Carbon Capture and Sequestration: A Regulatory Gap Assessment

Topical Report

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Principal Authors: Lincoln Davies, Kirsten Uchitel,
John Ruple, Heather Tanana

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Project Officer: David Lang

University of Utah
Institute for Clean and Secure Energy
155 South 1452 East, Room 380
Salt Lake City, Utah 84112

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Abstract

Though a potentially significant climate change mitigation strategy, carbon capture and sequestration (CCS) remains mired in demonstration and development rather than proceeding to full-scale commercialization. Prior studies have suggested numerous reasons for this stagnation. This Report seeks to empirically assess those claims. Using an anonymous opinion survey completed by over 200 individuals involved in CCS, it concludes that there are four primary barriers to CCS commercialization: (1) cost, (2) lack of a carbon price, (3) liability risks, and (4) lack of a comprehensive regulatory regime. These results largely confirm previous work. They also, however, expose a key barrier that prior studies have overlooked: the need for comprehensive, rather than piecemeal, CCS regulation. The survey data clearly show that the CCS community sees this as one of the most needed incentives for CCS deployment. The community also has a relatively clear idea of what that regulation should entail: a cooperative federalism approach that directly addresses liability concerns and that generally does not upset traditional lines of federal-state authority.

Executive Summary

This Report examines the regulatory gaps that presently act as impediments to commercial-scale CCS deployment. Despite longstanding government efforts to promote CCS, and mounting concern over climate change, CCS technology has languished in the United States. Given our nation's substantial reliance on coal-fired power plants for baseload electricity production, many see this as particularly problematic if we are to address climate change.

Prior studies have identified numerous potential barriers to CCS commercialization. However, no study to date has attempted to empirically assess which of those barriers matters most. This Report's aim is to compare prior assessments in the CCS literature with the perceptions of the CCS community. To do so, the Report utilizes an opinion survey issued and completed in the first quarter of 2011. The survey was completed by 229 members of the CCS community: CCS operators working directly in the industry, consultants who provide professional services to the CCS industry, CO_2 emitters, CCS technology and policy researchers, non-profit advocacy organizations involved with CCS, and government regulators.

Using the results of the survey, the Report seeks to answer three questions: What are the most significant obstacles to broad-scale CCS use? What incentives might best overcome those obstacles? How should CCS regulation be shaped to close the gap between the state of the CCS industry today and its realization as a full-fledged climate change solution?

The survey data confirm the conclusions of prior CCS studies in two key ways. First, the data show that the CCS community believes the primary barrier to CCS deployment is the lack of a carbon price, or some other comparably strong economic

signal to incentivize CCS use. This is consistent with the overwhelming majority of previous CCS studies. Thus, it is increasingly clear: Without certain governmental action on climate change, the United States will continue to lag behind other nations in implementing CCS technology.

Second, our survey results are consistent with the CCS literature's view that potential liabilities associated with long-term carbon storage must be addressed to encourage CCS deployment. While some analyses have looked somewhat skeptically on the option, our survey data suggest that the CCS community favors eventual government ownership of stored CO_2 as part of the liability solution.

In other ways, the survey data reveal preferences in the CCS community that diverge sharply from prior work. Perhaps most significantly, the survey results show that one of the chief impediments to CCS commercialization is the lack of a clear, comprehensive CCS regulatory framework. This differs from the conclusions of many CCS analysts and policymakers, who appear to believe that a regulatory framework for CCS can be developed over time, in stages. Our survey data directly contradict this view, revealing a clear preference in the CCS community for comprehensive CCS regulations in the very near-term.

Further, our survey calls into question suggestions from prior literature that (1) inadequate CCS technology and (2) gaps in knowledge of storage reservoir geology and CO_2 plume movement are key barriers to CCS deployment. Instead, CCS community concerns about technology appear to focus primarily on cost and investor confidence issues, not on the technology itself. Likewise, concerns about site geology certainly were noted by survey participants, but were among the lowest ranked of possible CCS barriers. And prior studies have identified social ill ease with CCS as an

obstacle to commercialization, but again, this did not register as a significant concern in the survey results.

Finally, the survey data offer insights into how future CCS regulation and incentives might be structured. The data show that the CCS community has strong preferences favoring both holistic CCS policymaking and a federal role in developing regulations and incentives. However, the data also show that the CCS community would like to see a cooperative federalist approach to implementation of CCS regulations. Substantively, these regulations must address liability as one of their primary objectives. According to the survey responses, the CCS community also favors state primacy over property rights issues (*e.g.*, pore space ownership, reservoir unitization, rights-of-way, and easements) but federal control over interstate movement of CO_2 and the transport phase of CCS.

The totality of the survey responses, particularly when compared to the existing CCS literature, offers additional granularity on both CCS stakeholder preferences and concerns. Ideally, this additional detail will help policymakers effectively and efficiently address the regulatory gaps and barriers that currently impede widespread CCS deployment.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Acronyms

AEP	American Electric Power
BACT	Best Available Control Technology
CAA	Clean Air Act
CCS	Carbon Capture and Sequestration
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CO_2	Carbon Dioxide
CWA	Clean Water Act
DEQ	Department of Environmental Quality
DOE	Department of Energy
DOT	Department of Transportation
DWQ	Division of Water Quality
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GAO	Government Accounting Office
GCS	Geologic Carbon Capture and Sequestration
GHG	Greenhouse Gas
IGCC	Integrated Gasification Combined Cycle
IOGCC	Interstate Oil and Gas Compact Commission
IPCC	Intergovernmental Panel on Climate Change
IRGC	International Risk Governance Council
LAER	Lowest Achievable Emission Rate
MVA	Monitoring, Verification, and Accounting
NAAQS	National Ambient Air Quality Standards
NETL	National Energy Technology Laboratory
NSPS	New Source Performance Standards
NSR	New Source Review
PSD	Prevention of Significant Deterioration
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
WCI	Western Climate Initiative

I. Introduction

In 2009, the Department of Energy (DOE), acting under the Clean Coal Power Initiative, entered into a cooperative agreement with American Electric Power (AEP) to develop and install a commercial carbon capture and sequestration (CCS) operation at AEP's coal-fired Mountaineer power plant in New Haven, West Virginia. DOE committed up to $334 million in funding to the project, which was to proceed in four stages to commercialization in 2015.[1]

AEP, partnering with Alstom, commenced work on a smaller-scale project, intended to validate the CCS technology and design.[2] That validation, financed entirely by AEP and Alstom, was "the first fully-integrated capture and storage facility in the world . . . , captur[ing] up to 90 percent of the CO_2 from a slipstream of flue gas equivalent to 20 megawatts of generating capacity and inject[ing] it into suitable geologic formations for permanent storage approximately 1.5 miles below the surface."[3] In May 2011, the validation project closed as planned after meeting project goals.[4] It operated for more than 6,500 hours, capturing more than 50,000 metric tons of carbon dioxide (CO_2) and sequestering over 37,000 metric tons of that pollutant.[5]

Despite this success, on July 14, 2011, AEP announced that it was "terminating its cooperative agreement with DOE and placing its plans to advance . . . [CCS] technology

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[1] American Electric Power, News Release: AEP Selected to Receive DOE Funds to Advance Carbon Dioxide Capture and Storage to Commercial Scale (Dec. 4, 2009), http://www.aep.com/newsroom/newsreleases/?id=1580.
[2] American Electric Power, News Release: AEP Places Carbon Capture Commercialization On Hold, Citing Uncertain Status Of Climate Policy, Weak Economy (July 14, 2011), http://www.aep.com/newsroom/newsreleases/?id=1704.
[3] *Id.*
[4] *Id.*
[5] *Id.*

to commercial scale on hold."[6] Explaining its decision, AEP cited "the current uncertain status of U.S. climate policy and the continued weak economy as contributors."[7] AEP's partner Alstom went even further:

> State and federal policy makers must recognize the long-term implications of failing to adopt policies that establish the economic certainty needed to drive development of low carbon energy technologies. In addition, policy makers should fund large scale demonstration projects and allow utilities to recover investments in such projects, which are essential if the industry is to move forward in de-carbonizing electricity in the most cost-effective manner possible. If we deviate from the critical path for commercializing CCS technology and do not build large-scale demonstration plants, it will take longer to drive down the technology cost curve and significantly increase delivered electricity costs.[8]

Despite DOE funding, such as that made available to AEP, creating a viable deployment strategy for CCS technology continues to be a vexing challenge. While the threats posed by climate change are increasingly acknowledged, even to the point of becoming an issue of security concern for the U.S. Department of Defense,[9] CCS technology deployment in the United States continues in halting starts and stops. This stagnation is particularly problematic due to the scope of domestic reliance on coal for

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[6] *Id*.
[7] *Id*. AEP agreed to finish Phase I of the project, "completing front-end engineering and design, development of an environmental impact statement and development of a detailed Phase II and Phase III schedule," but declined to move to Phase II "until economic and policy conditions create a viable path forward." *Id*.
[8] Alstom, Press Release: Alstom Supports American Electric Power (AEP) Decision on Next Phase of Carbon Capture and Sequestration (CCS) Project (July 14, 2011), http://www.alstom.com/us/news-and-events/press-releases/alstom-supports-aep-on-ccs-technology/.
[9] DEP'T OF DEFENSE, QUADRENNIAL DEFENSE REVIEW REPORT 20 (2010) ("Climate change and energy are two key issues that will play a significant role in shaping the future security environment. The Department is developing policies and plans to manage the effects of climate change on its operating environment, missions, and facilities.").

power production.[10] Absent an improbable shift in our baseload power supply, CCS has been widely identified as a crucial near-term solution to abating climate change.[11]

Numerous impediments to CCS deployment have been identified in the CCS literature, including the recent study by the Interagency Task Force on Carbon Capture and Storage. The aim of this Report is twofold. First, it seeks to provide new empirical data on both CCS impediments and possible policy initiatives. Second, it endeavors to explain what that data says about a possible path forward for incentivizing CCS commercialization in the United States.

Specifically, the Report seeks to compare the barriers identified in the literature with the barriers identified and prioritized by the CCS community. The centerpiece of the Report is an opinion survey conducted earlier this year of over 200 individuals active in CCS technology, industry, regulation, and related areas. The Report aims to use the resulting survey data to provide policymakers with greater granularity concerning both the regulatory issues and gaps that the CCS community believes must be addressed if CCS projects such as the one begun by AEP and Alstom are to proceed to commercialization rather than wither on the vine.

The Report proceeds in six parts. Section II begins with a brief overview of CCS technology. Section III follows with a summary of CCS regulatory efforts. Section IV then surveys the literature on barriers to CCS deployment and incentives for its use. Section V presents the results of our survey of the CCS community. Section VI

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[10] *See* U.S. Dep't of Energy, Energy Information Administration., *Electricity Explained: Electricity in the United States*, http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states

[11] *See* INT'L RISK GOVERNANCE COUNCIL (IRGC), REGULATION OF CARBON CAPTURE AND STORAGE 4 (2008) (citing INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), 4TH ASSESSMENT REPORT (2007)).

concludes by suggesting an initial architecture for CCS regulation based on prior studies and the survey results.

II. Carbon Capture and Sequestration

Fossil fuels are the primary source of reliable and affordable energy in the United States. In 2009, nearly 70% of electricity in the United States was produced using fossil fuels: 45% from coal, 23% from natural gas, and 1% from oil.[12] One byproduct of this reliance on fossil fuels is climate change. It is well documented that fossil fuels produce substantially more greenhouse gas (GHG) emissions than other fuels used for electricity production, such as renewables and nuclear power. Currently, worldwide CO_2 emissions from human activity are more than 33 billion tons annually—a level now well acknowledged as unsustainable.[13] In the United States, about 1.5 billion tons of CO_2 emissions come annually from coal combustion for power production.[14] In light of coal's role in climate change, opposition to expanded, or even continued, coal consumption is growing.[15]

Concerns over national energy security also have prompted a reexamination of mitigation strategies for continued fossil fuel use, particularly coal. With more of this resource than any other nation in the world, the United States has been dubbed the "Saudi Arabia of coal."[16] According to a 2009 Energy Information Administration report, the United States has approximately 260,551 million short tons in estimated recoverable coal

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[12] U.S. Dep't of Energy, Energy Information Administration, *Electricity Explained: Electricity in the United States*, http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states.
[13] U.S. Dep't of Energy, NETL, Technologies, http://www.netl.doe.gov/technologies/carbon_seq.
[14] MASSACHUSETTS INSTITUTE OF TECHNOLOGY, THE FUTURE OF COAL ix (2007), http://web.mit.edu/coal/The_Future_of_Coal.pdf.
[15] Susan Moran, *Fight Against Coal Plants Draws Diverse Partners*, NEW YORK TIMES, Oct. 20, 2007; Steven Mufson, *Coal Industry Plugs Into the Campaign*, WASHINGTON POST, Jan. 18, 2008.
[16] Cathy Booth Thomas, *Is Coal Golden?*, TIME, Oct. 2, 2006, http://www.time.com/time/magazine/article/0,9171,1541270,00.html.

reserves—enough to supply the nation's coal needs for over 250 years, using the 2009 rate of consumption.[17] One possible strategy for utilizing these reserves while combating climate change, is to deploy CCS technologies. Potentially, CCS could be a climate change game changer. As one recent report observed, "To continue to extract and combust the world's rich endowment of oil, coal, peat, and natural gas at current or increasing rates . . . is no longer environmentally sustainable, unless carbon dioxide capture and storage (CCS) technologies currently being developed can be widely deployed."[18]

Deployment of CCS technologies thus offers one means of achieving a balance between energy security and climate change mitigation.[19] CCS has three basic parts: CO_2 capture, transport, and permanent storage, or "sequestration," underground.[20] Because the CO_2 is pumped underground rather than emitted into the atmosphere, the power plant's carbon footprint decreases. Given the current state of technologies, and depending on the type of power plant, capital cost estimates for CCS range from $60 to $114 per ton of CO_2 avoided.[21] But with scant economic incentive to capture GHG emissions, few of the available CCS technologies are being deployed on a broad scale.

This Section provides an overview of CCS, including the technologies it would use for climate change mitigation. Although technologies exist for all three components

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[17] U.S. Dep't of Energy, Energy Info. Admin., Annual Coal Report 2009, at 7, 33, http://www.eia.gov/cneaf/coal/page/acr/acr.pdf.

[18] IRCG, REGULATION OF CARBON CAPTURE AND STORAGE 4 (2008) (citing IPCC, 4TH ASSESSMENT REPORT (2007)).

[19] U.S. Dep't of Energy, Carbon Capture and Storage R&D Overview, http://fossil.energy.gov/sequestration/overview.html.

[20] This report focuses solely on underground geologic carbon sequestration. However, there are other means of sequestering CO_2, such as deep sea injection, developing or augmenting natural carbon sinks, such as forests, and industrial fixation of CO_2 into inorganic carbonates. IPCC, CCS Summary for Policymakers 3 (2005). Ocean storage and its ecological impacts are still in the research phase. *Id.* at 7.

[21] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 28 (2010).

of CCS, they have not yet been deployed at electric power plants at commercial scale—the scale necessary to help achieve greenhouse gas reduction targets.[22] Our study focused on what barriers deploying CCS on a commercial scale will face, even as the industry makes strides with demonstration-scale projects. The remainder of this Section briefly overviews the distinct elements of CCS technology most relevant from a regulatory and policymaking perspective.

