure, new power plants would be required to capture at least 50 percent of their CO_2 and existing power plants must capture at least 30 percent of their CO_2...The captured CO_2 must be stored."

Expanding MLPs to the full range of CCS equipment and infrastructure would broaden access to financing using a well-established and understood mechanism, and would entail amending the existing tax code as opposed to creating an entirely new policy tool. A potential downside is that this may add complexity to an already challenging process in cobbling together financing for a CCS project. In addition, this approach would require amending the tax code and could become part of that debate beyond strictly energy considerations.

Price stabilization: Contract for differences

The U.K. government aims to support CCS projects during operation with contracts for differences. Established by the U.K. Energy Bill of 2012, contracts for differences (CfDs) are bilateral contracts between an individual low-carbon generator and the CfD counterparty, a government-owned limited liability company.[119] Generators receive a strike price, a "fixed price for the low carbon electricity they produce."[120] Should the market price be lower than the strike price, generators will receive a "top up payment," and conversely, the generator pays the difference if the market price is greater than the strike price.

Under the CCS Commercialization Program, two projects—WhiteRose and Peterhead—are negotiating for the first CfDs for CCS. For future allocation frameworks, the U.K. Department of Energy and Climate Change (DECC) is designing a generic CCS CfD with input from the industry.[121] Details, such as the strike price, were not released in the 2013 Electricity Market Reform (EMR) Delivery Plan.[121] However, the Government has planned to allocate CfDs through a competitive application process. Because the overall electricity market reform in the United Kingdom aims to decarbonize the electricity grid in the least expensive way,

[116] Ibid.
[117] Ibid.
[118] Letter from Joint Committee on Taxation to sponsors of S.795 on 13 November 2013.
[119] "Annex A: Feed-in Tariff with Contracts for Difference: Operational Framework," U.K. Department of Energy & Climate Change, November 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66554/7077-electricity-market-reform-annex-a.pdf.
[120] "Next Steps in CCS: Policy Scoping Document," U.K. Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/341995/Final_Version_Policy_Scoping_Document_PSD.pdf.
[121] Ibid., p. 26.
[122] "Electricity Market Reform Delivery Plan," U.K. Department of Energy & Climate Change, December 2013, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/268221/181213_2013_EMR_Delivery_Plan_FINAL.pdf.

the government aims to encourage "competition within and between low carbon technologies."[123]

Several U.S. bills have proposed a similar method. The Coal with Carbon Capture and Sequestration Act of 2015 (S.1285) introduced in May 2015 proposes 25-year binding contracts between the secretary of energy and electric generators to provide price stabilization support for both electricity produced and captured CO_2. However, this act is limited to coal-fired electric generation units and CO_2 sold for EOR or other uses for which a commercial market exists.[124]

The ACCTION Act of 2015 (S. 601) proposed a similar system of variable price support for CO_2 sequestration.[125] Eligible projects must use coal for more than 75 percent of a project's fuel, capture at least 50 percent of carbon dioxide produced, and use the CO_2 for EOR. Similar to the CfD approach in the U.K., this program would have a competitive bidding process.

CfDs provide a way to address the gap between the costs of CCS and the revenue stream needed from the sale of electricity or CO_2. In addition, it is a voluntary mechanism that can be structured as a competitive, market-based tool that reduces the impact on government outlays, making it more politically feasible to implement. However, enactment of this policy would require new enabling legislation and careful design to work within a complex U.S. electricity market. In particular, electricity price volatility in wholesale markets may not provide the kind of predictable revenues required for a CCS project. Moreover, if the federal government is a counterparty, implementation will require careful consideration of how CfDs would be managed institutionally, and what processes and monitoring and evaluation protocols will be needed.

Institutional approaches

There are a variety of proposals to create institutional structures in an effort to organizationally streamline and better manage CCS programs and policies. Generally these proposals either recommend programs or entities specific to CCS or clean coal (such as the trust fund mentioned earlier), or other concepts to create organizations tasked with promoting R&D and clean energy technology more broadly, of which CCS could be a part. For example, in 2007, the Massachusetts Institute of Technology recommended the formation of a quasi-public Clean Coal Demonstration Corporation to oversee the development and deployment of large-scale demonstration projects over a 10-year period.[126] The Inter-Agency Task Force on CCS proposed the creation of a Federal agency roundtable "to act as a single point of contact for project developers seeking assistance to overcome financial, technical, regulatory, and social barriers facing planned or existing projects."[127] More recently, Senator Heidi Heitkamp's (D-ND) *ACCTION Act of 2015* (S. 601) called for the DOE to "establish an advisory committee to report on the carbon capture and sequestration program and the coal and related technologies program."

Concepts for creating broader programs and organizations dedicated to low carbon technologies have also been suggested. In 2008, John Podesta, John Deutsch, and Peter Ogden argued for establishing an interagency *Energy Innovation Council* located in the Executive Branch "responsible for developing a multiyear National Energy RD&D

[123] "Next Steps in CCS: Policy Scoping Document," U.K. Department of Energy and Climate Change, p. 25.
[124] *Coal with Carbon Capture and Sequestration Act of 2015*, 114th Congress, 1st session, S. 1285, Washington, D.C., 2015, https://www.congress.gov/bill/114th-congress/senate-bill/1285/text.
[125] *Advanced Clean Coal Technology Investment in Our Nation (ACCTION) Act of 2015*, 114th Congress, 1st session, S. 601, Washington, D.C., 2015, https://www.congress.gov/bill/114th-congress/senate-bill/601.
[126] *The Future of Coal: Options for a Carbon-constrained World*, MIT, 2007, p. 102, http://web.mit.edu/coal/The_Future_of_Coal.pdf.
[127] "Report of the Interagency Task Force on Carbon Capture and Storage," Interagency Task Force on Carbon Capture and Storage, August 2010, p. 11, http://www3.epa.gov/climatechange/Downloads/ccs/CCS-Task-Force-Report-2010.pdf.

Strategy for the United States."[128] The American Clean Energy Leadership Act of 2009 proposed a Clean Energy Deployment Administration (CEDA) to manage loans, loan guarantees, or other financial products to promote and deploy clean energy technologies. CEDA would also manage a portfolio of investments.

The American Energy Innovation Council (not related to the proposed entity mentioned above), comprising leading business executives, recommended the creation of an independent national Energy Strategy Board charged with developing and monitoring a national energy plan for Congress and the Executive Branch, as well as "guiding and coordinating energy research investments by DOE.[129] In addition, the Council recommended establishing and funding a New Energy Challenge Program operating under an independent corporation outside of the federal government and in partnership with private industry to "focus on the transition from pre-commercial, large-scale energy systems to integrated, full-size systems."[130]

Creating a CCS-specific institution generally would be better at marshalling and concentrating resources dedicated for CCS. All else being equal, the more high profile and institutionally and legally distinct this entity, i.e. located higher in the bureaucracy, with a more senior reporting requirement, and created with a separate budget, the more effective it would be. A committee or roundtable will likely be insufficient to generate the extended focus needed to move CCS forward. However, there are important questions concerning the character and authority of any new entity: Public, private, quasi-governmental? Created within an existing federal entity, or stand-alone? The challenge in creating new institutions is that they require legislative action, time to establish, and funding.

Mandatory approaches

The United States government may also use policies that establish requirements for market actors. These instruments can be categorized further based on how they are implemented and the level of flexibility in compliance:[131]

- *Market-based policies*: providing market and price signals
- *Command and control regulations*: providing explicit directives

While both types of policy tools help to create markets for a technology, there is a consensus in the economic literature that market-based approaches are better based on the flexibility provided to firms and their lower cost of compliance: "Even though they do require government to set the price of pollution… the regulated firms have the flexibility to respond to that price that a command-and-control system denies. And this flexibility exists not only within each firm, but across firms in the entire market."[132] However, in both approaches timing is important since promoting or even forcing the deployment of a technology that is not ready for commercial deployment is both costly and inefficient.

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[128] Peter Ogden, John Podesta, & John Deutch, "A New Strategy to Spur Energy Innovation," Issues in Science and Technology, Volume XXIV Issue 2, Winter 2008, http://issues.org/24-2/ogden/.

[129] "A Business Plan for America's Energy Future," American Energy Innovation Council, September 2011, http://bipartisanpolicy.org/wp-content/uploads/sites/default/files/AEIC_REPORT_Final.pdf.

[130] Ibid., p. 5.

[131] Robert N. Stavins, "Experience with market-based environmental policy instruments," Harvard University and Resources for the Future, Prepared for the Handbook of Environmental Economics, Amsterdam: North-Holland/Elsevier Science, Revised: 26 October 2001.

[132] Ted Gayer, "Pricing Pollution," The Brookings Institution, Winter 2011, http://www.brookings.edu/research/articles/2011/01/pricing-pollution-gayer.

Market-based policies: Carbon pricing

The most prominent market-based policies are a cap and trade system and a carbon tax. Both of these set a price for CO_2 either directly (through a tax) or by establishing an emissions cap (through a cap and trade system) that yields a price.[133]

There is considerable literature examining the advantages and disadvantages of these policies, as well as assessments of the experience with each in several countries, including in the United States (the cap and trade system for SO_2 in the electricity sector).[134] In general, they largely accomplish the same result—the creation of a price for CO_2—but in cap and trade the emissions limits are set with the price emerging through a trading system, while with a carbon tax the price is set and the actual emissions levels emerge from that price signal.

In the United States, there have been several legislative attempts to create a cap and trade system, most prominently the Waxman-Markey bill.[135] This bill proposed bonus allowances to help early deployment of CCS projects. In a first phase, supporting the first 6 GW of CCS projects, the equivalent of a $90/tonne subsidy was proposed to be paid for 85 percent capture, and $50/tonne for 50 percent capture; for the second phase (beyond 6 GW), the value of the subsidy would be allocated by a reverse auction.[136]

More recently, there have been several legislative initiatives that have proposed a cap and trade system or carbon tax, although these have not move forward.[137] However, at the state level, a cap and trade program has been operating since 2009 among nine states in the eastern United States: the Regional Greenhouse Gas Initiative (RGGI).

As noted in our research, there was broad acceptance that a CO_2 price signal would be very beneficial for spurring CCS commercialization—providing a driver for the creation of a market for CCS technology. However, there is also a prevalent view that this price signal alone would not be sufficient since in near-term it will not be politically feasible to establish a carbon price high enough to drive CCS deployment. Beyond current political opposition to pricing carbon, even if a pricing mechanism were established, it may take some time to impact the market. From a utility perspective, there also is a question of whether a CO_2 price would help in light of cheap gas: Any price on carbon would have to somehow take into consideration the abundance of shale gas. Moreover, CCS is politically behind other low carbon technologies in that it has not been a part of a program to buy-down the cost of low carbon technologies in

133 Ibid.

134 See for example: "Policy Options for Reducing CO2 Emissions," Congressional Budget Office, Pub. No. 2930, February 2008, https://www.cbo.gov/sites/default/files/110th-congress-2007-2008/reports/02-12-carbon.pdf.

135 There were several other notable legislative initiatives in the 2009-2010 timeframe. For relevant summaries see: "Federal Summary and Analyses," C2ES, accessed 21 September 2015, http://www.c2es.org/federal/summary-analysis.

136 See Waxman-Markey, section 115. A reverse auction subsidy is a competitive mechanism in which sellers (companies) submit bids, and buyers (a utility or government) can select the winning seller based on the lowest-price. The Clean Air Task Force has examined the advantages and disadvantages of applying a reverse auction approach to finance deployment of CCS projects, see Bruce Phillips, *Using Reverse Auctions in a Carbon Capture and Sequestration (CCS) Deployment Program*, Clean Air Task Force, May 2010, http://www.catf.us/resources/publications/files/Using_Reverse_Auctions_in_a_CCS_Deployment_Program.pdf. Another interesting variation is The Roadmap for America's Energy Future (HR 909) which proposed a trust fund financed by royalties from oil and gas leases to support renewable energy. The bill established reverse auction program overseen by DOE to disburse funds based on lowest cost bids. *Roadmap for America's Energy Future*, 112th Congress, 1st session, H.R. 909, Washington, D.C., 2011, https://www.congress.gov/bill/112th-congress/house-bill/909; and Saqib Rahim, "Republicans Weigh a Federal 'Reserve Auction' to Push Clean Energy," *The New York Times*, 4 April 2011, http://www.nytimes.com/cwire/2011/04/04/04climatewire-republicans-weigh-a-federal-reverse-auction-18453.html?pagewanted=all.

137 See for example the following: Healthy Climate and Family Security Act of 2014, 113th Congress, 2nd session, H.R. 5271, Washington, D.C., 2014, https://www.congress.gov/bill/113th-congress/house-bill/5271; American Opportunity Carbon Fee Act of 2015, 114th Congress, 1st session, S. 1548, Washington, D.C., 2015, https://www.congress.gov/bill/114th-congress/senate-bill/1548; Tax Pollution, Not Profits Act of 2015, 114th Congress, 1st session, H.R. 2202, Washington, D.C. 2015, https://www.congress.gov/bill/114th-congress/house-bill/2202; and Managed Carbon Price Act of 2014, 113th Congress, 2nd session, H.R. 4754, Washington, D.C., 2014, https://www.congress.gov/bill/113th-congress/house-bill/4754.

a market pull manner, leaving it at a competitive disadvantage, especially vis-a-vis renewables.

Command and control regulations: Portfolio standards

A portfolio standard is a mandate for utilities to produce a certain percentage of total electricity generation from eligible sources by a specified period of time. This mandated quota is intended to help deploy and commercialize certain technologies. In the United States, 29 states and the District of Columbia have renewable portfolio standards.[138] Several legislative efforts have proposed a national renewable energy standard (RES), or a national clean energy standard (CES), with the latter incorporating a broader array of eligible technologies. President Barack Obama called for a national CES in his 2011 State of the Union address, and in March of 2012, Senator Bingaman (D-ND) introduced the Clean Energy Standard Act of 2012 which included any facility "that captures carbon dioxide and prevents the release of the carbon dioxide into the atmosphere."[139]

As noted in section 3 of this paper, a few states include clean coal and/or CCS in their portfolio standards and Illinois' Clean Coal Portfolio Standard Law specifically addressed facilities that capture and store CO_2. However, a recent report by the Illinois Commerce Commission has concluded that meeting the law's mandate of 25 percent of all electricity sold from clean coal facilities would be "prohibitively expensive" requiring $34.3 billion in federal aid and raise electricity rates for consumers by 46 percent."[140]

The Illinois experience illustrates that if the technology is not ready and/or if other sufficient and complementary policy incentives are not in place, portfolio standards alone may not be able to force the technology into the market. It is notable that the Illinois Commerce Commission also indicated that since Illinois law limits the retail rate impact to 2.015 percent, it is unlikely that a sufficient number of projects would get built to meet the clean coal mandate.[141] Another central drawback of portfolio standards, as Brookings learned in past research on the RPS in the United States is that "mandates become a government approved appropriate number and stifle the market's ability to find something better."[142] Nevertheless, the RPS policy mechanism is credited with helping to create a market for renewable technologies while limiting cost impacts.[143] One concept suggested in our interviews was not just to consider adding CCS or some other definition of clean coal to a portfolio standard, but to require "clean dispatchable" resources. With this approach, various hybrid combinations of technologies could emerge to produce "more bang for the buck" in carbon reductions.[144]

Command and control regulations: Performance standards

A performance standard is commonly viewed as a regulatory tool in which the government sets pollution limits at the plant or unit level (although

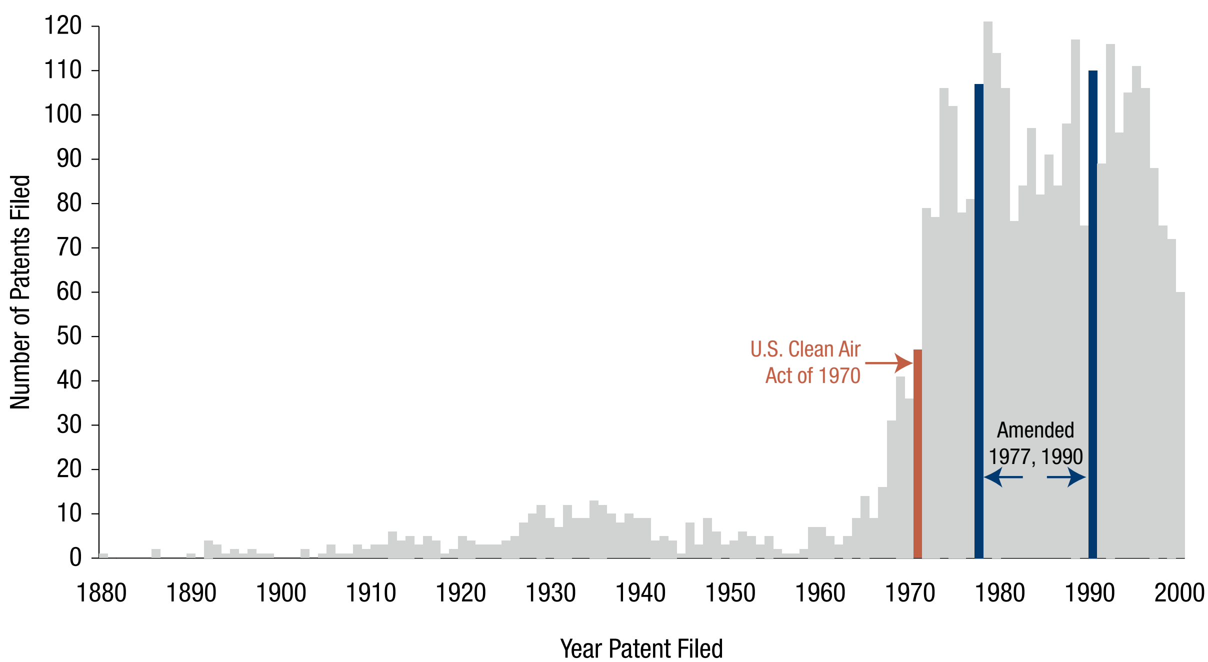
[138] "Renewable Portfolio Standard Policies," U.S. Department of Energy, Energy Efficiency & Renewable Energy, June 2015, http://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2014/11/Renewable-Portfolio-Standards.pdf.
[139] *Clean Energy Standard Act of 2012*, 112th Congress, 2nd session, S. 2146, Washington, D.C., 2012, http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=7ece72ff-6140-4b6e-b245-f382dcba65be.
[140] Jeffrey Tomlich, "Meeting Ill. 'clean coal' standard 'prohibitively expensive,' report says," EnergyWire, 17 June 2015.
[141] Ibid.
[142] John P. Banks, et al., "Assessing the Role of Distributed Power Systems in the U.S. Power Sector."
[143] A recent analysis concluded that state RPS did not have large impact on retail electricity rates: from 2010-2012 RPS compliance costs were the equivalent of 0.9 percent of retail rates. See J. Heeter, G. Barbose, L. Bird, S. Weaver, F. Flores-Espino, K. Kuskova-Burns, and R. Wiser, "A Survey of State-Level Cost and Benefit Estimates of Renewable Portfolio Standards," National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, May 2014.
[144] For mention of this concept see also: Mackler, "Financing CCUS: How targeted policies can drive the industry."

conceptually it could also apply to larger aggregations of plants, including utility portfolio standards). In the United States, federal performance standards for new power plants began in 1971 as part of the Clean Air Act (CAA), applied at the unit level in pounds of pollutant per MWh of net electricity output.