A. Carbon Capture

The first step of CCS, carbon capture, separates out the CO_2 from the rest of the power plant's emissions stream.[23] CO_2 has been captured from industrial gas streams since the 1930s. However, application of these technologies to coal-based power generation is both new and expensive.[24] There thus is substantial technical uncertainty

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[22] *Id*. at 9. Six demonstration-scale CCS projects are underway: (1) Sleipner West, currently storing one million tons of CO_2 from a natural gas field in a saline formation under the North Sea in Norway; (2) the Snohvit Natural Gas Field, injecting CO_2 beneath the Barents seabed since 2008 with an annual capacity of 700,000 tons, also in Norway; (3) the Weyburn Flood Project, storing seven million tons of CO_2 from enhanced oil recovery since 2004 in Canada; (4) the In Salah Project, the world's first full-scale CCS project at a natural gas field in Algeria, storing approximately one million tons of CO_2 annually since 2004; (5) the K12-B Project on the Dutch Continental Shelf, storing CO_2 since 2004 in the same natural gas fields from which the CO_2 was originally produced in the Netherlands; and (6) the LaBarge Project in Wyoming, capturing and storing four million tons of CO_2 annually in depleted gas reservoirs. National Mining Association, Current Worldwide CCS Projects, http://www.nma.org/ccs/ccsprojects.asp; U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT APPENDIX C (2010). Numerous other pilot and demonstration scale CCS projects are in the planning or initial operational stages. National Mining Association, Current Worldwide CCS Projects, http://www.nma.org/ccs/ccsprojects.asp*; see also* CCS Carbon Capture and Storage at Vatenfall, http://www.vattenfall.com/en/ccs/index.htm; Mongstad, http://www.statoil.com/en/TechnologyInnovation/ProtectingTheEnvironment/CarbonCaptureAndStorage/Pages/TheMongstadCPHstation.aspx. Along with these efforts, DOE has revived the FutureGen project,[22] now named FutureGen 2.0. FutureGen 2.0 aims to complete "the world's first, near-zero emissions commercial scale coal-fueled power plant [by] [r]epowering an existing Ameren coal-fueled power plant in Meredosia, Illinois with cutting edge oxy-combustion clean coal technology," and storing captured CO_2 at a new regional storage facility in Illinois. FutureGen Facts (Feb. 24, 2011), www.FutureGenAlliance.org .DOE also has developed seven regional sequestration partnerships, six of which have reached the stage of implementing large-scale CCS projects and one of which is in the CO_2 injection stage. NETL, Carbon Sequestration Regional Partnerships, http://fossil.energy.gov/sequestration/partnerships/index.html; U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 43 (2010). Another CCS project led by AEP and Alstom, developed pursuant to a 2009 cooperative agreement between DOE and AEP, was terminated in July 2011.

[23] NETL, CARBON SEQUESTRATION PROGRAM: TECHNOLOGY PROGRAM PLAN 16 (Feb. 2011).

[24] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 9, 28 (2010). These processes have been used in the natural gas industry and to produce food and chemical-grade CO_2. *Id*.

about the scale-up needed to achieve widespread CCS deployment.[25] Only a handful of studies have evaluated the applicability of CO_2 capture technologies to industrial sources, which are responsible for 25% of total CO_2 emissions in the United States.[26]

CO_2 capture is expensive because separating the CO_2 from the rest of the emissions stream requires additional energy that is not required for electricity production itself. This reduction in the power plant's energy efficiency is typically referred to as CCS's "parasitic load" or "energy penalty." The penalty may be substantial. Capturing CO_2 represents an estimated 75% of the total cost of CCS.[27] The Intergovernmental Panel on Climate Change (IPCC) estimates the cost of capture to be \$15-75/tCO_2 net captured, depending on the type of plant.[28] Translating capture and storage costs into increased costs of electricity production, the IPCC calculates that with CCS, the cost of electricity from a pulverized coal power plant would increase from 4-5¢/kWh to 6-10¢/kWh.[29] Likewise, according to the 2007 MIT study, *The Future of Coal*, including CCS in power plants may increase the price of power in the range of 33 to 84%.[30] However, "[o]pportunities for significant cost reductions exist since very little research and development has been devoted to CO_2 capture and separation technologies."[31] In

[25] *Id.* at 35-36 (2010). Areas of technical uncertainty include maintaining adequate gas and/or liquid flow distribution in larger reactions, the impacts of flue gas contaminants on CO_2 capture system, increased water consumption, and obtaining a cost-effective O_2 supply for oxy-combustion systems. *Id.*
[26] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 29 (2010).
[27] U.S. Dep't of Energy, Carbon Capture Research, http://fossil.energy.gov/sequestration/capture/index.html.
[28] IPCC, CCS SUMMARY FOR POLICYMAKERS 10 (2005).
[29] *Id.* Similar increases are estimated for natural gas combined cycle and ICGG plants, increasing from 3-5¢/kWh to 4-8¢/kWh, and from 4-6¢/kWh to 5-9¢/kWh, respectively. *Id.*
[30] *See* MIT, *supra* note 14, at 36.
[31] U.S. Dep't of Energy, Carbon Capture Research, http://fossil.energy.gov/sequestration/capture/index.html.

fact, at least some studies have suggested the potential for a 30 to 45% cost reduction in CO_2 capture technologies.[32]

B. Carbon Transport

Once captured and compressed, the liquefied CO_2 must be transported to a suitable sequestration site. The weight of CO_2 requiring shipment may be more than twice the weight of the coal from which the CO_2 was derived, depending on the moisture and carbon content of the fuel.[33] CO_2 has been transported throughout the United States via pipelines for almost forty years.[34] Currently, such transport technology moves approximately 80 million tons of CO_2 through 3,600 miles of existing CO_2 pipelines annually.[35] The primary use of this pipeline network is for "tertiary," or "enhanced," oil recovery (EOR), in which the oil and gas industry pumps CO_2 into oil and gas formations to increase the field's production.[36]

While ships, trains, and road tankers may also be used to ship compressed CO_2,[37] pipelines represent the most economic and efficient means of transport. CO_2 pipelines are substantially comparable to natural gas pipelines. Both systems transport pressurized gas and utilize carbon steel pipe for their construction.[38] While these similarities allow for some overlapping cost modeling for materials, fabrication, and rights-of-way

[32] U.S. Dep't of Energy, NETL, Technologies: Carbon Sequestration, http://www.netl.doe.gov/technologies/carbon_seq/.

[33] Coal is a mixture of carbon, hydrogen, and oxygen molecules. When combined with air, the carbon combustion produces carbon dioxide, which weighs 3.664 times the weight of carbon itself. Babcock & Wilcox, Steam Its Generation and Use 2-4, 2-8 (37th ed. 1960); B.D. Hong & E.R. Slatick, *Carbon Dioxide Emission Factors for Coal*, DOE, Energy Information Administration, http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html.

[34] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 8 (2010).

[35] *Id.* at 9.

[36] *See* Jennifer Skougard Horne, *Getting from Here to There: Devising an Optimal Regulatory Model for CO_2 Transport in a New Carbon Capture and Sequestration Industry*, 30 J. LAND, RESOURCES & ENVTL. L. 357, 359 (2010).

[37] IPCC, CCS SUMMARY FOR POLICYMAKERS 5-6 (2005).

[38] NETL, Carbon Sequestration FAQ Information Portal: Carbon Capture, http://www.netl.doe.gov/technologies/carbon_seq/FAQs/carboncapture3.html.

expenses, there are important differences as well.[39] Specifically, "CO_2 is transported at higher pressures, thus requiring thicker and more expensive pipe and welds; CO_2 is piped as a liquid-like supercritical fluid, which utilizes pumps instead of compressors; and CO_2 and natural gas require different materials for joints and seals."[40] Predicting the exact costs of constructing new CO_2 pipelines and transporting CO_2 through these pipelines depends on a variety of factors, including the distance between the capture and storage points, terrain type, anticipated flow of CO_2, population and infrastructure development density, and local labor and materials costs.[41]

C. Carbon Sequestration

Carbon storage, also referred to as sequestration, is the process of injecting CO_2 into subsurface geologic formations for long-term sequestration.[42] Geologic storage options include depleted oil and gas reservoirs, deep saline formations, organic-rich shales, basalt formations, and unmineable coal beds.[43] CO_2 storage costs are estimated to be $0.40 to $20 per ton of CO_2 stored, not including potential costs associated with long-term liabilities. Like CO_2 transport, the cost of CO_2 storage depends on numerous factors, including reservoir type, existing information about the reservoir's geology and capacity, available infrastructure, the extent of monitoring needed, regional factors, and the type of storage (*i.e.*, onshore or offshore).[44]

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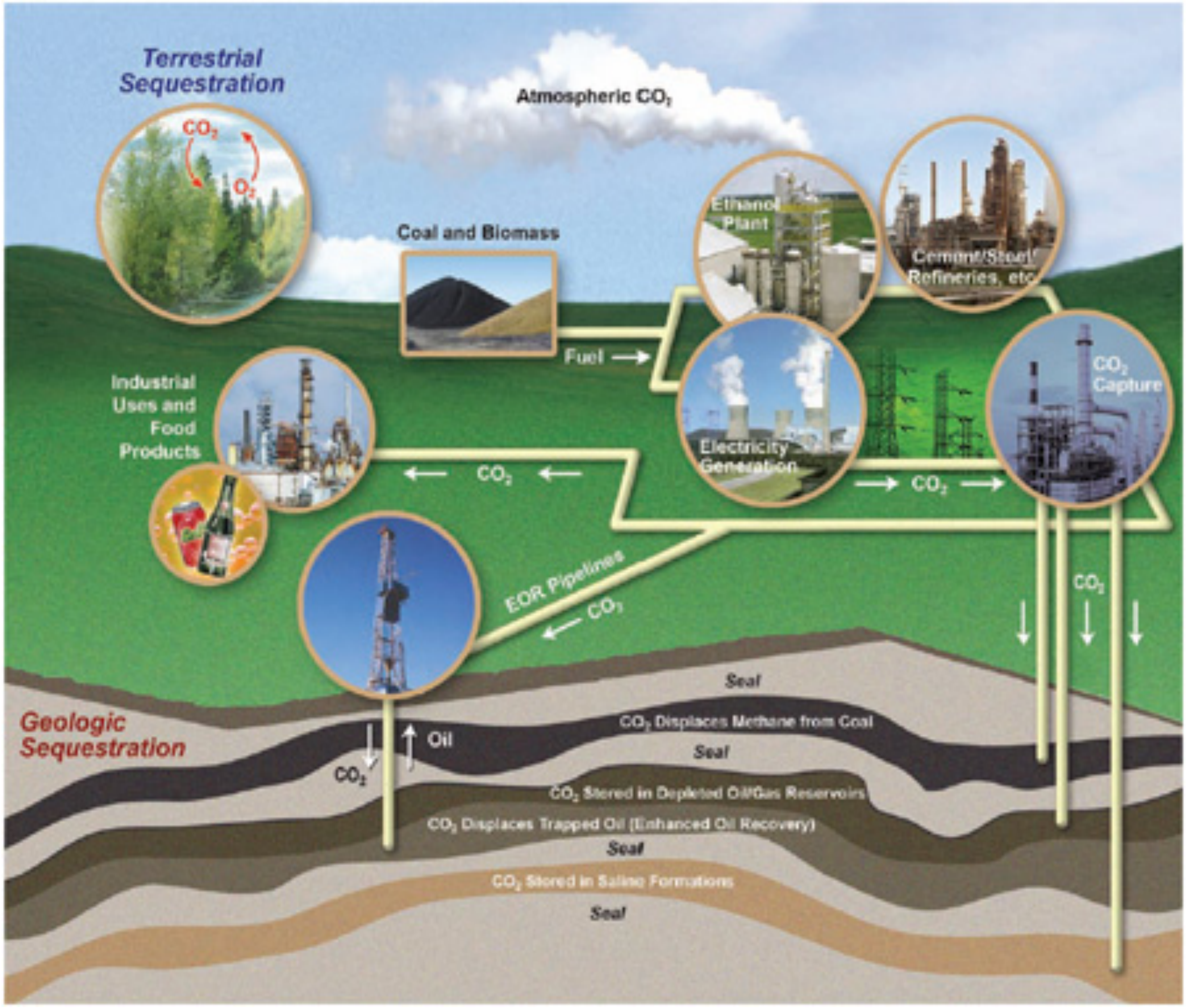
[39] *Id.*
[40] *Id.*
[41] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 38, APPENDIX B.4 (2010).
[42] IPCC, CCS SUMMARY FOR POLICYMAKERS 3 (2005).
[43] *Id*. at 6.
[44] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 44 (2010).

Figure 2.1: Geologic Carbon Sequestration Diagram[45]



Engineered injection of CO_2 into geologic reservoirs has been used since the 1970s for purposes of EOR. In EOR operations, the injected CO_2 permeates the lower density formation pores and displaces previously resident oil and natural gas, forcing them to the surface for recovery. CCS relies on the same fundamental permeation principles as EOR, injecting and trapping the supercritical CO_2 deep in the formation's

[45] Figure is courtesy of NETL Carbon Sequestration: FAQ Information Portal, http://www.netl.doe.gov/technologies/carbon_seq/FAQs/carbonseq.html.

pore space. Over geologic time, sequestered carbon may react to the minerals in the formation, calcify, and bond to the surrounding rock.

Although EOR operations today typically do not monitor for atmospheric CO_2 releases following injection, experience with EOR has led to below-ground reservoir management and operation practices that may help ensure safe, large-scale storage of CO_2.[46] Furthermore, the stable retention of CO_2 in natural reservoirs has demonstrated that large CO_2 volumes can be sequestered in the subsurface over time.

CO_2 storage is a multi-phase operation, consisting of three primary phases: pre-injection, site operation, and post-injection.[47] The pre-injection phase involves site characterization to evaluate suitability of the geologic depository, modeling to predict the extent of the CO_2 plume and pressure front, and identification and plugging of existing penetrations (*e.g.*, abandoned wells) that could serve as conduits for fluid movement.[48] Site characterization is a fundamental component of selecting safe locations for geologic storage. During the site operation phase, the CO_2 is injected, the injection well is tested, groundwater geochemistry is monitored, and the CO_2 plume is tracked.[49] Finally, the post-injection phase involves sequestration site monitoring to verify that there are neither unwanted atmospheric CO_2 releases nor negative impacts to underground drinking water sources or valuable mineral deposits. Site closure follows.[50]

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[46] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 9, 39 (2010). "Injection of CO_2 is one of several enhanced recovery techniques that have successfully been used to boost production efficiency of oil and gas by re-pressurizing the reservoir, and in the case of oil, by also increasing mobility." *Id*. at 40. The United States is the world leader in enhanced oil recovery. U.S. Dep't of Energy, Geologic Sequestration Research, http://fossil.energy.gov/sequestration/geologic/index.html.
[47] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 39 (2010).
[48] *Id.*
[49] *Id.*
[50] *Id.*

Various potential environmental risks are associated with CO_2 injection and storage, primarily resulting from the potential for CO_2 leakage from the sequestration site. Leakage could either occur rapidly due to failures associated with the injection well, or gradually through undetected fissures in the geologic formation targeted for sequestration.[51] A rapid leak leading to an excessively high concentration of CO_2 in the ambient air could present a significant, even potentially lethal threat to proximate human and animal populations.[52] Gradual CO_2 leakage could contaminate groundwater or subsurface minerals and substantially damage affected vegetation and subsoil animals.[53] Events of induced seismicity and subsidence are considered unlikely, but are also possible concerns associated with CO_2 injection.[54] Lastly, any leakage represents the environmental harm of failing to effectively reduce CO_2 emissions.[55] The process of ensuring that CO_2 storage does not lead to these environmental risks is referred to as "monitoring, verification, and accounting," or "MVA."[56] "The overall goal" of MVA "is to demonstrate to regulatory authorities and the general public that the practice of geologic storage is safe, permanent, does not create significant adverse local environmental impacts, and is an effective [GHG] control technology."[57]

Despite the limited use of CCS today, DOE estimates that the United States contains enough storage for more than 3,000 billion tons of CO_2—"large enough to store the amount of CO_2 emissions currently emitted from the entire coal-fired electricity

[51] ELIZABETH WILSON ET AL., WORLD RESOURCES INSTITUTE, LIABILITY AND FINANCIAL RESPONSIBILITY FRAMEWORKS FOR CARBON CAPTURE AND SEQUESTRATION 3 (2007).
[52] IPCC, CCS SUMMARY FOR POLICYMAKERS 12 (2005).
[53] *Id* at 13.
[54] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 72 (2010)
[55] Adam Gardner Rankin, *Geologic Sequestration of CO_2: How EPA's Proposal Falls Short*, 49 NATURAL RESOURCES JOURNAL 883, 888 (2009).
[56] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 47 (2010).
[57] NETL, CARBON SEQUESTRATION PROGRAM: FY 2008-2009 ACCOMPLISHMENTS 28 (Nov. 2010).

sector in the United States for over 1,000 years."[58] The promise of these estimates puts CCS squarely in the mix of potential climate change mitigation strategies. At the same time, however, several uncertainties surrounding carbon sequestration remain, due to both geologic (*e.g.*, reservoir porosity/permeability, caprock integrity) and fluid dynamics (*e.g.*, CO_2 movement, brines and pressure fronts) factors.[59] That is, while many aspects of the science behind geologic storage security are relatively well understood, especially for EOR purposes, additional information is required to confirm predictions of the behavior of natural systems in response to larger-scale, climate changed-based CO_2 storage.[60]

[58] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 40 (2010); *see also* U.S. Dep't of Energy, Carbon Sequestration Atlas of United States and Canada (2008) (evaluating the geologic storage potential for oil/gas fields, unmineable coal steams, and saline formations in North America).
[59] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 41 (2010).
[60] *Id*. at 42.