Performance standards can be very effective in spurring the deployment of a technology while driving down costs over time. The experience with SO_2 scrubbers and NOx systems suggests that Clean Air Act standards played a significant role in improving the performance of these technologies and reducing costs.[145] The impact of the CAA is also illustrated by the number of SO_2 technology patents in the aftermath of the law's implementation and subsequent amendments (see **Exhibit 6**). Thus, performance standards are a familiar tool and have been shown to work for environmental control technologies in the power sector. Applying the experience curves associated with high-efficiency (80 to 90 percent) SO_2 and NOx capture technologies, research conducted at Carnegie Mellon University projects that the cost of electricity would decrease 3 to 5 percent for each doubling of CCS plant capacity.[146]

Nevertheless, there are also drawbacks to using performance standards. Most importantly, they can spur higher costs than a more market-based solution—given limits on compliance flexibility, while providing no incentive to improve emissions reductions beyond set targets. There are also challenges in terms of timing, i.e., imposing requirements on utilities or industry before the technology and infrastructure are ready. If the technology remains expensive—has not moved far enough along the innovation spectrum—then standards may incentivize deployment of cheaper,

EXHIBIT 6: U.S. patents in sulfur-dioxide control technology, 1880-2000



Source: E.S. Rubin, Plenary Presentation to the 13th Annual CCUS Conference, Pittsburgh, P.A., 1 May 2014.

[145] See Edward S. Rubin et al., "Cost and performance of fossil fuel power plants with CO2 capture and storage", Energy Policy, Volume 35, Issue 9, September 2007, pp 4444-4454, http://www.sciencedirect.com/science/article/pii/S0301421507000948.

[146] Rubin et al., "Use of Experience Curves."

non-CCS options, or if one capture technology is closer to commercialization standards can lock-in that particular technology.[147]

There are some who also argue that a mandatory performance standard is not required since current tax credits in effect set a standard: In order to receive the tax credit, projects must meet defined capture and sequestration targets. The difference is that the tax credits are voluntary mechanisms and thus far have not driven large-scale deployment.

The analogy of post-combustion SO_2 and NOx technology deployment with CCS is also not perfect. Carbon capture and storage is a more costly and complex technology, processing far more material than either SO_2 scrubbers or catalytic reactors for NOx control. Thus, the latter equipment had a narrower bandwidth of risks to address than CCS, especially with regard to costs and the disposal of captured pollutants.

Performance standards for new coal-fired power plants were proposed under the Waxman-Markey bill in 2009, calling for a 65 percent reduction in CO_2 emissions for each unit in operation after 2020 and a 50 percent reduction for units in operation before that.[148]

Most recently, the EPA has finalized performance standards for both existing and new fossil-fuel power plants (see **Text Box 4**).[149] The EPA's proposal for new plants under Section 111b of the Clean Air Act assumes CCS is "adequately demonstrated" but this contention is questioned. The Coal Utilization Research Council, representing a cross section of coal industry organizations, stated that "the record of CCS projects to date does not

TEXT BOX 4: EPA carbon regulations
Clean Air Act, Sections 111b and 111d

111b

- Output-based performance standard for NEW plants based on gross (not net) electrical generation
- Limit of no more than 1,400 lbs of CO_2/MWh
- EPA bases standard on a supercritical PC technology and partial capture–16 percent if burning bituminous coal, and 23%if burning sub-bituminous or dried lignite
- Gas-fired units restricted to 1,000 lbs/MWh for baseload, and 120lbs/MMBtu for non-baseload units

111d

- Calls for 32percent reduction of CO2 from 2005 levels by 2030 from EXISTING plants
- Targets met on state-by-state basis,with rate of emissions, mass-based of emissions approaches
- There are three "building blocks" to achieving reductions–none include CCS
    - Improve average efficiency of coal-fired plants (EPA assumes average heat rates can improve 6 percent by 2020)
    - Increase generation from NGCC plants
    - Reducing fossil fuel-fired generation through increased zero carbon generation

[147] Dominique Finon, "Efficiency of policy choices for the deployment of large scale low carbon technologies: the case of Carbon Capture and Sequestration (CCS)," Larsen, Working Paper No. 27, January 2010.

[148] *See: American Clean Energy & Security Act of 2009*, 111th Congress, 1st session, H.R. 2998, section 116, Washington, D.C., https://www.congress.gov/111/bills/hr2998/BILLS-111hr2998ih.pdf. The bill states that the standard becomes effective on January 1 2025 or when other metrics are met: at least 4 GW of CCS capacity is in place (of which 3 GW is in electricity), at least 2 units of 250 MW or greater are capturing or storing CO2 in non-EOR sites, and at least 12 metric tons of CO2 are being captured and stored per year.

[149] "What EPA is Doing," Clean Power Plan, U.S. Environmental Protection Agency, 17 July 2015, http://www2.epa.gov/cleanpowerplan/what-epa-doing.

support EPA's claim that this technology is ready for commercial deployment."[150] Some also argue that the proposed standard will actually dis-incentivize deployment of CCS: "Without new coal plants, it is unlikely technology developers will continue to invest in CCS development. Since the proposed regulation provides a significantly lower cost alternative (NGCC without controls) to the application of CCS to coal, there is unlikely to be a market for at least 10 years, and most R&D cannot be sustained for that period."[151]

The final standards for existing plants under 111d are subject to an array of criticisms revolving around their legality, impact on reliability, and cost to consumers, although there are also a number of analyses suggesting that these issues are overblown.[152] Moreover, despite the fact that CCS is not included in EPA's "building blocks," there is some preliminary modeling being done indicating that there is a potentially large number of coal-fired units in the south and southwest where it is cost effective to deploy CCS in response to 111d. Specifically, about 60 GW of coal-fired plants with certain characteristics may be suitable for CCS retrofits.[153]

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[150] "Comments of Coal Utilization Research Council on EPA's Proposed Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units," Docket ID No. EPA-HQ-OAR-2013-0495, 9 May 2014.

[151] Testimony of Robert Hilton, Hearing on Science of Capture and Storage: Understanding EPA's Carbon Rules, Subcommittee on Environment and Subcommittee on Energy, Committee on Science, Space, and Technology, U.S. House of Representatives, 12 March 2014, http://docs.house.gov/meetings/SY/SY18/20140312/101893/HMTG-113-SY18-Wstate-HiltonR-20140312.pdf. An analysis from the Congressional Research Services makes the same argument, see J.E. McCarthy, "EPA Standards for Greenhouse Gas Emissions Power Plants: Many Questions, Some Answers," Congressional Research Service, 2013.

[152] See, for example: Jurgen Weiss, Bruce Tsuchida, Michael Hagerty, Will Gorman, "EPA's Clean Power Plan and Reliability: Assessing NERC's Initial Reliability Review," The Brattle Group, February 2015; Paul Hibbard, Andrea Okie, Susan Tierney, "EPA's Clean Power Plan: States' Tools for Reducing Costs and Increasing Benefits to Consumers," Analysis Group, July 2014; and "Markets Drive Innovation: Why History Shows that the Clean Power Plan Will Stimulate a Robust Industry Response," Advanced Energy Economy, July 2015.

[153] These characteristics are: plants between 20 and 40 years old, a net thermal efficiency of more than 30 percent, more than 6,000 operating hours, and already equipped with FGD and SCR systems. See Haibo Zhai, Yang Ou, and Edward S. Rubin, "Opportunities for decarbonizing existing coal-fired power plants via CO_2 capture, utilization and storage," Environmental Science & Technology, 29 May 2015.

6. Conclusions and Recommendations

Conclusions

CCS can meet environmental, economic, and national security objectives. First, it is a carbon disposal approach that can be deployed on new or existing facilities in the power and industrial sectors to meet an environmental goal of reducing or eliminating CO_2 emissions. Addressing climate change will require a transformation in the way we produce and use energy based on a portfolio of different technologies, and investing in CCS offers insurance that this technology is a viable and available tool in this portfolio. Investing in the commercialization of CCS now offers a hedging strategy: Without knowing what the market and competitiveness of different fuels will look like decades in the future, portfolio diversity ensures that we don't have to rely on a limited set of technologies. Moreover, the fact is that in the United States and other developed economies fossil fuels will continue to play a significant role for a number of decades, and in emerging markets, different drivers are spurring expanded use of fossil fuels. These realities support the idea of developing CCS at least as a viable tool for future use. Second, supporting innovation and commercialization of CCS technologies provides various economic benefits. Moving to a low carbon economy will take time given entrenched existing infrastructure and the extent of fossil fuel use and investment. CCS offers a pathway to transition fossil-fuel assets to a low carbon economy and to responsibly use the large existing resource base in coal and natural gas. Positioning the United States at the forefront of CCS technology development also potentially opens export markets for U.S. companies. This is particularly relevant since most of the growth in coal use in the coming decades will be in emerging market countries with large projected increases in coal-fired electricity generation. Perhaps most importantly from an economic perspective, the majority of analyses indicate that, in the long run, with CCS as part of the technology portfolio overall costs of transitioning to a low carbon economy will be lower. Third, CCS can meet national security goals by providing a way to take advantage of abundant domestic fossil fuel resources, including increased oil production by using captured CO_2 for EOR, while simultaneously reconciling this with the goal of reducing GHGs.

> The conclusion of all reputable modeling exercises is that we need a portfolio of technologies to address climate change—and that without CCS in that portfolio, the mitigation costs are much higher

Current policy does not adequately address CCS technology status and risks. The U.S. government has supported CCS since 1997 and in the last decade the Department of Energy has implemented a robust, world-leading program with policy support focused on carbon capture technologies, and storage. Specifically, CCS policy mainly comprises early stage financial support for R&D and demonstration projects to help nurture various technologies, and financial incentives implemented through the tax code to facilitate deployment in the market. Despite this support, integrated CCS projects in the power sector are proceeding slowly along the innovation and commercialization pathway.

In our research, it was widely acknowledged that commercializing CCS is not a technology challenge: technologies at the capture, transportation, storage stages work. Rather, what is needed are policies that spur development of *integrated* projects at scale. Specifically, disadvantages of the current policy approach are:

- Insufficient support for large-scale demonstrations
- Inadequate financial incentives
- Lack of policies that establish sizeable markets for CCS technology

Together these gaps and weaknesses in the CCS policy framework present major barriers for commercialization of the technology.

A portfolio of "next generation" polices is required. The range of risks along the innovation spectrum involved in commercializing CCS means that a portfolio of multiple policies is required encompassing front-end "technology push" to back-end "technology pull" approaches. In other words, diverse policies are required to meet diverse risks. It is generally accepted that "in the presence of multiple externalities, the use of multiple policy instruments is likely to be justified," although care must be taken in the design of such an approach since combining various policy instruments can increase costs.[154] This approach will require government action or intervention not only to improve existing policy tools but also to implement new mechanisms.

> "The main barrier to CCS is not technology, but policy"
>
> —U.S. government official

Supporting front-end, technology launch (R&D and demonstration) has long been accepted as an appropriate government role in technology innovation, for example spurring research and development of next generation capture technologies. However, there is an immediate need to establish more robust back-end policies comprising some combination of financial incentives (voluntary tools), regulatory command and control mechanisms, and market based approaches. In particular, since CCS is a technology that reduces or eliminates CO_2 emissions, some policy approach that requires emissions reductions or directly establishes a carbon price signal is required to create a market for CCS technology. A policy portfolio that addresses the current lack of climate (regulatory) policy will be required to pull the deployment of large-scale integrated CCS projects beyond their current demonstration phase and into the early commercialization stages.

In addition, a new policy portfolio for CCS will need to reflect evolving political realities, addressing concerns over the extent of the government's role in the market, whether policies are voluntary or mandatory, and in particular the impact on the federal budget and taxpayers. Policies requiring more direct government action and expense will require clear "off-ramps" for decreasing or phasing out support as the technology becomes more commercialized and/or costs come down. Policy approaches that reduce government/taxpayer exposure/liability, for example "revenue neutrality"

[154] Samuel Frankhauser, Cameron Hepburn, and Jisung Park, "Combining multiple climate policy instruments: How not to do it," *Climate Change Economics*, Volume 1, Issue 3, December 2010, p. 1-17.

provisions or ways to ensure that government funds are provided in a "competitive" process are required. Perhaps most importantly, the policy portfolio will need to be able to stand the test of time. A multi-policy approach to address diverse challenges must be in place for many years to succeed: this means spanning political cycles and leadership changes.

This policy approach requires government financial support. Although advocating more government spending certainly poses a political challenge, increasing financial support for R&D and demonstration is appropriate since it addresses one of the key challenges of CCS commercialization: R&D and demonstration projects are needed to continue to lower costs of existing technologies, as well as to find and demonstrate new and cheaper technologies. Although the exact level of funding, the number of projects, or the GWs of demonstration plants operating are arguably viable metrics to frame the discussion and help forge a reasonable commercialization pathway, it is equally important to implement efficient and politically feasible mechanisms to fund these projects.[155] In addition, it is not just a question of providing adequate financial assistance: The experience of the European Union demonstrates that simply allocating and spending money for CCS does not actually further the technology.[156]

Off-ramps for technologies in R&D pipeline should be considered. There is increasing support for modifying existing front end policy to streamline the R&D technology pipeline, i.e. instituting a process for deciding if and when to drop R&D for certain technologies if they do not show promise in performance or cost reduction. This concept is supported in the recent report issued by the National Coal Council as a way to speed up CCS deployment and better focus limited resources. However, it is typically difficult to drop programs once established, and this approach requires that an agreed process—and likely a supporting institutional structure—be established to govern how decisions would be made to drop certain technologies.

EOR is a transitional stepping stone for CCS commercialization. The ability to sell CO_2 for EOR will certainly help reduce the cost of CCS, but it lowers the cost for a technology that still has no market in the electric power sector. The major promise and potential of CCS is deployment for mitigating climate change (see **Text Box 5**). This in turn means widespread deployment on power plants and long-term geologic storage of billions of tons of CO_2 per year, well beyond the demands of the EOR market (especially in the current situation of relatively low oil prices). As one CCS expert noted: "we should not lose focus on what we are really trying to accomplish" and treat CO_2-EOR as a transition step in CCS commercialization.[157]

In short, any serious consideration of developing CCS as a low carbon technology requires a "next generation" policy framework that recognizes the range of risks and policy mechanisms needed to address them, as well as a somber assessment of the political challenges. This is a complex public policy issue: A CCS policy approach needs to accomplish multiple strategic national objectives, address existing risks in a timely and comprehensive manner, be cost effective and tailored to commercialization stages, and not be bound to short-term political and legislative cycles.

[155] Cost estimates and other metrics are subject to an array of debatable assumptions, and there are many credible estimates produced by highly qualified individuals and institutions working on this issue for many years, some of whom are mentioned here. Rather than assess these estimates or develop our own, we focus on policy tools to organize and fund CCS R&D and demonstration.
[156] Bassi et al., Bridging the gap: improving the economic and policy framework for carbon capture and storage in the European Union.
[157] Quote from private conversation with CCS expert.

TEXT BOX 5: Does using captured CO_2 for EOR defeat the goal of reducing GHGs?

A common criticism of using captured carbon for EOR to support CCS is that this increases the life-cycle of carbon emissions, and thus defeats the whole purpose of capturing carbon in the first place. Even the IEA, which supports CCS, states that "a CCS project involving CO_2-EOR will deliver a smaller net emissions reduction than a comparable project storing CO_2 in a saline aquifer…at present the extent to which CO_2-EOR can contribute to emission reduction goals is unclear."* However, in the course of our discussions there was a strong view that the benefits of CO_2-EOR outweighed these concerns.

First, there is no question that CO_2-EOR creates a revenue stream to improve CCS project economics, and thus can be a transitional policy to help deploy CCS faster than otherwise through learning by doing. Second, in terms of life cycle emissions, it is preferable to extract oil from areas already in production. As one expert noted: "If we have a responsible policy and take advantage of the co–benefits of CO_2-EOR and at the same time avoid expansion of oil and gas activities to new areas, this is tradeoff worth taking." Third, another viewpoint held that if captured CO_2 for EOR is only a stepping stone, then we don't need to worry about the long-term carbon balance. Moreover, with captured CO2-EOR at least some of the CO_2 gets stored, which would be better than if the oil were produced without it. Finally, CO_2-EOR may be a source of political leverage, offering a trade-off between the economic benefits accruing to the oil industry and progress on carbon policy.

* IEA, Technology Roadmap Carbon capture and storage, p. 20.

Recommendations

If the U.S. government wants to develop CCS as part of the low carbon portfolio, a concerted policy effort is required. Moreover, it is clear from our discussions and the status of CCS technology development that no single policy approach will work in isolation. R&D alone is not the answer, and financial incentives used thus far, while helpful in addressing up-front capital costs, suffer from some specific structural design weaknesses and do not address the development of a market for CCS technology.

> "Cost of technology depends on how much is deployed, and all analyses come up with the same answer–the sooner you start deployment, the lower the cost in the long run."
>
> —CCS expert

These considerations raise the important question as to whether CCS policy should be implemented through CCS-targeted legislation, or as part of an overall energy policy approach, or perhaps some combination. As we have heard repeatedly in past research and again in this current effort, many stakeholders, including those in industry, prefer an overarching energy-climate policy approach providing clarity and certainty for business planning and operations. However, reaching a baseline consensus on what this policy should look like has been impossible to achieve. Earlier attempts to develop legislation with the market-based mechanism of cap and trade failed, and in lieu of this the Obama administration has proposed a regulatory approach through the EPA.

By way of comparison, increased renewable energy deployment has not occurred through comprehensive national climate policy: It's been driven largely by using the tax code at the federal level and portfolio standards at the state level. We have forced market creation for renewable technology and subsidized the cost. This approach has certainly been successful in furthering the decarbonization of the power sector and spurring major decreases in wind and solar technology costs, but has not been without its costs and inefficiencies. We should be cautious of replicating this experience with CCS. However, CCS is a low carbon technology option, and if we want all options available to us to meet the climate change challenge, it is only prudent to develop an effective and politically feasible policy portfolio to support it.