III. Existing and Proposed CCS Regulations

One possible barrier to the commercialization of CCS is the lack of sufficient—or the enactment of inapt—regulation. Numerous studies have suggested that regulatory and legal gaps and ambiguities prevent CCS from reaching commercial deployment.[61] Increasingly, both the federal government and the states have begun considering how best to address the legal issues surrounding CCS. Some of these proposals have remained just that, proposals. Others have resulted in legislation and regulation.

Despite this growing trend of regulatory action, the status quo ante remains. There is no comprehensive regulatory scheme to which the CCS community can turn for clear guidance. Federal action on CCS is fragmented at best. Some existing statutes, such as the Safe Drinking Water Act, clearly apply, with new rules recently adopted. Others, however, present as many open questions as they do answers. Meanwhile, more holistic proposed CCS legislation has failed to pass. At the state level, action has been both quicker to come and more thorough. A number of states have put liability regimes in place, created permitting schemes, and begun incentivizing CCS through tax code reforms and otherwise. Yet these efforts are neither uniform nor ubiquitous; most states have not yet acted to facilitate CCS in their boundaries. This leaves much room for regulatory action.

This Section provides an overview of federal and state legislative and regulatory efforts on CCS, as of 2011.

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[61] *See, e.g., Id.*; DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT (2009); GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION (2008); IRCG, REGULATION OF CARBON CAPTURE AND STORAGE 18 (2008); IPCC, CCS SUMMARY FOR POLICYMAKERS 3 (2005).

A. Federal Legislation

No comprehensive federal regulatory scheme for CCS has been enacted. Nonetheless, several existing laws and regulations, primarily environmental in nature, govern various aspects of the CCS process. A summary of proposed congressional action follows the discussion of current laws, which are addressed first.

1. Environmental Regulation

The Environmental Protection Agency (EPA) is responsible for protecting human health and the environment.[62] While many of the nation's environmental laws may apply to parts of the CCS process,[63] EPA administers four primary environmental laws that could impact CCS commercialization. These include the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund).

a. Safe Drinking Water Act

Under the SDWA,[64] EPA establishes minimum requirements for the Underground Injection Control (UIC) Program, which regulates subsurface injection of fluids to protect drinking water quality.[65] When EPA initially promulgated UIC regulations, it defined five classes of injection wells.[66] CO_2 injection was permitted under Class II wells for

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[62] U.S. Envtl. Protection Agency, About EPA, http://www.epa.gov/aboutepa/whatwedo.html.
[63] *See* ARNOLD REITZE, FEDERAL CONTROL OF GEOLOGICAL CARBON SEQUESTRATION, TOPICAL REPORT, 54-60 AND 62-66 (2010) (discussing other environmental laws, such as the Clean Water Act, National Environmental Policy Act, and the Endangered Species Act).
[64] P.L. 93-523; 42 U.S.C. § 300f *et seq*.
[65] 42 U.S.C. § 300h *et seq*.
[66] 40 C.F.R. § 144.6.

EOR,[67] and under Class V experimental technology wells for geologic sequestration technology tests.[68]

Recently, however, EPA promulgated a new SDWA rule governing underground injection of CO_2 for long-term geologic sequestration.[69] The rule creates a new Class VI well category for subsurface geologic CO_2 sequestration and sets forth minimum technical criteria for such injection.[70] The rule also includes requirements for permitting, siting, construction, operation, financial responsibility, testing and monitoring, post-injection site care, and site closure.[71]

Specifically, the rule requires owners and operators of Class VI wells to provide storage site characterization information demonstrating that the wells will be sited in areas with suitable geology.[72] Owners and operators must further delineate the "Area of Review" for any proposed geologic sequestration project, to be reevaluated every five years.[73] In addition, permit applicants must submit both a "Corrective Action Plan" and an "Emergency and Remedial Response Plan." The former specifies the means used to ensure that wells within the Area of Review do not serve as conduits for fluid movement into any Underground Source of Drinking Water (USDW),[74] and the latter details the actions that will be taken if any injected fluids become a threat to USDW.[75] The rule also sets new injection well construction, operating (including monitoring and shut-off),

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[67] *Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration Wells*, 75 Fed. Reg. 77,237 (Dec. 10, 2010).
[68] 40 C.F.R. § 144.81(14).
[69] 75 Fed. Reg. at 77,230.
[70] 75 Fed. Reg. at 77,230-77,231.
[71] 75 Fed. Reg. at 77, 246. *See* REITZE, *supra* note 77, at 22- 33 (discussing Class VI permits in more detail).
[72] 40 C.F.R. §§ 146.82-83.
[73] *Id*. § 146.84.
[74] *Id*. § 146.84.
[75] 40 C.F.R. § 146.94.

mechanical integrity testing, and recordkeeping/reporting requirements.[76]

Further, the rule places new regulatory requirements on the well plugging and closure phases of Class VI wells. Owners and operators must provide notice of their intent to plug, furnish a well plugging plan, and maintain well plugging reports for a decade.[77] Post-injection monitoring must continue for a minimum of 50 years, and then continue until the project is deemed to no longer pose a threat to USDW.[78]

Finally, the rule sets new financial responsibility requirements aimed at ensuring that all Class VI well owners and operators have adequate financial resources to address the endangerment of any USDW. This demonstration of sufficient financial resources must be submitted for permit approval, and must include detailed estimates of the costs of performing corrective action, in addition to well plugging, post-injection site care, and remedial response.[79]

Thus, while EPA's SDWA rules address some of the concerns related to CO_2 sequestration, their scope is limited. Rather than resolving the myriad legal issues that might arise from geologic CO_2 storage, including, among others, pore space ownership, long-term liability, and seismicity, these rules focus on a single question: water quality. Given the scope of the SDWA itself, this can hardly be unexpected. The SDWA was designed to protect drinking water. But EPA's promulgation of the Class VI rules did not go without criticism for failing to clarify that CO_2 injection under a Class VI permit

[76] 40 C.F.R. §§ 146.86, 88-91.
[77] 40 C.F.R. § 146.92.
[78] 40 C.F.R. § 146.93.
[79] 40 C.F.R. § 146.85. The EPA is expected to recommend both a revised minimum Tangible Net Worth requirement and revised cost estimation methodology for Class VI wells in 2011. *Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2 Geologic Sequestration (GS) Wells, Final Rule*, 75 Fed. Reg. 77,229, 77,269 (to be codifed at 40 C.F.R. pts. 124, 144, 145, *et seq*.).

would absolve the injector of other environmental statutory liability.[80] If anything, this highlights the limited nature of the rules themselves. They do not deal comprehensively with long-term liability or other injection and storage issues the CCS community is worried about.[81]

b. Clean Air Act

EPA also has implemented a mandatory greenhouse gas emissions reporting program under the Clean Air Act.[82] As of December 1, 2010, this program was expanded to include CO_2 from carbon injection and geologic sequestration.[83] Thus, owners of such sites now are required to develop and implement EPA-approved site-specific monitoring, reporting, and verification plans.[84]

Under the CAA, greenhouse gases, including CO_2, are considered air pollutants.[85] Consistent with this designation, EPA promulgated an endangerment finding in 2009 stating that CO_2 and other greenhouse gases threaten the public health and welfare.[86] Although EPA has not yet promulgated a final rule requiring greenhouse gas reductions, rulemaking proceedings are underway with respect to emissions from fossil fuel-fired power plants and refineries.[87] As a regulated pollutant, CO_2 may become subject to the CAA's prevention of significant deterioration (PSD) and new source review (NSR)

[80] *See, e.g.,* Adam Gardner Rankin, *Geologic Sequestration of CO_2: How EPA's Proposal Falls Short*, 49 NRJ 883 (2010); Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long-Term Storage of Carbon Dioxide* 58 EMORY L.J. 103 (2008-2009).
[81] *See infra* Section V.B.1.b.
[82] 42 U.S.C. §§ 7414 and 7542; *Mandatory Reporting of Greenhouse Gases*, 74 Fed. Reg. 56,260 (Oct. 30, 2009); 75 Fed. Reg. 39,736 (July 12, 2010) (expanding the reporting program).
[83] *Mandatory Reporting of Greenhouse Gases: Injection and Geologic Sequestration of Carbon Dioxide*, 75 Fed. Reg. 75,059 (Dec. 1, 2010) (to be codified at 40 C.F.R. pt. 98, subpt. RR).
[84] *Id*.
[85] Massachusetts v. EPA, 549 U.S. 497 (2007).
[86] *Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act*, 74 Fed. Reg. 66,495 (Dec. 15, 2009).
[87] *See* U.S. Envtl. Protection Agency, *Air Quality Planning and Standards: Addressing Greenhouse Gas Emissions,* http://www.epa.gov/airquality/ghgsettlement.html.

requirements: In areas that are in compliance with the national ambient air quality standards (NAAQS), a new or modified emissions source must satisfy stringent PSD requirements, such as use of the best available control technology (BACT).[88] Areas that do not meet the NAAQS for an emitted pollutant are subject to NSR requirements, such as the lowest achievable emission rate (LAER).[89]

EPA recently proposed regulating CO_2 under the NSR program. This Tailoring Rule sets a greenhouse gas emissions threshold by modifying regulations applicable to the PSD program and its Title V operating permit program.[90] Specifically, EPA determined that PSD and Title V apply to greenhouse gas emissions and that "GHG sources will become subject to PSD for their GHG emissions if they undergo PSD permitting anyway, either for new construction or for modification projects, based on emissions of non-GHG pollutants . . ..."[91]

Overall, the CAA may impact CCS commercialization in two ways. First, owners and operators of CO_2 sequestration sites are required to track emissions from those sites. Presumably, EPA's tracking of CO_2 emissions at these and other locations may be used in the future as a way to shape greenhouse gas emission limits. Second, to the extent EPA continues to use the Clean Air Act to regulate CO_2, this may become a driver of CCS technology. Discerning precisely how EPA will proceed along this path is, to some extent, the equivalent of reading tea leaves. The agency has, however, already taken some steps along this path. In a recent guidance document, for instance, EPA acknowledged that "[f]or the purposes of a BACT analysis for GHGs, . . . CCS is an

[88] 42 U.S.C. § 7475; *see also* 42. U.S.C. § 7479(3) (defining BACT).
[89] 42 U.S.C. § 7503(a)(2).
[90] *Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule*: Final Rule, 75 Fed. Reg. 31,514 (June 3, 2010).
[91] *Id*. at 31,523; *see also* REITZE, *supra* note 77, at 39-46.

option that merits initial consideration" as an "available" technology for BACT.[92] As further GHG regulations develop, the cost and time required to permit coal-fired power plants may increase. Likewise, the choice to install CO_2 capture technology at a plant may trigger PSD requirements for the entire industry.[93] And new or modified electric power facilities may either choose, or be required, to utilize CCS, IGCC, or both as BACT.[94]

c. RCRA and CERCLA

RCRA most likely applies to sequestered CO_2. Under this statute, solid waste is defined as discarded material that is solid, liquid, semisolid, or that contains gaseous material.[95] RCRA regulates the disposal of both non-hazardous and hazardous solid waste.[96] Because injection is deemed to be "disposal" under RCRA,[97] sequestered CO_2 may well be considered a solid waste under RCRA.[98] RCRA's more stringent hazardous waste provisions are unlikely to apply to sequestered pure CO_2, because CO_2 alone is unlikely to be considered a hazardous waste.[99] Nonetheless, EPA has indicated that other hazardous contaminants in an emission stream could mix with the CO_2, rendering the mingled stream subject to RCRA hazardous waste regulation.[100] EPA plans to issue a notice of proposed rulemaking, which, if ultimately promulgated, could conditionally

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[92] U.S. Envtl. Protection Agency, Office of Air Quality and Planning Standards, PSD and Title V Permitting Guidance for Greenhouse Gases 32-33 (March 2011), http://www.epa.gov/nsr/ghgdocs/ghgpermittingguidance.pdf.
[93] Compressing captured CO_2 requires more energy and may increase emissions, thereby triggering NSPS or PSD/NSR requirements.
[94] BACT/LAER requirements cannot be used to require a redesign of a proposed facility. However, several cases, EPA administrative hearings, and state proceedings are now questioning whether IGCC technology can be required as BACT. REITZE, *supra* note 77, at 46-50.
[95] 42 U.S.C. § 6903(27).
[96] 42 U.S.C. § 6901 *et seq*.
[97] 42 U.S.C. § 6903(3).
[98] REITZE, *supra* note 77, at 51-52.
[99] *Id.* at 51-54.
[100] 40 C.F.R. § 261.3(a)(2)(iv).

exempt CO_2 waste streams from RCRA's hazardous waste requirements, in order to facilitate CCS deployment.[101]

Whether a CO_2 stream is hazardous under RCRA also affects sequestration under the SDWA. If a CO_2 stream is hazardous, it may only be injected into a Class I hazardous waste injection well. This is because under EPA's new SDWA rules, Class VI wells cannot be used for the co-injection of RCRA hazardous wastes.[102]

CERCLA governs the clean up of hazardous waste.[103] CERCLA is a "strict liability" law that makes responsible parties subject to liability for the most hazardous waste contaminated sites. Under CERCLA, the federal, state, and local governments, as well as private parties, may recover the costs associated with a cleanup operation of jurisdictional hazardous materials.[104] CO_2 is not presently listed as a hazardous substance under CERCLA. However, hazardous contaminants mingled in the CO_2 waste stream could potentially trigger CERCLA liability.[105] This is only one way in which CCS liability appears potentially unbounded to the CCS community. Storage of CO_2 streams might lead to significant liability years or decades down the road despite compliance with all applicable environmental regulations in effect today.[106] Of course, CERCLA § 107 does exempt federally permitted releases from triggering liability under its provisions.[107]

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[101] *To Speed CCS, EPA Weighs Hazardous Waste Law Exemption for CO_2,* XXVII ENVTL POL'Y ALERT (Inside EPA) 6:31 (Mar. 24, 2010); EPA, Rulemaking Gateway*, Hazardous Waste Management Systems: Identification and Listing of Hazardous Waste: Carbon Dioxide (CO_2) Injectate in Geological Sequestration Activities*, http://yosemite.epa.gov/opei/RuleGate.nsf/byRIN/2050-AG60#1.

[102] 75 Fed. Reg. 77,260.

[103] 42 U.S.C. §§ 9601 *et seq*.

[104] 42 U.S.C. § 9607.

[105] REITZE, *supra* note 77, at 53.

[106] *See* WENDY B. JACOBS, EXPERT WORKSHOP ADDRESSING CCS LIABILITY, OVERSIGHT, AND TRUST FUND ISSUES: SUMMARY REPORT, HARVARD LAW SCHOOL, EMMETT ENVIRONMENTAL LAW AND POLICY CLINIC (Oct. 29, 2010).