Below we highlight specific mechanisms that we believe should form the basis of a reignited, substantive dialogue on what is required to support commercialization of CCS. These policy tools are geared toward what best addresses existing risks and are politically feasible. Where possible, in an effort to foster timely implementation, we propose steps that re-tool existing policy approaches or use familiar concepts, i.e. that have been implemented in the past or for other energy technologies.

It is beyond the scope of this brief to conduct an in-depth assessment of the pros and cons of how these policy tools would work together, and in particular a quantitative cost-benefit analysis. Rather, based on our review of the status of the technology, risks confronting deployment of CCS, and the existing policy framework, it is our intention to highlight certain approaches and concepts that could comprise a more comprehensive policy portfolio.

Addressing technology risk

To move CCS commercialization forward, it is important to consider some off-budget funding mechanism that generates sufficient financial resources in support of large-scale demonstration projects, while limiting or reducing the impact on the federal budget.

1. ***Dedicated CCS trust fund supported by a wires or public good surcharge.*** Either of these approaches should be considered, and a detailed substantive policy discussion should be undertaken examining the pros and cons of each. Other key questions to examine are: How is an assessment applied (fossil fuel electricity generation on a per kWh basis, or fossil fuel exports, or offshore oil and gas exploration)? How is it utilized (addressing specific risks)? What governance structure is put in place (revenue generated could be deposited in a separate CCS-dedicated fund, overseen by an existing entity, or a new entity created specifically to implement and monitor CCS commercial deployment? Given the multiple policies required, and the need to continually monitor commercialization progress, costs, and the timing of policy phase out, it makes sense to establish a process and structure (a new entity, board, or organization) for program oversight and management that is targeted specifically to CCS. The CCS fund could support R&D, large-scale demonstrations, financial incentives, and a price stabilization mechanism.

Addressing financial risk

There is little disagreement that high capital and operating costs present barriers for CCS projects. The following steps to revise *existing* policy could improve access to financing and address operating costs.

2. ***Modifications to loan guarantee program.*** To improve access to government loan guarantees, several revisions should be considered: eliminate the requirement for an appropriation to pay the credit subsidy cost, allow entities that have received other financial support also to be eligible for a loan guarantee, and consider sourcing loan guarantee monies from a separate fund, not the U.S. Treasury.
3. ***Modifications to tax credits***. The Obama administration's proposal to make investment tax credits refundable should be

adopted to increase available support and reduce the cost of accessing the credits. The president also proposed a sequestration tax credit, which includes $10/tonne for CO_2 stored as a result of EOR. Consideration should be given to increasing this to more closely approximate the per MWh value assigned to other forms of low carbon energy.[158] The proposals contained in Senate legislation (Expanding Carbon Capture through Enhanced Oil Recovery Act of 2014 S. 2288 and Advanced Clean Coal Technology Investment in Our Nation Act of 2014 S. 2152) to modify 45Q tax credits for CO_2-EOR, largely reflective of the detailed recommendations of NEORI, should be implemented. These changes make needed improvements in the structural design of the tax credit in line with our call for next generation policy: For example, the tax credits are allocated on a competitive basis and increase or decrease based on oil prices. Also, more of the tax credit is earmarked specifically for power sector projects.

While improving the design and implementation of existing policy tools is appropriate, the magnitude of the financing challenges require consideration of *new* approaches.

4. ***CCS projects eligible for master limited partnerships.*** MLPs are a well understood, existing mechanism that have been successfully employed for decades that would broaden access to financing for CCS projects. In addition, legislation can be designed that limits the impact on the federal budget, as indicated by the JCT scoring of Master Limited Partnership Parity Act of 2013 (S. 795) in 2013.

5. ***CCS projects eligible for private activity bonds.*** PABs are also a familiar tool that would increase the ability of developers and utilities to raise capital at little cost to taxpayers since CCS eligibility would be added to other options available under a cap on PAB funding.

6. ***Financial support for front end engineering and design work***. Providing funding for early stage project due diligence will reduce the financial burden on project developers and facilitate borrowing from commercial lenders. This approach has been used effectively in the United Kingdom for its two CCS projects.

Addressing climate policy uncertainty: Creating markets for CCS technology

7. ***A federal carbon policy***. Discussions in our research revealed a widespread view that a price on carbon is needed in order to commercialize CCS. In the view of many, the only way to use coal (and eventually natural gas) is with CCS; to deploy CCS requires a market for the technology; and the best way to develop a market is to establish a sufficiently high CO_2 price. In short, what is missing right now is a market for CCS technology. Although this step no doubt is highly politically challenging, there may be ways to implement a carbon tax or fee that meets our political feasibility criteria. Some prominent Republicans for example have called for a revenue-neutral carbon tax, with revenues from the tax offset by tax reductions in other areas. Other proposals have earmarked carbon tax revenues for

[158] For example, assuming that CO2 emissions from a coal-fired power plant are around 1 tonne per mWh, the sequestration tax credit for CO_2-EOR of $10/tonne is equivalent to about $10/mWh. The current wind PTC is equivalent to $23/mWh.

deficit reduction. Adele Morris, a Brookings Institution scholar, proposed that one option under EPA's CPP would be to allow a state to implement a carbon tax as a compliance approach.[159] More importantly, the majority of economists agree that a carbon tax is the most effective and efficient way to price carbon.[160]

One approach in particular warrants serious consideration and is reflected in some recent legislative proposals: using the revenues from a carbon tax or fee to be allocated into a fund that could finance a variety of technologies, including CCS. A price on carbon with some fraction of proceeds going to subsidize CCS does have the advantage of creating a potentially large pool of resources. It also yields two benefits: the impact from a price on carbon, and income to subsidize CCS technology. The subsidy coming from some sort of cap or price on carbon provides more leverage than an approach that uses a similar amount of dollars in absence of carbon constraint.

> ***"Without a tax or a sufficiently restrictive limit on CO_2 emissions, plant operators lack an economic incentive to use CCS technologies."***
>
> —GAO, 2010

Since a market price for carbon is politically difficult to implement at the levels needed in the near-term to spur CCS, performance standards can help establish a market for CCS technology. Performance standards in some ways are more straightforward than market based mechanisms—entities know what emissions levels have to be achieved, whereas either emission levels or CO_2 price vary depending on whether a carbon tax or cap and trade is used, respectively. Moreover, industry is familiar with performance standards and they have worked in the past in controlling conventional air pollutants like SO_2, NOx, and particulates. EPA's final rules under 111b and 111d of the CAA will no doubt be challenged and a detailed review of whether these rules will promote CCS on coal and gas fired generation is beyond the scope of this policy brief. To be sure, the "devil is in the details" regarding the effect of specific emissions standards on CCS deployment, both on coal- and gas-fired generation. As one analysis has indicated, "the incentive to invest in coal-CCS from emissions standards depends on the natural gas price, the CO_2 price, and the EOR recovery prices, as well as on the level of the emission standard."[161] For this reason, our policy portfolio recommendations address all of these components.

Despite their drawbacks, performance standards can be especially effective in combination with a market-based price signal, where there is significant complementarity. Performance standards would help offset the inability to set a high enough CO_2 price, and a market based approach would provide an incentive to improve beyond the targets set by a performance standard.[162] Moreover, as stated by one private sector investor, "we need a bridge between now and 2030 to rely on because we won't know what the impacts of the Clean Power Plan will be," and this means "an economy wide push to value carbon reductions."

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[159] See Adele Morris, "An EPA-Sanctioned State-Based Carbon Tax Could Reduce Emissions and Improve State Finances," The Brookings Institution, 1 April 2014, http://www.brookings.edu/blogs/up-front/posts/2014/04/01-epa-carbon-tax-can-help-environment-state-finances-morris.

[160] See Adele Morris, "Want a Pro-Growth Pro-Environment Plan? Economists Agree: Tax Carbon," The Brookings Institution, 7 February 2013, http://www.brookings.edu/blogs/up-front/posts/2013/02/07-carbon-tax-morris; Adele Morris and Aparna Mathur, "A Carbon Tax in Broader U.S. Fiscal Reform," The Brookings Institution, 22 May 2014, http://www.brookings.edu/research/papers/2014/05/22-carbon-tax-in-broader-us-fiscal-reform-morris.

[161] Jan Eide, Fernando J. de Sisternes, Howard J. Herzog, and Mort D. Webster, "CO_2 emission standards and investment in carbon capture," *Energy Economics*, Volume 45, September 2014, pp 53-65, http://www.sciencedirect.com/science/article/pii/S0140988314001388.

[162] Edward S. Rubin, "A Performance Standards Approach to Reducing CO_2 Emissions from Electric Power Plants," White Paper Series, Pew Center on Global Climate Change, Arlington, V.A., May 2009, http://www.c2es.org/docUploads/Coal-Initiative-Series-Rubin.pdf.

It is interesting that the CPP's final rule encourages the trading of carbon credits among states, effectively promoting a regional cap and trade approach, which of course would effectively set a carbon price.[163] This is commensurate with a number of analyses conducted by ISOs that concluded that a regional approach to compliance would be cheaper than states meeting the requirements alone. In this way the CPP performance standards would be providing state utility regulators the broader policy impetus to allow CCS cost recovery.

8. ***An electricity price stabilization framework.*** In markets that are not currently subject to a CO_2 reduction requirement or climate change policy, some form of support is required to bridge the gap between costs of building a CCS project and revenues generated from electricity sold from the project.[164] A mechanism that ensures the purchase of low carbon (CCS-based) power or a stable price of such power would help offset operating costs and address policy uncertainty, although this approach may still need to be complemented with grants and other incentives to deal with high capital costs.

Providing this support at the federal level is likely to be more efficient than seeking cost recovery at the state level and would, similar to the implementation of federal emissions performance standards, help develop a framework for including CCS as part of the electricity supply mix. This mechanism would be similar to the CfD approach in the U.K., with the level of support varying according to a market based benchmark or index. It should be allocated on a competitive basis, with a path for phase out over the life of the project. Legislative proposals such as ACCTION Act of 2015 (S.601) and Coal with Carbon Capture and Sequestration Act of 2015 (S.1285) are representative of this approach.

In sum, CCS can be a viable technology to meet our environmental goals, as well as yielding related economic and national security benefits, but policymakers and the general public should be aware of what is required from a policy standpoint. We hope this policy brief helps re-ignite a thoughtful dialogue on the role of CCS.

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[163] Emily Holden and Elizabeth Harball, "EPA regulation includes 'panoply' of changes to help states trade carbon emissions," *ClimateWire*, 5 August 2015.

[164] We do not propose an additional price support mechanism for CO_2 given that the President's sequestration tax credit and the improvements to 45Q (including our suggestion to increase the amount of the tax credit for CO_2 used in EOR) should address this issue.

Annex A: Defining CCS

This Annex provides a brief overview of the major components of CCS (see **Exhibit A-1**).

CO_2 capture

Carbon capture has taken place since the early 1970s when U.S companies became interested in using CO_2 for EOR.[165] There are three methods for CO_2 capture in electricity generation: post-combustion, pre-combustion, and oxyfuel combustion (See **Exhibit A-2**).

Post-combustion capture

In this process, CO_2 is separated from flue gases after combustion of the feedstock. This separation is the result of a chemical reaction utilizing amine compounds, which bond with the CO_2 to facilitate the capture of 90 percent or more of the carbon dioxide in the flue gas. The solvent is then pumped into a stripper, where the CO_2 is released by using steam.[166] The concentrated CO_2 is then compressed in preparation for transport. Post-combustion capture equipment can be retrofitted to existing pulverized coal- and natural gas-fired power plants, as well as applied to new fossil-fuel facilities.

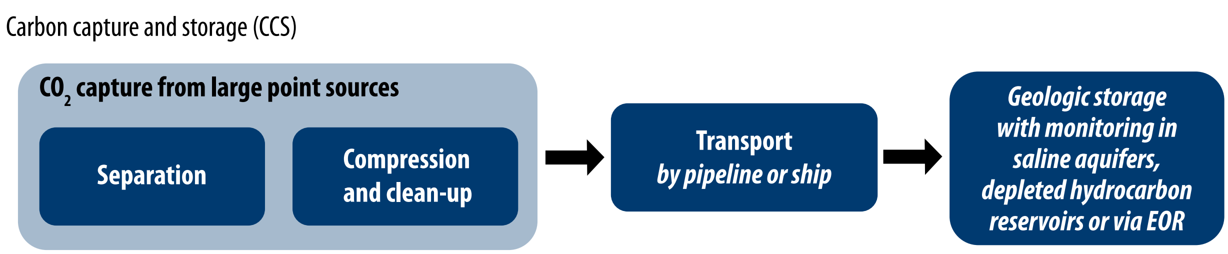
Amines have been used for many years for CO_2 separation in the natural gas processing and refining industries, as well as in power generation. But for power plants these capture systems have been applied mostly to small slipstreams and thus there is limited experience with larger flue gas streams for CO_2 capture at scale. Current research focuses on reducing overall energy loss during the capture and compression process.

Pre-combustion capture

In pre-combustion capture, CO_2 is separated and captured from fuel before it is burned for electricity production. Coal is first gasified with steam and oxygen resulting in a syngas—a mix of carbon monoxide and hydrogen. The syngas goes through a shift reactor, which delivers a mixture of CO_2 and hydrogen. A physical (chemical) solvent is used to separate CO_2 from the syngas, and the hydrogen can be used to generate electricity in a combined cycle power plant. This process has been in use for fertilizer and hydrogen production but not commercially in the power sector.[167]

Pre-combustion technologies also can be applied to natural gas,[168] but not to *existing* fossil fuel

EXHIBIT A-1: CCS chain



Source: "Technology Roadmap: Carbon Capture and Storage," IEA, 2013, p 13.

[165] H.J. Herzog, "Scaling up carbon dioxide capture and storage: From megatons to gigatons," Energy Econ, 2010, doi:10.1016/j.eneco.2010.11.004. In EOR, CO_2 is injected into a mature oilfield and mixes with the residual oil increasing its viscosity allowing the oil to flow to the production well. See "Enhanced Oil Recovery," Energy.gov: Office of Fossil Energy, http://energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery.

[166] Rubin et al., "The Outlook for Improved Carbon Capture Technology," *Progress in Energy and Combustion Science* 38 (2012): p. 633.

[167] IPCC Working Group III, *IPCC Special Report on Carbon Dioxide Capture and Storage*, p. 5.

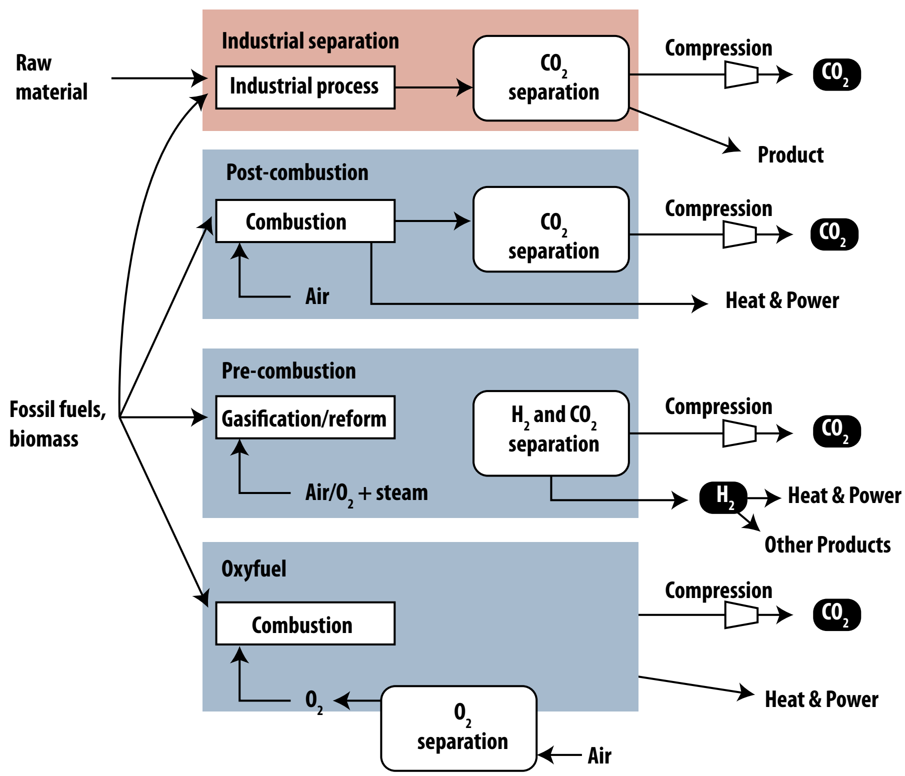
[168] In that case the feedstock is converted to syngas using oxygen and steam ("reforming"). For more details, see Rubin, et al., "The Outlook for Improved Carbon Capture Technology," p. 630-671.

plants. In addition, it is more complex and costly than post-combustion due to the fuel conversion steps involved, however, the CO_2 separation process is easier and less costly owing to a higher pressure and concentration of CO_2 in the syngas. A major challenge with pre-combustion is the amount of energy lost when applied to an integrated gasification combined cycle (IGCC) plant.[169]

Oxy-fuel combustion capture

CO_2 can also be captured via a process known as oxyfuel combustion. During this process, coal is combusted with pure oxygen rather than air, producing mainly CO_2 and water vapor. By not allowing nitrogen to enter into the combustion chamber, oxyfuel combustion allows the CO_2 to become highly concentrated and easier to separate and compress. This process also allows for the use of smaller equipment, because the volume of gas being treated is lower. There is still an energy efficiency loss associated with oxyfuel combustion, as well as an added cost of using pure oxygen and the potential for corrosion.[170] This capture technology has been tested and proven in various sectors, but it has yet to be deployed commercially in power plants.[171]

Exhibit A-2: Carbon capture in electricity generation and industry



Source: CO2CRC, from IPCC Working Group III [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)], IPCC *Special Report on Carbon Dioxide Capture and Storage*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2005, https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf.

[169] Global CCS Institute, *CO_2 Capture Technology: Pre Combustion Capture* (Global CCS Institute, 2012), http://hub.globalccsinstitute.com/sites/default/files/publications/29756/co2-capture-technologies-pre-combustion-capture.pdf.

[170] Leung, et al. "An Overview of Current Status of Carbon Dioxide Capture and Storage Technologies," Renewable and Sustainable Energy Reviews 39 (2014), p. 426-443, http://ac.els-cdn.com/S1364032114005450/1-s2.0-S1364032114005450-main.pdf?_tid=beb75c92-5180-11e5-a7ec-00000aacb362&acdnat=1441205090_175be89f8bf2046792059299932d26a7.