[107] CERCLA §§ 107, 101(10), 42 U.S.C. §§ 9607, 9601(10).

Consequently, this provision could protect industry from CERCLA liability if injected streams remain within the scope of a SDWA Class VI permit.[108]

2. Proposed Legislation

Efforts at passing a comprehensive federal regulatory scheme for CCS have failed.[109] The primary way in which Congress has sought to incentivize CCS is through cap-and-trade legislation. Raising the costs of using fossil fuels would promote CCS as a way to avoid penalties for climate change emissions.[110]

During the 111th Congress, the American Clean Energy and Security Act of 2009 (H.R. 2454), also known as the Waxman-Markey bill, was the most significant CCS legislation proposed. The bill sought "to create clean energy jobs, achieve energy independence, reduce global warming pollution and transition to a clean energy economy."[111] Its most high profile feature was a cap-and-trade system for greenhouse gas emissions. With respect to CCS specifically, H.R. 2454 would have imposed four important requirements. First, the bill would have required a study to be completed within one year of the bill's enactment identifying key legal, regulatory, and other barriers to CCS, including recommendations for addressing those barriers.[112] Second, H.R. 2454 would have required EPA to promulgate regulations for CO_2 geological

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[108] 75 Fed. Reg. 77,260.

[109] Despite failed legislative efforts, the Obama Administration has supported development of clean coal technologies. In 2010, the Interagency Task Force on Carbon Capture and Storage was established in order to develop a comprehensive and coordinated federal strategy to speed the commercial development and deployment of clean coal technologies. U.S. Dep't of Energy, Interagency Task Force on Carbon Capture and Storage, http://fossil.energy.gov/sequestration/ccs_task_force.html. The Task Force's final report makes recommendations on overcoming barriers to widespread deployment of CCS within ten years. DEP'T OF ENERGY, CCS TASK FORCE REPORT (2010), http://fossil.energy.gov/sequestration/ccstf/CCSTaskForceReport2010.pdf.

[110] Notably, the Energy Improvement and Extension Act of 2008 and Emergency Economic Stabilization Act, Pub. L. No. 110-343 (2008), already provides tax credits for taxpayers that capture and sequester CO_2 from a qualified facility.

[111] American Clean Energy and Security Act of 2009, House of Rep., 110th Cong. 1st Sess., rept. 111-137, Pt. 1, at 277.

[112] H.R. 2454 at §§ 111-116.

sequestration wells, including "requirements for maintaining evidence of financial responsibility, including financial responsibility for emergency and remedial response, well plugging site closure, and post-injections care,"[113] as well as regulations distributing GHG emission allowances to support CCS deployment.[114] Third, and perhaps most importantly, H.R. 2454 would have required CCS to be standard equipment for new coal-fired power pants permitted after 2020, and would have imposed retrofit requirements on coal-fired power plants permitted between 2015 and 2020.[115] Finally, H.R. 2454 would have promoted CCS through an amendment to the CAA's offset program.[116]

Although H.R. 2454 narrowly passed the House of Representatives, a Senate vote never occurred.[117] The bill has not been reintroduced in the 112th Congress. Consequently, many CCS issues remain unresolved at the federal level, such as which agency will have oversight over long-term liability for sequestration and who will regulate CO_2 transportation pipelines. Instead, bills introduced in the 112th Congress largely aim not to promote CCS but to disincentivize its—and other climate change solutions'—use. To the extent these bills do address issues of CCS regulation, they are much narrower in scope than prior bills like Waxman-Markey.

For instance, the Free Industry Act (H.R. 97), the Energy Tax Prevention Act (H.R. 910), the No More Excuses Energy Act (H.R. 1023), the Energy Production Freedom Act (H.R. 1292), and the Energy Tax Prevention Act (S. 482) all seek to amend

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[113] H.R. 2454 at § 112(b), (e).
[114] H.R. 2454 at § 115.
[115] H.R. 2454 at § 116.
[116] H.R. 2454 Title III.
[117] *See* REITZE, *supra* note 77, at 72-91 (discussing the bill in more detail, as well as other legislation proposed during the 111th Congress). The EPA subsequently articulated these requirements in its Class VI rules under the SDWA. *Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2 Geologic Sequestration (GS) Wells, Final Rule*, 75 Fed. Reg. 77,229, 77,260 (to be codifed at 40 C.F.R. pts. 124, 144, 145, *et seq.*).

the CAA to exclude CO_2 and other greenhouse gases from the statute's definition of "air pollution." H.R. 910 and S. 482 also seek to repeal recent EPA rules and actions regarding greenhouse gases, such as the endangerment finding for CO_2. Similarly, the Ensuring Affordable Energy Act (H.R. 153), the Protect America's Energy and Manufacturing Jobs Act (H.R. 199) and the EPA Stationary Source Regulations Suspension Act (S. 231) would prohibit the EPA from regulating greenhouse gases under the CAA,[118] through a cap-and-trade program,[119] or until other countries have initiated CO_2 emission reductions.[120]

While most of the proposed legislation would remove incentives for CCS deployment, some pending legislation would promote CCS technology and clarify legal requirements for CO_2 transport. The New Manhattan Project for Energy Independence (H.R. 301) and the Department of Energy Carbon Capture and Sequestration Program Amendment Act (S. 699) either require the President to accelerate the progress of large-scale CCS systems[121] or amend the Energy Policy Act of 2005 to support CCS commercial deployment through financial and technical assistance.[122] Finally, the Strengthening Pipeline Safety and Enforcement Act (S. 234) and the Pipeline Transportation Safety Improvement Act (S. 275) would direct the Secretary of Transportation to prescribe minimum safety standards for CO_2 pipelines.

[118] H.R. 199 and S. 231.
[119] H.R. 153.
[120] S. 15.
[121] H.R. 301.
[122] S. 757 and S. 699.

B. State Legislation

In the absence of a federal framework, some states and regional bodies have taken action to regulate CO_2 and facilitate CCS use.[123] On CCS specifically, these efforts fall into four broad categories: property law, project authority, liability, and CCS incentives.

1. Property Law

State law generally governs property issues, except on federal lands. Legislation aimed at clarifying property issues include ownership of geologic pore space, unitization of those storage resources, eminent domain, and settling conflicts between surface, pore space, and mineral right owners.

Pore space and CO_2 ownership have received the most attention, as these issues speak to who has the right to inject CO_2 and who owns the CO_2 once injected. Most states follow the traditional common law approach in determining these rights, finding that the surface estate owners also own the pore space, and that the injector owns the CO_2.[124] However, some states have begun specifying ownership through legislation.

Montana, North Dakota, and Wyoming have declared pore spaces to be the property of the surface owner.[125] Therefore, when surface rights are conveyed, the pore space below is also conveyed unless it is severed or explicitly excluded from the

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[123] One example of such efforts is the Interstate Oil and Gas Compact Commission (IOGCC), a regional body that represents oil and gas interests of thirty-eight member states and nine international affiliates. IOGCC advocates for state-level regulation of stored CO_2. IOGCC, Press Release: *States Are Best Positioned to Regulate Carbon Dioxide Storage, Report Concludes* (Sept. 26, 2007), http://www.iogcc.state.ok.us/states-are-best-positioned-to-regulate-carbon-dioxide-storage-report-concludes. Yet other extra-federal efforts focus on regional GHG strategies, such as the Regional Greenhouse Gas Initiative, Midwest Regional Greenhouse Gas Reduction Accord, and the Western Climate Initiative. *See* REITZE, *supra* note 77, at 11-32.

[124] Southern States Energy Board, Carbon Capture and Sequestration Legislation in the United States of America (Mar. 2010), www.sseb.org/files/ccs-legislation-full-version.pdf; *see also* Ian J. Duncan, Scott Anderson, & Jean Phillipe Nicot, *Pore Space Ownership for CO_2 Sequestration in the U.S.*, 1 ENERGY PROCEDIA 4427, 4429-30 (2009); IOGCC, STORAGE OF CARBON DIOXIDE IN GEOLOGIC STRUCTURES, A LEGAL AND REGULATORY GUIDE FOR STATES AND PROVINCES 116 (2007).

[125] MONT. CODE ANN. § 82-11-180 (S.B. 498); N.D. CENT. CODE § 47-31 (N.D. 2138); WYO. STAT. ANN. § 34-1-152 (H.B. 89).

conveyance.[126] While Wyoming allows severance of pore space from the surface interest, North Dakota expressly forbids it.[127]

Additionally, many states have followed the recommendation of the Interstate Oil and Gas Commission (IOGCC) in designating the CCS facility owner as the owner of any injected CO_2.[128] In Montana, North Dakota, Louisiana, Oklahoma, Texas, and Wyoming, the operator owns the CO_2 during injection.[129] Therefore, all rights, benefits, burdens, and liabilities regarding injected CO_2 also belong to the injector, at least during the injection phase.[130]

2. Project Authority

Recent state legislation also has charged state regulatory agencies with developing and administering regulations governing CCS projects. The three state agencies commonly used for this purpose are oil and gas regulatory agencies,[131] environmental agencies, and public utility commissions.[132] Although states differ on which agency they choose, designating an environmental agency appears to be the preferred approach.

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[126] WYO. STAT. ANN. § 34-1-152(b).
[127] *Id.*
[128] The IOGCC believes that the operator of the sequestration project should control the storage project, regardless of who owns the pore space. IOGCC, STORAGE OF CARBON DIOXIDE IN GEOLOGIC STRUCTURES, A LEGAL AND REGULATORY GUIDE FOR STATES AND PROVINCES 23 (2007).
[129] MONT. CODE ANN. 82-11-182 (S.B. 498); N.D. CENT. CODE § 38-20-16 (S.B. 2095); LA. REV. STAT. ANN. §§ 30:1109 (H.B. 1117); 27A OKL. ST. ANN. § 3-5-105 (S.B. 610); TEX. NAT. RES. CODE ANN. T.3, Subpt. D, Ch. 120 (HB 1387); *see also* H.B. 1796 (2009) (proposing that CO_2 be owned by the state for offshore sequestration); WYO. STAT. ANN. § 34-1-153.
[130] *See, e.g.*, WYO. STAT. ANN. § 34-1-153(a).
[131] Louisiana authorized its state Mineral Board and Commission of Conservation to lease state lands for underground CO_2 storage (H.B. 1117 (2008)), while Montana authorized its Board of Oil and Gas Conservatory, with comments from the Department of Environmental Quality, to regulate CCS (S.B. 498 (2009)). In Texas, the Railroad Commission is authorized to regulate CO_2 storage and injection. 35 TEX. REG. 9177; 16 TEX. ADMIN. CODE §§ 5.101, 5.102, 5.201-208.
[132] Colorado legislation empowered the state's Utilities Commission to include CCS in their permitting of power producing facilities. COLO. REV. STAT. ANN. § 40-2-123. Other agencies include a state's Corporation Commission (Kansas, *see* Kansas Stat. Ann. §§ 55-1636 *et seq.*) and an Industrial Commission (North Dakota, *see* S.B. 2095 (2009)).

States such as Wyoming, West Virginia, Washington, Oklahoma, and Texas rely on environmental agencies to address issues associated with CCS.[133]

Wyoming provides a leading example of how states have begun to approach CCS permitting issues. In Wyoming, the Department of Environmental Quality (DEQ) regulates the injection of CO_2, including permit application and notice requirements.[134] Wyoming requires the Administrator of the Division of Water Quality (DWQ) to issue rules for permanent sequestration, and to create a permit application process for geologic sequestration.[135] Sequestration site operators must provide immediate verbal notification to DEQ if migrating CO_2 is discovered, as well as notification to all subsurface owners, mineral claimants, mineral owners, lessees, and other subsurface interest owners.[136] The Administrator of the DWQ must promulgate procedures for termination or modification of any UIC permit in the event that an excursion cannot be controlled or mitigated.[137] Wyoming law also directs the Director of the DEQ to work with the State Oil and Gas Supervisor and the State Geologist to develop appropriate bonding procedures and other financial assurance methods to cover mitigation and reclamation costs.[138]

3. Liability

States also have taken various legislative actions to address liability issues related to CCS, primarily focused on who is liable for injected CO_2 during the various phases of

[133] Wyoming H.B. 90 (Dep't of Envt'l Quality); West Virginia H.B. 2860 (Dep't of Envt'l Protection); Washington E.S.S.B. 6001 (Dep't of Ecology); Oklahoma S.B. 610 (Corp. Commission for fossil-fuel bearing formations and DEQ for all others); and Texas H.B. 1796 (Railroad Commission for CO_2 injection into EOR wells and General Land Office and Bureau of Economic Geology for state-owned, offshore, submerged land).
[134] WYO. STAT. ANN. §§ 35-11-313, 3-5-501.
[135] *See* WYO. STAT. ANN. § 35-11-313(f)(ii)(A)-(N) (requirements that sequestration permit applications must include).
[136] *Id.* § 35-11-313(f)(iii).
[137] *Id.* § 35-11-313(f)(iv).
[138] *Id.* § 35-11-313(g).

the project.[139] Generally, liability resides with the operator, but some states allow state assumption of long-term liability after a specified period of time and issuance of a certificate of completion.

Under Montana law, for example, operators must post a bond to cover projected liability during the injection phase.[140] Until a certificate of completion is issued, the operator is liable for the operation and management of the injection well, the storage reservoir, and the actual liquids injected. A certificate of completion may not be issued until at least fifteen years after injection activities have been completed and certain requirements are met.[141]Like Montana, North Dakota and Louisiana assign liability to the operator during the injection phase and until a certificate of completion is issued.[142] In North Dakota, the Industrial Commission has authority over all CCS activities and may issue a certificate ten years after injections have ceased.[143] Once a certificate has been issued, the operator may transfer liability and ownership of the reservoir to the state.[144] The Louisiana Geologic Sequestration of Carbon Dioxide Act also allows the state to assume liability ten years after injection is complete.[145] In Washington, the operator is liable for the sequestration site until post-closure requirements are complete, including confirmation from the Department of Ecology.[146] However, in Wyoming, liability for the site and injected CO_2 remains with the operator even after a closure certificate is

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[139] Although not discussed in this Section, tort liability may also arise during CCS operations. *See* REITZE, *supra* note 77, at 47-54.
[140] Montana S.B. 498.
[141] Mont. S.B. 498 § 3.
[142] N.D. CENT. CODE § 38-20-16; Louisiana H.B. 661.
[143] *Id.* § 38-20-17.
[144] *Id.* § 38-20-17.
[145] Louisiana H.B. 661.
[146] WASH. ADMIN. CODE § 173-218-115.

issued.[147] Kansas' Carbon Dioxide Reduction Act similarly precludes the state from assuming liability for underground storage of CO_2 and the injection wells.[148]

In addition to identifying liable parties, some states have developed trust funds to cover post-closure liability. For example, Kansas and Texas have created trust funds to pay for the costs of regulation, remediation, and monitoring of CCS activities.[149] Wyoming, Montana, North Dakota, and Oklahoma also have developed trusts or accounts, funded by storage permit and sequestration fees, to cover state measuring, monitoring, and verification costs of sequestration sites after closure.[150] In North Dakota, fees from storage permits will be used to develop a trust fund, allowing the Industrial Commission to assume long-term liability and responsibility for storage reservoirs.[151] Notably, Wyoming also requires certain financial assurances from CCS operators (*e.g.*, insurance).[152]

4. Incentives

Whether CCS succeeds on a broad scale depends in significant part on whether the associated costs can be reduced to a commercially acceptable level. States have sought to address this issue and to incentivize CCS deployment in two ways: GHG regulation and direct financial support, including tax incentives.