[171] Global CCS Institute, *CO_2 Capture Technology: Oxy Combustion with CO_2 Capture.*

Transportation

Once CO_2 is captured and compressed it is transported for long-term storage or other uses. Pipeline transportation is the most widely used and established technology: In the U.S., there are 50 dedicated CO_2 pipelines totaling 4,500 miles, used mainly for EOR.[172] This pipeline network, largely built in the 1980s and 1990s, transported 68 million tons of CO_2 in 2014.[173] However, a pipeline infrastructure for dedicated, large-scale transport of CO_2 to geologic reservoirs for long-term storage is not in place.

CO_2 storage and utilization

Two types of geologic formations are of greatest interest for carbon storage: depleted oil and gas fields, and deep saline aquifers.[174] The IPCC observes it is "likely" that approximately 99 percent of CO_2 that has been stored in appropriately selected and managed reservoirs will remain contained for 1000 years or more.[175]

Oil and gas fields have naturally trapped hydrocarbons for millennia, and the IPCC has estimated that there is about 675 to 900 Gt of storage capacity available in oil and gas reservoirs (excluding "undiscovered") worldwide.[176] As noted, the oil and gas industry has injected carbon dioxide into depleted oil fields for EOR for a number of decades. One expert we interviewed indicated that on the order of 90 percent of all CO_2 stays permanently underground over the course of multiple injections in a CO_2-EOR project. As such, the oil and gas industry has built substantial knowledge about the effects of long-term CO_2 storage underground, and there are well developed tools for monitoring well integrity, groundwater and surface leak detection, and in some circumstances for the modeling/imaging of underground CO_2 migration.[177]

Additionally, in a few cases, the oil industry has injected CO_2 in geological reservoirs for long-term sequestration as a GHG mitigation option.[178] For example, since 1996 Statoil has been injecting CO_2 from a natural gas processing plant into a reservoir offshore in the North Sea: Since it started operating, the Sleipner project has captured and stored nearly 1 million tonnes of CO_2 annually.[179]

Deep saline aquifers are naturally occurring formations of permeable reservoir rock inundated with salt water. These geological formations have a layer of shale or clay rock which acts as a natural impermeable cap that can trap injected CO_2. Storage typically takes place at depths deeper than 800 meters.[180] Eventually, injected CO_2 will dissolve into the salt water and the heavier mixture migrates to the bottom of the aquifer. Other mechanisms also work to permanently sequester the carbon such as mineralization, where it binds

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[172] *Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure*, Department of Energy, Washington, D.C., April 2015, p. 7-24, http://energy.gov/sites/prod/files/2015/07/f24/QER%20Full%20Report_TS%26D%20April%202015_0.pdf. This is mostly naturally sourced CO_2 and the pipeline network is concentrated in the Permian Basin in W. Texas, New Mexico and southern Colorado. See JJ Dooley, RT Dahowski, and CL Davidson, "Comparing Existing Pipeline Networks with the Potential Scale of Future U.S. CO_2 Pipeline Networks," Pacific Northwest National Laboratory, February 2008, available here: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-17381.pdf.

[173] Ibid.

[174] "Carbon Capture & Storage Technologies," World Coal Association, http://www.worldcoal.org/coal-the-environment/carbon-capture-use--storage/ccs-technologies/ccs-technologies-more/.

[175] IPCC Working Group III, *IPCC Special Report on Carbon Dioxide Capture and Storage*, p. 34.

[176] Ibid. See also "Carbon Capture & Storage Technologies," World Coal Association.

[177] IPCC Working Group III, *IPCC Special Report on Carbon Dioxide Capture and Storage*, p. 33.

[178] Ibid., p. 199.

[179] "Sleipner West," Statoil, 17 December 2013, http://www.statoil.com/en/TechnologyInnovation/NewEnergy/Co2CaptureStorage/Pages/SleipnerVest.aspx.

[180] "Carbon Capture & Storage Technologies," World Coal Association.

chemically with the surrounding rock. Due to the abundance of saline aquifers, this storage method has the greatest potential globally. More experience with large volume injection of CO_2 in saline aquifers will help to confirm that permanent CO_2 sequestration can be done cost effectively, safely and without impact on surface ecosystems.

Annex B: CCS Projects in Operation or Under Construction

According to the Global CCS Institute's (GCCI) project database, eleven large-scale power generation projects with CCS will be in operation by 2020, each capturing at least 800,000 tonnes of CO_2 (see **Table B-1**).[181] Three of these projects are located in the United States (excluding the recently terminated FutureGen 2.0 project). In addition, the GCCI database outlines active CCS projects in industry, in particular natural gas processing and refining.

Below we highlight the three CCS power generation projects in operation and under construction.

Boundary Dam 3: Canada

SaskPower's Boundary Dam 3 facility (BD3) in Saskatchewan, Canada began operating in September 2014 and is the world's first commercial electricity plant with CCS. The coal-fired unit is a post-combustion retrofit of a unit built in 1969 with a base load capacity of 120 MW. BD3 is expected to capture 1 million tonnes of CO_2/year and plans to utilize this for EOR: Rough estimates indicate that total EOR revenues over a 20 year period could be around $400 million to $500 million.[182] The plant also captures fly ash, which is sold for concrete making, and sulfur dioxide, which is sold for conversion into sulfuric acid. Even though the renovation of the power plant went over budget by CAD $115 million and caused some minor delays, the CCS facility itself came in on budget.[183] The total cost to build BD3 was $1.3 billion, of which the Canadian federal government provided $240 million in subsidies.[184]

Since October 2014, BD3 plant operators are seeing in real-time how components work together and are learning that the facility's versatility, durability, and efficiency are better than expected, including amine absorption (not drawing as much electricity), the absorption rate of CO_2 and SO_2, and the purity of the CO_2.[185] Based on this experience, SaskPower officials have stated publicly that the next CCS units can be built 30 percent cheaper.[186] SaskPower is also taking a portion of the plant's captured CO_2 and conducting storage testing in a saline aquifer over 2 miles deep. In addition, the operators are working on various new amine technologies in order to increase the efficiency of the capture component.

It is important to note that both the geography and policy were major factors in bringing the Boundary Dam project on-line. The plant is located in an area with large coal deposits nearby and limited access to natural gas as an alternative feedstock. There are opportunities for enhanced oil recovery and carbon storage in saline aquifers. In addition, the Canadian government instituted an emissions standard of 1,100 lbs/MWh for new and existing coal fired power plants, and provided subsidies. In order to comply with the new regulations,

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[181] For a detailed listing and explanation of all CCS projects refer to the Global CCS Institute project database: "Large-Scale CCS Projects," Global CCS Institute, http://www.globalccsinstitute.com/projects/large-scale-ccs-projects#map. In addition, the MIT CCS project database strictly covers power generation projects, see "Power Plan Carbon Dioxide Capture and Storage Projects," Carbon Capture & Sequestration Technologies at MIT, 5 February 2015, http://sequestration.mit.edu/tools/projects/index_capture.html.

[182] Brian Banks and Mark Bigland-Pritchard, *SaskPower's Carbon Capture Project: What Risk? What Reward?* Canadian Centre for Policy Alternatives, Saskatchewan, January 2015, p. 12, https://www.policyalternatives.ca/sites/default/files/uploads/publications/Saskatchewan%20Office/2015/02/Saskpowers_Carbon_Capture_Project.pdf.

[183] Clare Clancy, "SaskPower to Launch $1.4B Carbon-Capture Project," *Global News*, 29 September 2014, http://globalnews.ca/news/1587771/saskpower-to-launch-1-4b-carbon-capture-project/.

[184] "Boundary Dam Fact Sheet: Carbon Dioxide Capture and Storage Project," Carbon Capture & Sequestration Technologies at MIT, 22 June 2015, https://sequestration.mit.edu/tools/projects/boundary_dam.html.

[185] Gail Reitenbach, "SaskPower's Boundary Dam Carbon Capture Project Wins POWER's Highest Award," POWER Magazine, 1 August 2015, http://www.powermag.com/saskpowers-boundary-dam-carbon-capture-project-wins-powers-highest-award/?printmode=1.

[186] Ben Potter, "SaskPower's Mike Monea on carbon capture and storage," Australian Financial Review, 19 May 2015, http://www.afr.com/business/energy/saskpowers-mike-monea-on-carbon-capture-and-storage-20150519-gh4q8d.