[147] WYO. STAT. ANN. § 35-11-318(d).
[148] Kansas H.B. 2418.
[149] Kansas Stat. Ann. §§ 55-1636 *et seq.*; TEX. NAT. RES. CODE ANN. §§ 120.003-.004.
[150] WYO. STAT. ANN. § 35-11-318; Mont. S.B. 498; OKLA. STAT. ANN., tit. 27A, §§ 3-5-104 to -108.
[151] N.D. CENT. CODE § 38-20-14, 38-20-15.
[152] WYO. STAT. ANN. § 35-11-318.

a. Greenhouse Gas Accounting

States vary in their support of greenhouse gas regulation. While Wyoming fought against federal cap-and-trade legislation,[153] California and New Mexico, both members of the Western Climate Initiative (WCI), passed legislation to begin the WCI cap-and-trade program in 2012.[154] The WCI does not include provisions for CCS technology in its cap-and-trade program, but identifies it as a future possibility by recommending that members promote CCS development and deployment.[155] Under New Mexico's program, CCS may be recognized for offset credits if certain criteria are met.[156] New Mexico's program has come under unsuccessful attack from its new governor,[157] while enforcement of California's program has been delayed due to a pending legal challenge to its Global Warming Solutions Act, which defined California's participation in the WCI cap-and-trade program.[158]

Arizona enacted H.B. 2442, which forbid state agencies from regulating greenhouse gases without legislative approval.[159] However, many states have enacted legislation targeting greenhouse gas emissions. For example, the California Global

[153] *See* Dustin Bleizeffer, *Senators Say They'll Fight Cap-and-Trade Legislation*, BILLINGS GAZETTE, Aug. 20, 2009, http://billingsgazette.com/news/state-and-regional/wyoming/article_6d5b0f10-8d3c-11de-9c38-001cc4c03286.html.
[154] N.M. ADMIN. CODE §§ 20.2.350.1-20.2.350.399; Global Warming Solutions Act of 2006, A.B 32.
[155] Western Climate Initative, DESIGN FOR THE WCI REGIONAL CAP-AND-TRADE PROGRAM (July 2010), at § 8.2, http://westernclimateinitiative.org/the-wci-cap-and-trade-program/program-design.
[156] N.M. ADMIN. CODE § 20.2.350.208(A)(1).
[157] *See* Felicity Barringer, *Court Reverses New Mexico Governor on Environmental Rules,* NEW YORK TIMES, Jan. 26, 2011.
[158] *See* Margot Roosevelt, *California delays its carbon trading program for a year*, LOS ANGELES TIMES, June 29, 2011, http://latimesblogs.latimes.com/greenspace/2011/06/california-cap-and-trade.html.
[159] ARIZ. REV. STAT. § 49-117 (2010). However, the EPA included Arizona as one of the thirteen states that must adjust their CAA State Implementation Plans to apply PSD provisions to greenhouse gas emissions. *Action to Ensure Authority to Issue Permits under the Prevention of Significant Deterioration Program to Sources of Greenhouse Gas Emissions: Federal Implementation Plan*, 75 Fed. Reg. 82246 (Dec, 30, 2010).

Warming Solutions Act of 2006 was enacted to reduce greenhouse gas emissions.[160] That law also created an Economic and Technology Advancement Advisory Committee, which released a report promoting CCS as an emissions reduction method.[161] Washington set a greenhouse gas emissions reduction target,[162] and carbon captured and stored in that state is exempted from emission calculations.[163]

b. Financial Support

States have begun taking a variety of activities to support CCS financially. Wyoming specifically provides funding for CCS technologies and activities.[164] Colorado's Clean Energy Development Authority facilitates the production and consumption of clean energy. Facilities and/or technologies with the potential for substantial sequestration of carbon emissions may be eligible for Authority financing and support.[165] Following the tax incentive route, Texas H.B. 469 offers a multifaceted approach: a sales tax exemption for CCS equipment, a franchise tax credit of 10% of the project's capital costs for in-state CCS projects, and a reduced tax rate for oil recovered from EOR projects utilizing anthropogenic CO_2.[166] The legislation also provides a sales tax exemption for personal property used with a Clean Energy Project to capture, transport, or inject CO_2 within the state.[167] Kansas enacted the Carbon Dioxide

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[160] A.B. 32, California Air Resources Board, *AB 32 Fact Sheet – California Global Warming Solutions Act of 2006* (Sept. 25, 2006).
[161] CALIFORNIA ECONOMIC AND TECHNOLOGY ADVANCEMENT ADVISORY COMMITTEE, RECOMMENDATIONS OF THE ECONOMIC AND TECHNOLOGY ADVANCEMENT ADVISORY COMMITTEE FINAL REPORT: TECHNOLOGIES AND POLICIES TO CONSIDER FOR REDUCING GREENHOUSE GAS EMISSIONS IN CALIFORNIA (2008), http:www.arb.ca.gov/cc/etaac/etaac.htm.
[162] WASH. REV. CODE ANN. § 70.235.020.
[163] *Id.* §§ 80.80.60, .70; *see also* WASH. ADMIN. CODE § 173-218-115, 173-407-110 (Dep't of Ecology rules for evaluating carbon sequestration plans for any CCS used to avoid emission limits).
[164] WYO. STAT. ANN. §§ 34-1-152, 34-1-320.
[165] COLO. REV. STAT. ANN. § 40.9.7-106(1)(C)(I)(B) (requiring the Authority to assess whether carbon sequestration projects should be considered clean energy projects eligible for financing).
[166] TEX. GOV'T CODE ANN. § 490.352.
[167] TEX. TAX CODE ANN. § 151.334.

Reduction Act in 2007, directing the Kansas Corporate Commission to issue regulations for carbon sequestration and to create tax incentives for CCS projects.[168] Kansas also passed statutes providing property and income tax breaks for CCS.[169] Similarly, Montana adopted legislation providing tax breaks for CCS equipment.[170] Although New Mexico has not enacted legislation governing carbon sequestration, New Mexico S.B. 994 recognizes CCS as an "Eligible Generation Plant Cost" and provides tax incentives for CCS.[171] Public utilities that incur costs in adopting CCS technology in that state thus may be eligible to recover those costs through an advanced energy tax credit.[172] Finally, North Dakota provides tax relief for EOR-CCS injection projects.[173]

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[168] Kansas Stat. Ann. 55-1637.
[169] *Id.* § 79-233 (property tax exemption); *Id.* § 79-32-256 (CCS equipment deduction).
[170] MONT. CODE ANN. §§ 15-6-158; 15-24-3102, 3111; 82-11-180.
[171] N.M. STAT. ANN. §§ 7-2-18.25, 7-2A-25, 7-9-114, 7-9-114, 7-9G-2, 62-g-228.
[172] *Id.* § 62-6-28(B).
[173] N.D. CENT. CODE §§ 7-51.1-03(5), 49-19-01 *et seq*.

IV. CCS Legal and Policy Issues

For CCS advocates, sequestering carbon from coal combustion seems simple and logical.[174] There is an urgent need for climate change solutions, and we rely heavily on fossil fuels. For CCS policymakers, however, CCS's conceptual simplicity as a climate change mitigation strategy belies the challenges of effectively incenting and regulating the technology. Consider the following scenario, presented by former Wyoming Governor Dave Freudenthal:

> Rancher Smith, who owns 1,500 acres of Wyoming land and leases an additional 1,000 acres, is approached by Company Y with an offer to store carbon dioxide for the long term deep in the earth underneath his ranch. The gas would be pulled from the production of electricity at a coal-fired power plant 120 miles away, and pumped into a vast space deep in a geologic formation underneath Smith's ranch. Now attempt to answer these questions:
>
> • Does Smith have the authority and the right to lease that void under his fee and leased lands?
>
> • Once it is pumped underground, whose responsibility is that carbon dioxide?
>
> • Does Company Y have the authority to force Smith to accept this storage?
>
> • What federal and state regulations would apply?
>
> • Who is liable if the CO_2 doesn't stay where it is supposed to?
>
> • What other parties may possess rights that may be impacted by this transaction?
>
> • As Smith's attorney, what form of indemnification would you require?
>
> The answer to all of these questions at present is—we don't know. The new process of carbon sequestration has opened up a Pandora's Box of regulatory and statutory questions that must be answered—and quickly.[175]

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[174] Brian McPherson, *Clean Coal Technology, Gas Storage, and Carbon Sequestration Projects on Federal Lands*, ROCKY MOUNTAIN MINERAL LAW FOUNDATION ENERGY DEVELOPMENT: ACCESS, SITING, PERMITTING, AND DELIVERY ON PUBLIC LANDS 1 (September 10-11, 2009); IRGC, REGULATION OF CARBON CAPTURE AND STORAGE 4 (2008).

[175] Dave Freudenthal, *A Lawyer's Conucopia or Pandora's Box?,* WYOMING LAWYER 1 (Feb. 2008).

As Section III showed, there currently is no comprehensive set of CCS regulations. Federal efforts have been statute by statute, and those states that have grappled with CCS have adopted a patchwork of varying approaches. Many uncertainties stand as obstacles to developing comprehensive CCS regulation. These include gaps in knowledge of geologic performance, limitations of predictive modeling on geologic storage capacity and plume size and behavior, inadequacies in monitoring methodologies and remediation techniques, technical maturity, public perception, future regulatory requirements, and the underlying question of whether CCS can be both legal and profitable, with manageable liability.[176] For any government that wants to promote CCS, its regulatory scheme faces the daunting task of addressing these—and other—barriers.

Numerous government and academic studies have addressed the policy and regulatory challenges to commercial-scale CCS deployment. Many of these studies suggest specific solutions to narrow segments of the CCS regulatory chasm; others look at the question more broadly. Primarily, however, the literature focuses on barriers to CCS deployment, and within that discussion, chiefly on the need for effective carbon pricing. Analysis of CCS incentives in the literature is more limited than the discussion of barriers, but largely concludes that the capital cost requirements and myriad liability issues presented by long-term carbon storage necessitate some form of governmental financial support for CCS. Suggestions for designing CCS regulations in the legal CCS literature focus heavily on delineating property rights and liabilities relevant to CCS deployment, and secondarily on the utility of existing regulatory pieces for crafting a

[176] IRGC, REGULATION OF CARBON CAPTURE AND STORAGE 18 (2008); IPCC, CCS SUMMARY FOR POLICYMAKERS 3 (2005).

regulatory framework for CCS. The broader CCS literature focuses mainly on the practical and logistical need for governments to embrace a cooperative federalist framework for CCS going forward.

This Section surveys the literature in order to summarize what regulatory quandaries prior studies have suggested are most critical. It proceeds in three Subsections: barriers to CCS commercialization, incentives for CCS use, and suggested regulatory design.

A. Barriers to CCS Commercialization

In 2010, the Interagency Task Force on Carbon Capture and Storage, co-chaired by DOE and EPA, released the most recent domestic analysis of the barriers to "widespread, cost-effective deployment of CCS within [the next] ten years."[177] The Task Force concluded: "While there are no insurmountable technological, legal, institutional, regulatory or other barriers that prevent CCS [use], . . . CCS technologies [likely] will not be widely deployed in the next two decades absent financial incentives that supplement projected carbon prices."[178] Noting this need for a carbon price, the Report went on to identify a number of more specific barriers that CCS faces:

> In addition to the challenges associated with costs, these projects will need to meet regulatory requirements that are currently under development . . . . Key legal issues, such as long-term liability and property rights, also need resolution . . . . A climate policy designed to reduce our Nation's GHG emissions is the most important step for commercial deployment of low-carbon technologies such as CCS,

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[177] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT (2010).
[178] *Id.* at 7-8 (2010). The Task Force's assessment echoed the findings of a 2008 Government Accounting Office analysis of CCS impediments, which concluded that the key barriers to CCS deployment were cost, regulatory uncertainty, particularly in regard to issues of liability, technological inexperience, and the lack of a strategy for controlling domestic CO_2 emissions. *See* GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 2 (2008).

because it will create a stable, long-term framework for private investments.[179]

The Task Force thus identified four barriers as the greatest impediments to CCS commercialization: (1) the failure to enact climate policy, (2) technical scale-up challenges, (3) legal and regulatory uncertainty, including liability and property rights issues, and (4) the lack of public awareness and acceptance. These conclusions echoed over a dozen previous assessments completed in the past seven years attributing CCS lethargy to the entwined hurdles of cost, government inaction, and a private sector disinclined to expend resources to refine CCS technologies in the absence of either a regulatory framework or financial incentives.[180]

Both the Task Force Report and the larger body of CCS literature discuss barriers to CCS deployment from four general perspectives: economic, legal, social, and technological. Among these, the economic barrier of the lack of carbon pricing has been overwhelmingly viewed as the predominant barrier to CCS deployment. Remedying that market deficiency, presumably through adoption of a comprehensive climate change

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179 U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 7-8 (2010).

180 *See* INT'L ENERGY AGENCY, CARBON CAPTURE AND STORAGE: PROGRESS AND NEXT STEPS (2010); PETER FOLGER, CONG. RESEARCH SERV., RL33801, CARBON CAPTURE AND SEQUESTRATION (CCS) (2009); DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT (2009); LARRY PARKER *ET AL*., CONG. RESEARCH SERV., RL34621, CAPTURING CO_2 FROM COAL-FIRED POWER PLANTS: CHALLENGES FOR A COMPREHENSIVE STRATEGY (2009); L. STEPHEN MELZER, DEVELOPMENT OF A POLICY FRAMEWORK FOR CO_2 CARBON CAPTURE AND STORAGE IN THE STATES, PEW CENTER ON GLOBAL CLIMATE CHANGE (2008); THE PROGRAM TO FACILITATE INTERAGENCY ENVIRONMENTAL COOPERATION & THE ENVIRONMENT, ENERGY AND NATURAL RESOURCES LAW CENTER AT THE UNIVERSITY OF HOUSTON LAW CENTER, WHITE PAPER IN SUPPORT OF PROPOSED CARBON GEOLOGIC SEQUESTRATION LEGISLATION (2008); GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION (2008); WORLD RESOURCES INSTITUTE, CAPTURING KING COAL (2008); PEW CENTER ON GLOBAL CLIMATE CHANGE, CONGRESSIONAL POLICY BRIEF (2008); IRGC, REGULATION OF CARBON CAPTURE AND STORAGE (2008); WORLD RESOURCES INSTITUTE, OPPORTUNITIES AND CHALLENGES FOR CCS (2007); INT'L ENERGY AGENCY, LEGAL ASPECTS OF STORING CO_2 (2007); U.S. DEP'T OF ENERGY/NATIONAL ENERGY TECHNOLOGY LABORATORY, CARBON CAPTURE AND STORAGE PROJECTS: OVERCOMING LEGAL AND REGULATORY BARRIERS (2006); IPCC, CARBON DIOXIDE CAPTURE AND STORAGE (2005).

strategy, is seen as the critical threshold step for CCS deployment. The literature anticipates that imposing a price on carbon would expedite the resolution of remaining technological, economic, and regulatory obstacles. The theory behind this expectation is that carbon pricing will shift market realities and incent broader R&D efforts, which will in turn increase technological efficiency and cost-effectiveness, forcing agency action toward a CCS regulatory framework.

Open legal issues, in particular issues of liability, represent the second most formidable barrier to CCS deployment, according to the literature. These legal questions overlap with economic, technological, and social barriers to CCS because liability exposure is viewed by many as necessitating incentives or indemnification. Determining the nature and scope of CCS liabilities is hampered by incomplete information and modeling capabilities for carbon plume behavior and geological storage capacities. Resolving these CCS liability issues has implications for property rights, which are typically an issue of state law and thus not uniformly consistent. Further, the need for cooperation in overlapping federal and state jurisdictions presents its own barrier. The legal CCS literature focuses almost exclusively on these connected issues of ownership, liability, and federalism.

The CCS literature also investigates several tertiary barriers to CCS deployment, such as technical challenges to commercial scale-up, public acceptance, and the need to develop deeper knowledge and predictive modeling capabilities. On top of the various barriers to CCS deployment, additional issues examined in the literature include funding challenges and developing a sufficient CCS regulatory framework.

The remainder of this Subsection provides an overview of these issues, as represented in the recent CCS literature.

1. Economic

Prior analyses identify numerous economic barriers to CCS deployment. The first and most straightforward is that the cost of CCS technology is an inherent barrier to its use: "Cost estimates of current technology for CCS in power production range between \$60 and \$114 per ton of CO_2 avoided depending on the power plant type."[181] The need for R&D that would increase cost-effectiveness is also raised in the literature.[182] The current high costs of CO_2 capture and lost efficiency costs are concerns.[183] Particular cost concerns also include the expense of retrofitting power plants, which are expected to account for a substantial proportion of domestic CO_2 emissions for the next several decades.[184] Additional capital cost issues are presented by the pipeline infrastructure that would be required to transport captured CO_2 from power plants to sequestration sites.[185]

Beyond the capital expenses associated with CCS deployment, the most problematic economic barrier identified in the literature is the absence of effective carbon pricing. The Government Accountability Office (GAO) concluded in 2008 that significant inertia is created by "[t]he absence of a national strategy to control CO_2

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[181] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 27 42 (2010).

[182] GOVERNMENT ACCOUNTING OFFICE (GAO), REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 20 (2008).

[183] L. STEPHEN MELZER, DEVELOPMENT OF A POLICY FRAMEWORK FOR CO_2 CARBON CAPTURE AND STORAGE IN THE STATES, PEW CENTER ON GLOBAL CLIMATE CHANGE 33 (2008); PEW CENTER ON GLOBAL CLIMATE CHANGE, CONGRESSIONAL POLICY BRIEF 1 (2008).

[184] GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 20, 35-41 (2008).

[185] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 36 (2010); WORLD RESOURCES INSTITUTE, CAPTURING KING COAL 3 (2008).

emissions . . . without which the electric utility industry has little incentive to capture and store its CO_2 emissions."[186] The GAO concluded, moreover, that the lack of climate change regulation in the United States is not just a barrier to CCS but to effective CCS regulation as well:

> [A]ccording to key agency officials, the absence of a national strategy to control CO_2 emissions has also deterred their agencies form resolving other important practical issues, such as how sequestered CO_2 will be transported from power plants to appropriate storage locations and how stored CO_2 would be treated in a future CO_2 emissions trading plan.[187]

This connection may create a Catch-22 of sorts. CCS needs regulatory certainty to proceed, but regulators are loath to act without clearer signals that CCS is ready for broad-scale deployment.

As one study recently observed, "[t]o achieve commercialization, the technology must also meet a market demand—a demand created either through a price mechanism or a regulatory requirement (demand-pull mechanisms)."[188] The failure of the United States to create a market that reflects the true price of carbon acts as a disincentive for actors to invest in and deploy CCS technologies.[189] Thus, in contrast to the European Union, where climate change regulation is expected to make CCS viable as early as 2013, some commentators have suggested that CCS is unlikely to be economically favorable in the

[186] GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 2 (2008).
[187] *Id.*; *see also* PEW CENTER ON GLOBAL CLIMATE CHANGE, CONGRESSIONAL POLICY BRIEF 7 (2008).
[188] PETER FOLGER, CONG. RESEARCH SERV., RL33801, CARBON CAPTURE AND SEQUESTRATION (CCS), 25 (2009).
[189] Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH. L. REV. 937, 955-56 (2010). This disincentive may be particularly potent for a public utility in a traditionally regulated state, which may have difficulty justifying CCS capital costs as a prudent investment given the absence of costs associated with GHG emissions and the potential liabilities associated with CCS. PEW CENTER ON GLOBAL CLIMATE CHANGE, CONGRESSIONAL POLICY BRIEF 7 (2008).

United States for at least two decades.[190]

2. Legal

Perhaps the largest regulatory barriers to wide-scale CCS deployment suggested by the CCS literature relate to the potential long-term legal liabilities for the storage phase of CCS.[191] "To have viable carbon storage will require overcoming many technical problems," one study observed, "but it also will require cost effective environmental protection requirements, settling the ownership issues concerning carbon storage, and resolving the issue of long-term liability."[192]

Liability for CO_2 storage is unclear. Two groups potentially bear the long-term risks for CO_2 post-injection: private companies that take on CCS projects and the government/taxpayers. Which group ultimately will bear the risk is an open question.[193] The uncertainty surrounding potential liability for carbon storage is seen in the literature as a source of industry reluctance to invest in CCS.[194] "CCS projects are expensive, and the nature and extent of potential liabilities in the form of injury to human health,

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[190] JP MORGAN, GLOBAL CORPORATE RESEARCH, CAPTURING THE GAINS FROM CARBON CAPTURE 10-14 (2007).
[191] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 53 (2010); *see also* Christopher Bidlack, *Regulating the Inevitable: Understanding the Legal Consequences of and Providing for the Regulation of the Geologic Sequestration of Carbon Dioxide*, 30 J. LAND, RESOURCES & ENVTL. L. 199 (2010); Nathan R. Hoffman, *The Feasibility of Applying Strict-Liability Principles to Carbon Capture and Storage*, 49 WASHBURN L.J. 527 (2010); Donna M. Attanasio, *Surveying the Risks of Carbon Dioxide: Geological Sequestration and Storage Projects in the United States* 39 ELR 10376 (2009); Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long Term Storage of Carbon Dioxide*, 58 EMORY L.J. 103 (2008); Sumit Som, *Creating Safe and Effective Carbon Sequestration,* 17 N.Y.U. ENVTL. L.J. 961 (2008).
[192] REITZE, *supra* note 77, at 18.
[193] *See* Carbon Capture and Storage Technologies Hearing Before the U.S. Senate Committee on Energy and Natural Resources, at 30.
[194] *See id*. at 27-28; *see also* Nina Chestney, *Zurich Financial Seeks Uptake for CCS Insurance*, Reuters, July 7, 2009, available at www.reuters.com/article/rbssFinancialServices AndRealEstateNews; *see also* U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 68-74, 109-118 (2010).

property, and the environment are unknown."[195] Additionally, long-term stewardship of sequestered CO_2 may require assuming legal responsibility for possible interactions with adjoining injection sites.[196] Suggested strategies to manage financial liability associated with long-term stewardship include: traditional bonding and insurance approaches, a wholly private-sector solution, imposing responsibility on states for sequestration sites within their borders, mandating federal responsibility for all sequestration sites, and a hybrid private-public solution.[197]

Also related to liability, the literature observes that geologic sequestration will require continuous monitoring, including thorough risk assessments and mitigation measures.[198] "Continued development is needed for MVA tools to improve aspects related to quantification and resolution of CO_2 in the subsurface, detection of fractures and other potential leakage paths, intermittent leakage, etc."[199] While monitoring strategies must be site-specific to account for local surface and subsurface variations, these studies suggest that a comprehensive regulatory framework for monitoring, mitigation, verification, and accounting will be essential to achieving wide-scale CCS deployment.[200] In particular, the CCS literature suggests that more information is needed regarding the geologic performance of CO_2 in a variety of settings and reservoir types, the basin-scale impacts of CO_2 storage, including displacement of other resources such as

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[195] CCS LEGISLATION MEMO DRAFT 2, at 6 (citing Donna Antanasio, *Surveying the Risks of Carbon Dioxide: Geological Sequestration and Storage Projects in the United States*, Environmental Law Reporter, May 2009, at 5).

[196] DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 51 (2009).

[197] *Id*. at 91-97; *see* Victor Flatt, *Paving the Legal Path for Carbon Sequestration from Coal*, 19 DUKE ENVTL. L. & POL'Y F. 211, 222-24 (2009).

[198] U.S. Dep't of Energy, Monitoring, Verification, and Accounting, http://fossil.energy.gov/sequestration/Monitoring%2C_Verification%2C_and_Accounting.html.

[199] *Id.*

[200] *Id.*

groundwater and induced seismicity, and the adequacy of models to predict reservoir performance at scale.[201] Issues needing further research include: What types of geologic formations can be used? How far must a formation be from water, oil, natural gas, or coal reserves? How secure must the formation be?[202]

In addition to questions of liability for untoward impacts of sequestered CO_2, CCS raises significant, presently unanswered property law questions.[203] This is particularly true for "subsurface property rights and liability."[204] Observers have pointed to three central property law issues: "(1) the question of who owns the pore space deep underground where CO_2 will be stored; (2) the possibility for liability in a trespass action if a CO_2 plume migrates onto neighboring land; and (3) liability for interference with mineral rights by a migrating plume."[205] Additional property rights questions include the

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201 IRGC, REGULATION OF CARBON CAPTURE AND STORAGE 18 (2008).
202 PETER FOLGER, CONG. RESEARCH SERV., RL33801, CARBON CAPTURE AND SEQUESTRATION (CCS) 10-17 (2009).
203 *See* Thomas R. Decesar, *An Evaluation of Eminent Domain and a National Carbon Capture and Geologic Sequestration Program: Redefining the Space Below*, 45 WAKE FOREST L. REV. 261 (2010); Alexandra B. Klass & Elizabeth J. Wilson*, Climate Change, Carbon Sequestration, and Property Rights,* 2010 U. ILL. L. REV. 363 (2010); Owen L. Anderson, *Geologic CO_2 Sequestration: Who Owns the Pore Space*, 9 WYO. L. REV. 97 (2009); Victor B. Flatt, *Paving the Legal Path for Carbon Sequestration from Coal*, 19 DUKE ENVTL. L. & POL'Y F. 211 (2009); Jerry R. Fish & Thomas R. Wood, *Geologic Carbon Sequestration: Property Rights and Regulation*, 54 ROCKY MT. MIN. L. INST. 3-1 (2008); John G. Sprankling, *Owning the Center of the Earth* 55 UCLA L. REV. 979 (2008); Steven A. Kennett et al., *Property Rights and the Legal Framework for Carbon Sequestration on Agricultural Land*, 37 OTTAWA L. REV. 171 (2006).
204 THE PROGRAM TO FACILITATE INTERAGENCY ENVIRONMENTAL COOPERATION & THE ENVIRONMENT, ENERGY AND NATURAL RESOURCES LAW CENTER AT THE UNIVERSITY OF HOUSTON LAW CENTER, WHITE PAPER IN SUPPORT OF PROPOSED CARBON GEOLOGIC SEQUESTRATION LEGISLATION, 55-57 (2008); Victor Flatt, *Paving the Legal Path for Carbon Sequestration from Coal*, 19 DUKE ENVTL. L. & POL'Y F. 211, 237-38 (2009).
205 CCS LEGISLATION MEMO DRAFT 2, at 15; *see* Carbon Capture and Storage Technologies Hearing Before the U.S. Senate Committee on Energy and Natural Resources, at 30; *see also* THE PROGRAM TO FACILITATE INTERAGENCY ENVIRONMENTAL COOPERATION & THE ENVIRONMENT, ENERGY AND NATURAL RESOURCES LAW CENTER AT THE UNIVERSITY OF HOUSTON LAW CENTER, WHITE PAPER IN SUPPORT OF PROPOSED CARBON GEOLOGIC SEQUESTRATION LEGISLATION*,* 55-57 (2008); Victor Flatt, *Paving the Legal Path for Carbon Sequestration from Coal*, 19 DUKE ENVTL. L. & POL'Y F. 211, 237-38 (2009); U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 49 (2010); GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 29-30 (2008); DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE

need for obtaining permission from surface owners for injection wells and related facilities, securing rights-of-way (*e.g.*, for pipelines), placement and access to monitoring wells and devices, and elevated regional pressure fronts due to injection.[206]

3. Social

The potential health and safety risks associated with CCS present more than just legal questions. They also speak to the difficulty of gaining widespread public acceptance for CCS. Both the capture and sequestration phases of CCS present public risks. CO_2 capture presents similar dangers to public health and the environment as other industrial facilities.[207] Storage presents even farther-reaching implications: air pollution from CO_2 leakage, pollution of groundwater, and potential interactions between sequestration site geology and chemical contaminants mixed within the CO_2 stream.[208] Other potential public concerns that may give rise to opposition to CCS deployment are the specter of human fatalities due to high concentration CO_2 releases and seismic events

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MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 57-71 (2009). A fourth property rights issue, ensuring fair market value is paid by private companies leasing public lands for CCS, was addressed briefly by The Energy Independence and Security Act of 2007. It was not discussed extensively in hearings or other proposed legislation. *See* H.R. 6, § 713.

[206] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 48 (2010).

[207] DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 24 (2009).

[208] Carbon Capture and Storage Technologies Hearing Before the U.S. Senate Committee on Energy and Natural Resources, 110th Cong. (2008); *see* DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 46-47 (2009); JP MORGAN, GLOBAL CORPORATE RESEARCH, CAPTURING THE GAINS FROM CARBON CAPTURE 8-9 (2007); WORLD RESOURCES INSTITUTE, OPPORTUNITIES AND CHALLENGES FOR CCS 3-4 (2007).

from improperly injected CO_2.[209] Still further opposition may be prompted by the pipeline infrastructure, including issues connected to rights-of-way.[210]

CCS literature highlights the importance of public outreach, education, and the development of a regulatory framework as the solutions to social barriers to CCS deployment.[211] Studies and surveys have found that public understanding of CCS is low, illuminating the need for greater education and outreach.[212] The Interagency Task Force Report points to the need for integration of public information, education, and outreach throughout the entire lifecycle of a CCS project in order to identify key issues, foster public understanding, and build trust between communities and project developers.[213] In the absence of that trust, "[a] pessimistic public has the potential to take the CCS option off the table and could also shape the costs of deployment if permits are difficult to obtain."[214] Development of comprehensive and uniform best practices for the lifecycle of CCS projects has been proposed as one means of facilitating public acceptance.[215]

4. Technological

Although CO_2 is currently utilized in several industrial applications, technological advancements will be required before existing CCS technologies can be deployed at a commercial scale.[216] The first technological barrier examined in the literature is that a

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209 GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 52 (2008); WORLD RESOURCES INSTITUTE, OPPORTUNITIES AND CHALLENGES FOR CCS 3-4 (2007).
210 U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 36-37 (2010).
211 *Id*. at 53-54 (2010).
212 WORLD RESOURCES INSTITUTE, CAPTURING KING COAL 25 (2008).
213 U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 53-54 (2010).
214 WORLD RESOURCES INSTITUTE, CAPTURING KING COAL 24 (2008).
215 Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH. L. REV. 937, 957 (2010).
216 U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 28 (2010); Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH. L. REV. 937, 963-64 (2010).

nearly pure CO_2 stream is necessary for CCS transport and storage. Uncertainty remains, however, about exactly how pure the captured CO_2 must be and what contaminants will be permissible (*e.g.*, nitrogen, water vapor).[217] Additional unanswered questions are whether CO_2 purity requirements will vary depending on the type of power plant, the capture technology employed, method of CO_2 transport, or sequestration site characteristics.

The literature also raises a number of particular technical challenges related to CO_2 capture.[218] Uncertainties persist with regard to the technical scale-up needed for capturing CO_2 at a typical power plant.[219] For example, maintaining adequate gas and/or liquid flow distribution in larger reactors required for power plant applications could prove difficult.[220] Other technical challenges include high capture and compression auxiliary power loads, capture process energy integration with existing power systems, impacts of flue gas contaminants on CO_2 capture systems, increased water consumption, and achieving a cost-effective oxygen supply for oxy-combustion systems.[221]

Demonstrating that CCS capture can be cost-effective is another hurdle, made more complicated by "(1) the absence of any commercial-scale demonstration of the technology at a power plant; (2) certain limitations of coal gasification technology for capturing CO_2 emissions at new power plants; and (3) the high cost of retrofitting CCS to

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[217] *See* U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 48 (2010).
[218] *Id.* at 34 (2010); GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 20 (2008).
[219] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 34-35 (2010); *see* GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 22-25 (2008).
[220] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 34-35 (2010).
[221] *Id.* at 35; *see* GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 26-27 (2008).

existing pulverized coal-fired power plants . . . ."[222] Yet another hybrid economic-technical barrier is effectively addressing the energy penalty of CO_2 capture.[223]

The literature also raises technical challenges related to the storage phase of CCS, specifically the need to prove CO_2 storage permanence and to verify that sufficient storage exists: "Scientific confirmation of long-term storage security and the diversity of geologic storage media is a precondition to large-scale commercial deployment."[224]

B. Incentives for CCS Deployment

Overall, the CCS literature has focused much less on how to promote commercialization than on identifying the barriers to broad-scale deployment. However, testifying at congressional hearings, stakeholders have pointed to insufficient funding as a potential impediment to commercial-scale deployment of CCS.[225] Such criticisms raise the question of what is the appropriate level for federal investment in CCS R&D.[226] Commentators have noted that current DOE spending on CCS is far below funding committed to solving past technological challenges, such as the Manhattan Project and the Apollo program.[227] Stakeholders disagree over whether the government or private

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[222] GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 20 (2008).