TABLE B-1: CCS power generation projects operational by 2020 (Global CCS Institute)

Project name	Project lifecycle stage	Country	CO_2 capture capacity (Mt/yr)	Operation date	Capture type
Boundary Dam Integrated Carbon Capture & Sequestration Demonstration Project	Operate	Canada	1.0	2014	Post-combustion capture
Kemper County Energy Facility	Execute	United States	3.0	2016	Pre-combustion capture (gasification)
Petra Nova Carbon Capture Project	Execute	United States	1.4	2016	Post-combustion capture
Don Valley Power Project	Define	United Kingdom	1.5	2020	Pre-combustion capture (gasification)
Hydrogen Energy California Project (HECA)	Define	United States	2.7	2019	Pre-combustion capture (gasification)
Rotterdam Opslag en Afvang Demonstratieproject (ROAD)	Define	Netherlands	1.1	2019-2020	Post-combustion capture
Sinopec Shengli Power Plant CCS Project	Define	China	1.0	2018	Post-combustion capture
Texas Clean Energy Project	Define	United States	2.4	2019	Pre-combustion capture (gasification)
White Rose CCS Project	Define	United Kingdom	2.0	2020-2021	Oxy-fuel combustion capture
Peterhead CCS Project	Define	United Kingdom	1.0	2019-2020	Post-combustion capture
Sargas Texas Point Comfort Project	Define	United States	0.8	2017	Post-combustion capture

Source: "Large-Scale CCS Projects," Global CCS Institute, 17 September 2015, http://www.globalccsinstitute.com/projects/large-scale-ccs-projects#map Additionally the projects lifecycle, as defined by the Global CCS Institute, are categorized under various stages. "Operate" projects are defined as being able to operate the asset within regulatory requirements and the asset is currently operational. "Execute" projects have had their final investment decision confirmed and construction has begun. "Define" is described as just prior to undertaking a final investment decision and being able to demonstrate technical and economic viability of the project. For further details on definitions refer to, "Large-Scale CCS Projects—Definitions," Global CCS Institute, http://www.globalccsinstitute.com/projects/large-scale-ccs-projects-definitions.

SaskPower essentially had to decide to either retrofit the old coal plant with CCS or build a new natural gas power plant. These features combined led to the conclusion that CCS was the right technology to implement at Boundary Dam.

Kemper County: United States

Mississippi Power, a subsidiary of the Southern Company, is building a CCS facility in Kemper County, M.S. which will generate 582 MW of electricity and capture 65 percent of CO_2 emissions.[187] The Kemper project will be a pre-combustion IGCC plant that uses an innovative design known as TRIG™ to burn lignite from a mine located adjacent to the plant. The captured CO_2 will be used for EOR, adding 2 million barrels a year of crude oil production to total U.S. output, earning Kemper an extra $80 million a year.[188] Though Kemper is currently slated for commercial operations to begin in the first half of 2016, it has experienced

[187] "Southern Company – Kemper County," Department of Energy: Office of Fossil Energy, http://energy.gov/fe/southern-company-kemper-county.

several delays (originally operations were scheduled to commence in 2014) and cost overruns (with initial estimates of $2.4 billion now surpassing $6.1 billion).[189] At the time of this policy brief, the Kemper County facility was nearly completed, with the electricity plant running on natural gas instead of lignite.

The DOE awarded Southern Company $270 million in financial assistance under the CCPI to facilitate the development of TRIG™ technology.[190] DOE also awarded $133 million in investment tax credits, but due to project delays some of these tax benefits will be foregone since the project was unable to meet its initial deadlines.[191] The setbacks were partially caused by unforeseen circumstances, such as poor weather and contractor and supplier delays. However, other problems began owing to early miscalculations. Thomas Fanning, Southern Company's chief executive officer, stated: "We did not evaluate correctly the amount of pipe, the thickness of the pipe, the metallurgy of the pipe and the quantity of the pipe."[192]

Factors similar to those in the Boundary Dam project facilitated a final investment decision for Kemper: the proximity to coal resources, government support, and a market for the captured carbon in EOR.[193]

Petra Nova: United States

NRG Energy and JX Nippon Oil & Gas Exploration's Petra Nova CCS project in Thompsons, Texas is a greenfield, post-combustion power plant that is currently under construction. The project is estimated to cost around $1 billion upon completion, with DOE contributing $167 million from the CCPI.[194] Petra Nova is expected to generate 240 MW of electricity and have a 90 percent capture rate, which equates to approximately 1.6 million tons of CO_2 annually.[195] In order to compensate for the energy loss that occurs during the compression of CO_2, the Petra Nova project will use a 45 MW natural gas generator. The carbon emissions from the natural gas unit will offset some of the estimated overall emissions reduction.[196]

The Petra Nova project plans to utilize its captured CO_2 for EOR at Hilcrop Energy Company's nearby West Ranch Oil Field. This will boost oil production from 500 barrels per day to an estimated 15,000 barrels per day, and it is estimated that in total nearly 60 million barrels of oil may be recovered.[197] The additional revenue from selling the captured carbon is expected to help make Petra Nova commercially viable. The Petra Nova project is anticipated to be fully operational by the end of 2016.

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188 Steven Mufson, "Intended showcase of clean-coal future hits snags," The Washington Post, 17 May 2014, http://www.washingtonpost.com/business/economy/intended-showcase-of-clean-coal-future-hits-snags/2014/05/16/fc03e326-cfd2-11e3-b812-0c92213941f4_story.html.

189 "Kemper County IGCC Fact Sheet: Carbon Dioxide Capture and Storage Project," Carbon Capture & Sequestration Technologies at MIT, last modified 23 March 2015, http://sequestration.mit.edu/tools/projects/kemper.html and Kristi E. Swartz and Saqib Rahim, "Kemper 'clean coal' project shows the costly perils of being 'first of its kind,'" EnergyWire, 24 August 2015.

190 "Southern Company – Kemper County," Department of Energy.

191 Steven Mufson, "Intended showcase of clean-coal future hits snags."

192 Ibid.

193 "Kemper County IGCC Fact Sheet: Carbon Dioxide Capture and Storage Project," Carbon Capture & Sequestration Technologies at MIT.

194 Department of Energy Office of Fossil Energy, "DOE Signs Cooperative Agreement for Carbon Capture Project," Department of Energy: Office of Fossil Energy, 18 June 2010, http://energy.gov/fe/articles/doe-signs-cooperative-agreement-carbon-capture-project. Additionally, when the project was first proposed it planned to generate 60 MW of power and cost roughly $334 million. The final decision to expand the project came from the high demand for additional CO_2 for EOR. See W.A. "Parish Petra Nova Fact Sheet: Carbon Dioxide Capture and Storage Project," Carbon Capture & Sequestration Technologies at MIT, last modified 7 April 2015, http://sequestration.mit.edu/tools/projects/wa_parish.html.

195 "PETRA NOVA – W.A. Parish Project," Department of Energy: Office of Fossil Energy, http://energy.gov/fe/petra-nova-wa-parish-project.

196 Office of Fossil Energy & National Energy Technology Laboratory, U.S. Department of Energy, DOE/EIS-0473D, W.A. Parish Post-Combustion CO2 Capture and Sequestration Project Draft Environmental Impact Statement Summary, September 2012, http://energy.gov/sites/prod/files/EIS-0473-DEIS-Summary-2012.pdf. The natural gas plant is expected to produce 785,000 tons of carbon/year, bringing the net carbon reduction down from 1.6 million/year tons to 815,000 tons/year.

197 "WA Parish Carbon Capture Project," NRG, 2015, http://www.nrg.com/business/carbon-360/projects/wa-parish-ccs-project/.

Annex C: CCS RD&D Program Areas (U.S. Department of Energy Office of Fossil Energy – Fossil Energy Research and Development)

(Funding in nominal $'000)

PROGRAM	GOALS	ARRA 2009	FY 2012 enacted	FY 2013 enacted	FYI 2014 enacted	FY 2015 enacted	FY2016 requested
CCS & Power Systems							
Carbon Capture	• Develop post-combustion and pre-combustion CO_2 capture technologies for new and existing power plants. • R&D is underway to develop solvent-, sorbent-, and membrane-based capture technologies for both post- and pre-combustion pathways	–	66,986	63, 725	92,000	88,000	116,631
Carbon Storage	• Develop and validate technologies to ensure safe and permanent geologic storage of captured CO_2	–	112,208	106,745	108,766	100,000	108,768
Advanced Energy Systems	• Increase the availability and efficiency of fossil energy systems integrated with CO_2 capture; Focus on gasification, oxy-combustion, advanced turbines, and solid oxide fuel cells.	–	97,169	94,438	99,500	103,000	39,385
Cross Cutting Research	• Fosters the development of innovative systems for improving availability, efficiency, and environmental performance of advanced energy systems with CCS • Supports University-based energy research including science and engineering education at minority colleges and universities	–	47,946	45,618	41,925	49,000	51,242
NETL Coal R&D	• Serves as a bridge between basic and applied research by fostering the R&D of instrumentation, sensors, and controls targeted at enhancing the availability and reducing the costs of advanced power systems. • Develops computation, simulation, and modeling tools focused on optimizing plant design and shortening developmental timelines	–	35,011	33,338	50,011	50,000	34,031
Supercritical CO_2 Technology	• Supports technology development for supercritical carbon dioxide-based power conversion cycles.	–	0	0	0	10,000	19,300
	Sub-Total – CCS & Power Systems	__	**359,320**	**350,800**	**392,202**	**400,000**	**369,357**

PROGRAM	GOALS	ARRA 2009	FY 2012 enacted	FY 2013 enacted	FYI 2014 enacted	FY 2015 enacted	FY2016 requested
CCS Demonstrations							
FutureGen 2.0		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 (ICCS)		1,520,000	0	0	0	0	0
Site Characterization, Training, Program Direction		80,000	0	0	0	0	0
	Sub-total – CCS Demonstrations	**3,400,000**	**0**	**0**	**0**	**0**	**0**
Other Fossil R&D	**Sub-total – Other Fossil Fuel 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: "Carbon Capture and Sequestration: Research, Development, and Demonstration at the U.S. Department of Energy," Peter Folger, Congressional Research Service, April 24, 2015, table 1, pp 10-11; DOE FY 2016 budget request, pp 39-41; "Carbon Storage Technology Program Plan," NETL, December 2014; Carbon Capture Technology Program Plan," NETL, January 2015.

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