[223] Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH. L. REV. 937, 955-56 (2010).

[224] *Id*. at 957-58.

[225] *See* Carbon Capture and Storage Technologies Hearing Before the Committee on Energy and Natural Resources, 110th Cong. (2008) at 18, 43; *see also* H.R. 7239, 110th Cong. (2008); *see also* Energy Independence and Security Act of 2007, H.R. 6, 110th Cong. (2007).

[226] LARRY PARKER *ET AL*., CONG. RESEARCH SERV., RL34621, CAPTURING CO_2 FROM COAL-FIRED POWER PLANTS: CHALLENGES FOR A COMPREHENSIVE STRATEGY 24-26 (2009); *see* Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH L. REV. 937, 966-73 (2010).

[227] LARRY PARKER *ET AL*., CONG. RESEARCH SERV., RL34621, CAPTURING CO_2 FROM COAL-FIRED POWER PLANTS: CHALLENGES FOR A COMPREHENSIVE STRATEGY 26-27 (2009)). Analysts arguing that higher levels of CCS RD&D are crucial to deployment reference the Synthetic Fuels Corporation as a case study of unsuccessful federal involvement in technology development and a lesson of what to avoid in thinking about the federal role in CCS. *Id.* at 28.

industry should provide primary funding.[228] Four primary approaches[229] for funding CCS have been proposed: "1) government funding through loan or grant programs; 2) tax credits or other financial incentives; 3) private industry funding via a new industry organization; and 4) efforts to encourage international collaboration."[230]

One obvious way to incent CCS use is to price carbon. Retrofitting an existing power plant with CCS technology has the potential to increase electricity costs by 50 to80%.[231] The absence of any financial cost associated with GHG emissions is thus viewed as a fundamental barrier to CCS deployment.[232] The CCS literature consistently points to carbon pricing and appropriate financial incentives for new CCS technologies as critical elements for creating a stable framework for investment in CCS.[233] The literature also cites the need for an "[a]ccounting system, or protocol to quantify the CO_2 emissions from CCS."[234]

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[228] *See, e.g.,* Carbon Capture and Storage Technologies Hearing Before the Committee on Energy and Natural Resources at 43 (suggesting financial incentives similar to those offered for wind energy, ethanol, and other alternative energy sources for CCS) (Gary Loop of the Dakota Gasification Company); Regulatory Aspects of Carbon Capture, Transport and Sequestration Hearing Before the U.S. Senate Committee on Energy, Natural Resources and the Environment, 110th Cong. (2007) (arguing for private industry funding under a "polluter-pays" system) (Senator Robert Menendez).

[229] These four approaches are in addition carbon pricing. *See* Carbon Capture and Storage Technologies Hearing Before the U.S. Senate Committee on Energy and Natural Resources, 110th Cong. (2007); *see also* American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. (2009).

[230] CCS LEGISLATION MEMO DRAFT 2, AT 10-11; *see also* IRGC, REGULATION OF CARBON CAPTURE AND STORAGE 25 (2008) (citing cap and trade systems, market-oriented strategies, and sector-based performance standards for electricity generation as ways to incent CCS deployment); *see* Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH L. REV. 937, 972 (2010).

[231] Dep't of Energy's FutureGen Program Hearing Before the U.S. House Committee on Science and Technology, 110th Cong. (2008) (estimating a 50% increase); Prospects for Advanced Coal Technologies: Efficient Energy Production, Carbon Capture and Sequestration Hearing Before the U.S. House Committee on Science and Technology (2007) (estimating a 60-80% increase).

[232] PEW CENTER ON GLOBAL CLIMATE CHANGE, CONGRESSIONAL POLICY BRIEF 7-12 (2008).

[233] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 10 (2010); *see al*so DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 119-128 (2009); PETER FOLGER, CONG. RESEARCH SERV., RL33801, CARBON CAPTURE AND SEQUESTRATION (CCS) 22-26 (2009).

[234] GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 53 (2008).

Incenting CCS deployment despite its potential liabilities is yet another issue. Several possible legal and regulatory approaches to potential CCS liabilities have been suggested. Long-term liability for CO_2 sequestration could be addressed through a wide variety of actions, including: (1) reliance on existing legal and regulatory frameworks; (2) substantive/procedural limitations on claims; (3) federal legislation facilitating private insurance coverage; (4) establishing a liability fund; (5) government ownership or direct government liability; (6) federal indemnification; or (7) transfer of long-term risk to federal government after site closure.[235] However, concerns have been raised that unlimited federal indemnification risks creating an indefinite public subsidy of private development and implementation of CCS.[236]

C. CCS Policy Design

1. Substance

Throughout the CCS literature, "[r]egulatory uncertainty is widely identified as a key barrier to CCS deployment in the United States."[237] Some existing environmental statutes and programs apply to CCS, as summarized in Section III *supra*, but there is uncertainty about how they will apply, whether there are gaps or overlaps in the programs, and if a more comprehensive CCS framework is needed.[238]

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[235] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 109-118 (2010). *See also* WORLD RESOURCES INSTITUTE, CAPTURING KING COAL 31 (2008).
[236] WORLD RESOURCES INSTITUTE, CAPTURING KING COAL 31 (2008).
[237] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 56 (2010).
[238] *Id.*; *see also* GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 8 (2008); THE PROGRAM TO FACILITATE INTERAGENCY ENVIRONMENTAL COOPERATION & THE ENVIRONMENT, ENERGY AND NATURAL RESOURCES LAW CENTER AT THE UNIVERSITY OF HOUSTON LAW CENTER, WHITE PAPER IN SUPPORT OF PROPOSED CARBON GEOLOGIC SEQUESTRATION LEGISLATION*,* 76-111 (2008); Philip M. Marston & Patricia A. Moore, *From EOR to CCS: The Evolving Legal and Regulatory Framework for Carbon Capture and Storage*., 29 ENERGY L.J. 421 (2008).

In addition to regulation specific to CCS, questions remain about how generally applicable environmental statutes might apply. Among others, these include the National Environmental Policy Act, the Endangered Species Act, the Marine Mammal Protection Act, and the National Historic Preservation Act. Some observers have identified a need "to ensure that [the] effective operation [of these laws] does not hamper CCS for no additional benefit."[239]

The CCS literature also raises policy questions with regard to the transportation component of CCS. Although "the required CO_2 pipeline infrastructure [for CCS] could be very large," potentially as large as the existing natural gas infrastructure,[240] "[t]he design, construction, operation, and safety requirements for CO_2 pipelines have been developed over the past 30 years and are not considered barriers to the deployment of CCS technologies for the five to ten commercial projects planned by 2016 or the commercial efforts after 2020."[241] However, other legal and regulatory issues surrounding CO_2 transport remain. These include the "feasibility of constructing an adequate pipeline infrastructure . . . , rights of way for new pipelines, public participation

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[239] THE PROGRAM TO FACILITATE INTERAGENCY ENVIRONMENTAL COOPERATION & THE ENVIRONMENT, ENERGY AND NATURAL RESOURCES LAW CENTER AT THE UNIVERSITY OF HOUSTON LAW CENTER, WHITE PAPER IN SUPPORT OF PROPOSED CARBON GEOLOGIC SEQUESTRATION LEGISLATION, 112-126 (2008); Jeffrey W. Moore, *The Potential Law of On-Shore Geologic Sequestration of CO_2 Captured from Coal-Fired Power Plants,* 28 ENERGY L.J. 443 (2007).

[240] DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 25-26 (2009).

[241] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 36 (2010);*see also* Jennifer Skougard Horne, Note, *Getting from Here to There: Devising an Optimal Regulatory Model for CO_2 Transport in a New Carbon Capture and Sequestration Industry*, 30 J. LAND, RESOURCES & ENVTL. L. 357, 388-91 (2010); Philip M. Marston & Patricia A. Moore, *From EOR to CCS: The Evolving Legal and Regulatory Framework for Carbon Capture and Storage*, 29 ENERGY L.J. 421 (2008).

in the permitting process, safety concerns . . . , and questions about regulatory authority."[242]

Although the Federal Energy Regulatory Commission (FERC) regulates natural gas and oil pipelines, it has no legislative authority to regulate CO_2 pipelines. Consequently, CO_2 pipelines fall under the jurisdiction of the Department of Transportation (DOT) and its Office of Pipeline Safety.[243] While DOT has issued regulations governing CO_2 pipeline safety, it has not promulgated regulations regarding pipeline rates, access, and placement.[244] One question raised in the CCS literature is whether DOT should retain regulatory authority over CO_2 pipelines.[245] Further, there is no federal legislation granting CO_2 pipelines eminent domain authority (as is done for natural gas lines by the Natural Gas Act), and so obtaining rights-of-way for pipelines is currently a state law issue.[246] It is not clear whether state laws grant eminent domain to CO_2 pipelines, or whether each affected landowner has to consent to pipeline placement. An issue examined in the literature is whether there should be federal legislation allowing for eminent domain or some uniform method of acquiring land for pipelines.[247]

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[242] CCS LEGISLATION MEMO DRAFT 2, at 25. *See also* Regulatory Aspects of Carbon Capture, Transportation, and Sequestration Hearing; S. 2144, 110th Cong. (2007).

[243] DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 27-33 (2009).

[244] GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION 47-49 (2008); *see also* DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 25-33 (2009).

[245] Regulatory agencies are often underfunded and therefore may have difficulty committing the resources necessary to develop the requisite regulations for CCS deployment. *See* IRGC, REGULATION OF CARBON CAPTURE AND STORAGE 23-24 (2008).

[246] DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT 36-41 (2009).

[247] *Id.; see also* WORLD RESOURCES INSTITUTE, CAPTURING KING COAL 13 (2008).

Despite the expected federal role in promoting CCS deployment, there also are substantive regulatory challenges to deploying CCS on federal lands. Neither the Bureau of Land Management nor the Forest Service is authorized to manage long-term CO_2 sequestration.[248] Further, current agency regulations do not address issues of long-term liability, stewardship, ownership of pore space, and appropriate rent for use of federal pore space.[249]

2. Structure

Structural challenges for formulating CCS policy stem from the persistent question of how to divide regulation between states and the federal government.[250] One of the most common suggestions in the literature is that federal and state authorities take a cooperative approach to CCS.[251] Each component of CCS presents regulatory issues for large-scale CCS implementation, including the problematic issues of property rights and liability.[252] The necessary regulatory framework must address capture, transport, site characterization and permitting, operating standards, crediting of mitigated CO_2, and measures to deal with long-term stewardship.[253] This presents complicated political and policy hurdles for CCS deployment due to the "difficulty in establishing an agreed-upon regulatory framework because of the involvement and overlapping jurisdiction[s] of

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[248] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 67 (2010).
[249] *Id.*
[250] *See* J.R. DeSchazo & Jody Freeman, *Timing and Form of Federal Regulation: The Case of Climate Change,* 155 U.PA. L. REV.1499 (2007).
[251] WORLD RESOURCES INSTITUTE, OPPORTUNITIES AND CHALLENGES FOR CCS 6 (2007).
[252] *See* DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, POLICY BRIEF ON COMPREHENSIVE REGULATION (2009); 2008 CCS WHITE PAPER IN SUPPORT OF PROPOSED LEGISLATION, AT 15. However, some commentators suggest state law should govern property rights issues. *See, e.g.,* L. STEPHEN MELZER, DEVELOPMENT OF A POLICY FRAMEWORK FOR CO_2 CARBON CAPTURE AND STORAGE IN THE STATES, PEW CENTER ON GLOBAL CLIMATE CHANGE 24-26 (2008.
[253] WORLD RESOURCES INSTITUTE, OPPORTUNITIES AND CHALLENGES FOR CCS 6 (2007).

multiple regulatory agencies."[254] The CCS literature observes that regulations governing CCS should be flexible in order to readily adapt as new knowledge is gained.[255]

[254] DEP'T OF ENERGY, REGULATORY BARRIERS FOR CCS 6 (2002).
[255] PEW CENTER ON GLOBAL CLIMATE CHANGE, CONGRESSIONAL POLICY BRIEF 12-13 (2008); WORLD RESOURCES INSTITUTE, OPPORTUNITIES AND CHALLENGES FOR CCS 6 (2007), Victor K. Der, *Carbon Capture and Storage: An Option for Helping to Meet Growing Global Energy Demand While Countering Climate Change*, 44 U. RICH. L. REV. 937, 961-62 (2010).

V. Survey Data and Methodology

To test our hypotheses about what the most significant barriers are to commercial-scale use of CCS—and how government entities might best act to alleviate those barriers—we conducted an anonymous opinion survey of parties with expertise in the CCS field. Specifically, the survey included six overlapping classes of recipients: (1) those working directly in the CCS industry, (2) those who provide professional (*e.g.*, engineering, legal, or financial) services to the CCS industry, (3) CO_2 emitters, (4) those who conduct research involving CCS technology and policy, (5) non-profit advocacy organizations, and (6) government regulators. Using commercially available survey software, we distributed the survey via email. Survey participants responded anonymously via the internet. We received 229 responses, 195 of which were complete and 34 of which were partially complete. A copy of the survey is attached to this Report as Appendix A.

This Section describes the methodology used to design and conduct the survey, and details the survey results. Section VI further analyzes the survey data in relation to prior scholarship and policy work in the area. Based on that analysis, Section VI also makes policy recommendations for how CCS regulation should proceed, as suggested by the survey results.

A. Survey Methodology

Although prior CCS studies are numerous,[256] the scholarly literature has not yet systematically assessed the barriers to commercial-scale CCS deployment. Understanding these barriers is an important prerequisite to formulation of effective policies. Accordingly, we designed an anonymous opinion survey to assess those

[256] *See supra* Section IV.

barriers. The survey had four goals: (1) to identify perceived barriers to commercial-scale CCS deployment, (2) to rate the significance of those perceived barriers, (3) to compare the severity of perceived barriers across sectors, and (4) to identify discrepancies between perceived barriers and extant and proposed CCS policies.

1. Survey Design

The survey used three types of questions. First, we asked respondents open-ended questions on a variety of CCS topics. Second, the survey asked participants to rank written statements and options on multi-point scales. Third, we asked questions about the respondent's experience, organization, and role in CCS. We refer to these categories of inquiries as the survey's "open-ended questions," "ranking questions," and "demographic questions," respectively.

The ranking and open-ended questions cut across four broad areas of inquiry:

- <u>Potential barriers to CCS commercialization</u>. The survey asked respondents to identify and rank the largest barriers to CCS commercialization. Open-ended questions included "What is the most significant barrier to commercial-scale GCS deployment?"[257] and "What is the most significant legal or policy barrier to commercial-scale GCS deployment?" The survey also asked respondents to rank forty-one possible barriers to CCS commercialization on a five-point scale.

- <u>Possible government actions to promote CCS commercialization</u>. The survey asked what government can do to help CCS become more viable commercially. Open-ended questions included "What is the most important step that government can take to promote commercial-scale GCS deployment?" and "Are there other important steps that government should take . . . ? If so, what are they?" In addition, the survey asked recipients to rate eleven policy measures for promoting CCS on a multi-point scale of "most promising" to "least promising."

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[257] To be clear that it only addressed geologic carbon capture and sequestration, the survey used the defined acronym GCS. Because this report solely addresses geologic CCS, *see supra* note 20**,** we use the terms CCS and GCS interchangeably.

- Structure of CCS policy. The survey included questions about how United States CCS policy should be shaped. The survey asked open-ended questions such as "Are there areas of GCS regulation that are more appropriate for the federal government than state governments?" The survey also asked respondents to rank their agreement or disagreement with seventeen different statements about CCS regulation on a five-point scale.

- Demographic categories. The survey asked respondents various questions about their demographics. Although the survey was anonymous, respondents were asked to self-identify into the six broad classes of involvement in CCS discussed above. Respondents also were asked to identify the region of the country in which they operate, and how often they deal with CCS technology, policy, and related issues.

Prior to administration, the survey was reviewed and approved by the University of Utah Institutional Review Board. All research was conducted in accordance with applicable requirements and University policies.

2. Survey Participants

Potential survey recipients were identified based on participation in the Massachusetts Institute of Technology carbon sequestration program, the Department of Energy regional carbon sequestration partnerships, attendance at CCS conferences and seminars, internet searches, or participation in other CCS projects.

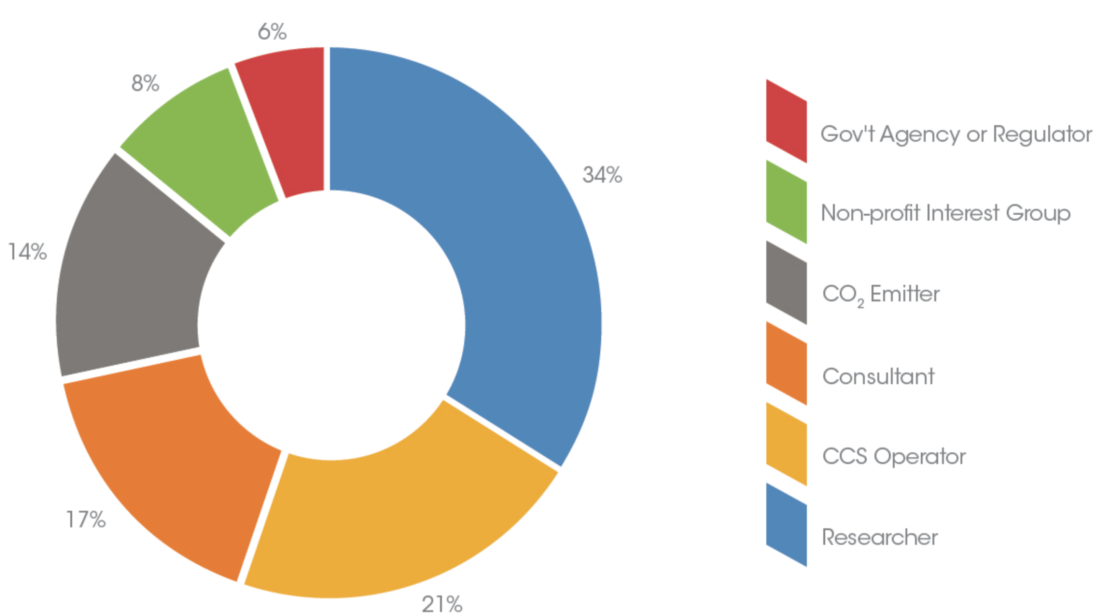
Approximately 620 potential survey respondents were identified initially. This pool of potential respondents reduced to 501, after those with incomplete or incorrect contact information and recipients that affirmatively opted out of the survey were eliminated. Potential recipients who (1) neither work in the United States nor (2) work for a company or organization with a CCS presence in the United States also were excluded.

Each survey recipient was contacted via email and directed to a unique internet address to access the survey, preventing unauthorized individuals from completing the

survey and ensuring that respondents completed the survey no more than once. Of the 501 recipients contacted, we received responses from 229 recipients, or 45.7%. In total, 195 of respondents completed the survey in its entirety, or 85.2% of survey respondents.

Survey respondents broke down as follows: 47 of the 229 survey respondents self-identified as CO_2 emitters, 70 self-identified as CCS operators (entities engaged in CO_2 capture, transport, or sequestration), 55 self-identified as consultants to either CO_2 emitters of CCS operators, 19 self-identified as government agency employees or regulators, 113 self-identified as researchers, and 27 self-identified as part of a non-profit interest group. These categories are not mutually exclusive, and many respondents self-identified in more than category. Figure 5.1 shows this breakdown.

Figure 5.1: Number of Respondents by Affiliation



3. Survey Data Analysis

Responses to the survey's ranking questions yielded numerical data. Answers to the open-ended questions were entirely textual. These responses were analyzed and placed into categories corresponding to the ranking questions, to facilitate statistical comparison across question type. To avoid coding bias, two separate researchers coded the open-ended responses independently and then compared coding. Where there were coding differences, they were reconciled by a third review of the textual answers. Analysis of the survey responses was conducted using commercial spreadsheets and statistical software.

B. Survey Results

The survey results identified several important lessons about barriers to CCS commercialization, and what regulatory measures might address these barriers. The eight primary points are:

- There are four primary, interrelated barriers to CCS commercialization: cost, lack of a price signal or other financial incentive for CCS use, liability, and lack of comprehensive CCS regulation.

- Of these, cost and cost-recovery are the greatest obstacles. Survey participants ranked these obstacles as the "most significant" to CCS commercialization, and cost received the overwhelming number of responses to the open-ended questions.

- Although insufficient technology is often cited as a barrier to CCS, this seems not to be the case. Survey participants expressed relative confidence in CCS technology compared to other possible CCS barriers, and the more often respondents work with the technology, the more confidence they are likely to have in it.

- Incentives for CCS commercialization are strongly favored by the CCS community. The four most favored are economic and regulatory: tax/financial incentives, liability limits, a comprehensive CCS regulatory framework, and a carbon tax.

- There is, however, little consensus regarding which incentive is best. Virtually every sector of the CCS community has a different preferred path forward. A combined approach may be necessary.

- The CCS community wants clear, comprehensive regulation of its processes. The most desired regulation is liability limits, followed by a general preference for comprehensive CCS regulation.

- The preferred form of liability protection is for the government to take legal custody of sequestered CO_2 at some point after site closure.

- All six classes of CCS community representatives believe that cooperative federalism, where the federal government sets uniform standards and states implement them, is the best approach for CCS regulation.

The remainder of this Section details the survey findings, first on CCS barriers, then on incentives, and finally on regulatory substance and structure.

1. Barriers to CCS Commercialization

Our survey confirms that there are four primary, interrelated barriers to commercial-scale CCS. They are (1) CCS's comparatively high cost, when weighed against current electricity production costs, (2) the lack of a price signal to incentivize CCS use, primarily because the United States has not adopted a climate change regulatory regime, (3) liability risks from underground CO_2, and (4) the "lack of comprehensive GCS regulation."

By contrast, a number of possible barriers that have been held out as key impediments to CCS commercialization received lower "obstacle" ranking scores. For instance, much attention has been paid to the need for "demonstration" projects showing that CCS can work not only for EOR but also on a stand-alone basis at a commercial scale.[258] Our survey shows, however, that while the CCS community considers the lack of such demonstration projects a barrier to the technology's commercialization, they

[258] *See supra* Section IV.A.4.

perceive it to be less significant than others. Likewise, although concern over public resistance to CCS projects has been cited as a CCS obstacle,[259] this registered much lower than other barriers.

Survey recipients were asked to rank forty-one different possible barriers to CCS commercialization on a one-to-five scale, with 1 representing "no obstacle" to CCS commercialization, 2 representing "minor" obstacles, 3 "measurable" obstacles, 4 "significant" obstacles, and 5 "critical" obstacles. These forty-one potential barriers fall into seven broad categories: CCS cost, liability, siting, technology insufficiency, lack of a CCS price signal (via climate change legislation or other financial incentive), lack of a CCS regulatory regime, and public resistance to CCS.[260] For each broad category, the survey included a generic "catchall" question asking about the category and more specific questions about discrete elements of the potential barrier. Mean values also were computed for the seven broad categories. A full table of the categories, their subcategories, and the survey results is appended hereto as Appendix B.

The possible CCS barriers can be ranked using the mean scores for each of the seven categories' "catchall" questions. Using these scores, no barrier category—and no barrier subcategory—received a ranking as a "critical" CCS obstacle (*i.e.*, a mean score of 4.5 or above). Rather, survey respondents ranked most of the potential barriers as "significant" obstacles to CCS commercialization (*i.e.*, a mean score of 3.5 or higher but less than 4.5). In all, five categories received mean scores of "significant" barriers to

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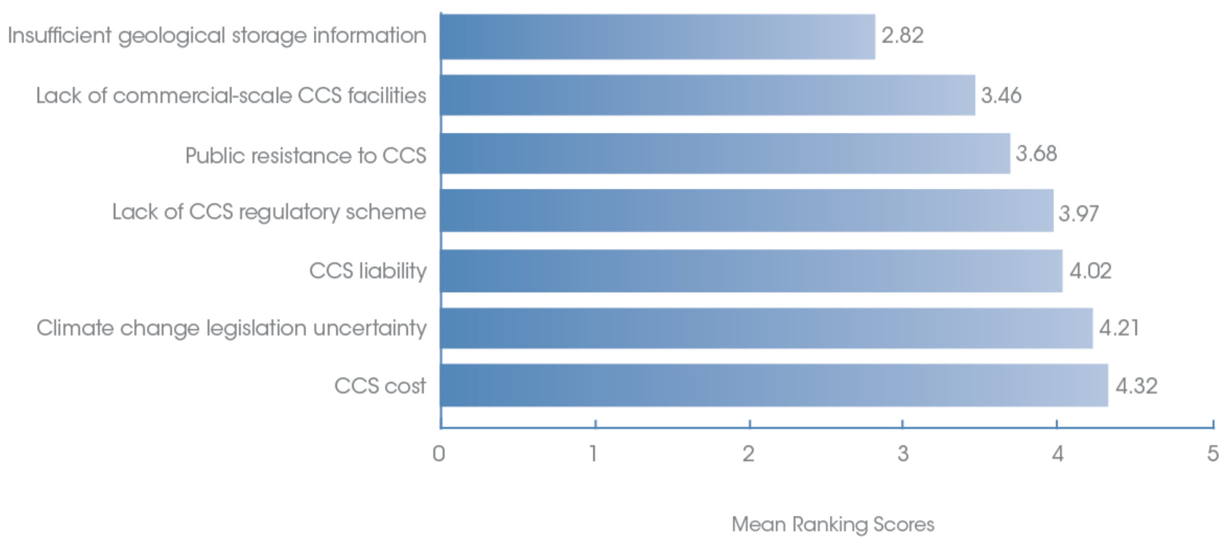
[259] *See supra* Section IV.A.3.

[260] Two of the forty-one barriers were excluded from the seven general categories. Those were "public resistance to new coal-fired power plants," which received a mean obstacle ranking score of 3.46, and "inadequate pipeline capacity for CO_2 transportation," which received a score of 2.81. Thus, the seven broad categories include only 39 of the ranking obstacle subcategories. These barriers were excluded because they are only indirectly related to CCS or did not align closely with the broader categories. The pipeline capacity ranking is consistent with other data in the survey suggesting that CCS transport is the least troublesome part of the three CCS processes.

CCS commercialization: CCS cost, the lack of a carbon price signal, CCS liability, the lack of a comprehensive CCS regulatory scheme, and public resistance to CCS. *See* Figure 5.2.

Although five of the seven categories were considered "significant" CCS obstacles, there was variation along this scale. Two categories—insufficient CCS technology and insufficient information and physical capacity for CCS storage—received markedly lower rankings, considered by survey respondents as "measurable" obstacles to CCS (*i.e.*, a mean score of 2.5 or higher but less than 3.5). In addition, one subcategory received a ranking as merely a "minor" obstacle (*i.e.*, a mean score of 1.5 or higher but less than 2.5): the adequacy of technology to transport CO_2. That subcategory received a mean score of 1.97. No category or subcategory received a ranking of "no obstacle" (*i.e.*, a mean score of less than 1.5).

Figure 5.2: Mean Ranking Scores of Possible Barriers to CCS



Together, these results highlight one of the key findings of our survey: that those with expertise in CCS consider the technology to be feasible. As shown in Figure 5.2, the respondents to our survey overwhelmingly see the largest barriers to CCS use as exogenous to CCS itself. In their view, the difficulty with CCS is not CCS technology, but rather, the "legal, policy, and economic considerations," as one survey respondent put it, that surround CCS.

Moreover, the barriers to commercialization that the survey participants considered most substantial relate primarily to a single issue: cost. Time and again, respondents pointed to the cost of CCS, the lack of a carbon price signal from climate change regulation or other government financial incentive for using CCS, uncertainty regarding their ability to recover costs, and the possibility of open-ended liability as the

largest impediments to CCS deployment. One respondent made the point this way: "CCS costs money. [P]ut a cost on carbon emissions and then industry will figure it out. [It is] really that simple." Others identified similar concerns, noting that the "[c]ost of uncertainty," including the risk of "investing in potential future stranded asset[s]" or putting money into "an investment that has no financial return," are the biggest stumbling blocks to CCS use.

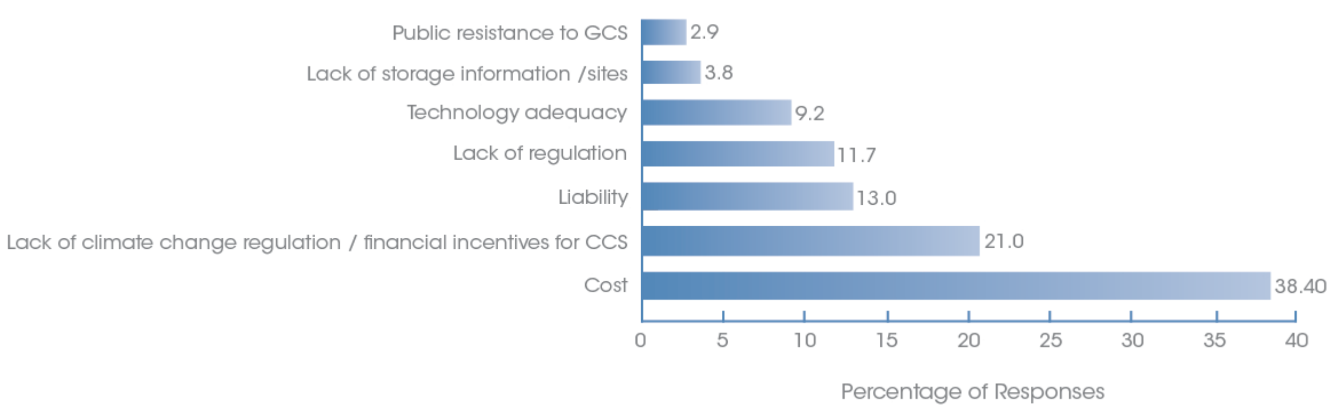
Survey respondents also clearly crave regulatory certainty. The desire for "comprehensive" CCS regulation received an obstacle ranking score almost identical to that for potential liability, long considered one of the most significant barriers to CCS.[261] This is perhaps understandable, given the myriad permitting, siting, property rights, liability, rate regulation, cost recovery, safety, and other legal issues that CCS presents. Thus, in response to the question "What is the most significant legal or policy barrier to commercial-scale GCS deployment?," one survey respondent answered: "Lack of the legal infrastructure necessary to support sound development of GCS, meaning long term responsibility management, [and] state and federal regulations . . . that address GCS implementation issues."

This ranking of barriers to CCS commercialization is further confirmed in two ways. First, the mean "obstacle ranking" scores for the barrier "catchall" questions can be compared against the responses that survey recipients gave to the survey's open-ended questions. When asked to identify "the most significant" obstacle to commercial-scale CCS deployment, participants' answers matched almost perfectly the order in which they

[261] *See supra* Sections IV.A and IV.A.2.

put the obstacles in the ranking questions.[262] In open-ended questions, the most cited obstacle to CCS commercialization was cost, followed by lack of a carbon price signal, CCS liability, and lack of comprehensive CCS regulation. *See* Figure 5.3. This was the same order of importance that survey respondents placed on these barriers in the numeric obstacle ranking questions. The list produced from this open-ended question does, however, slightly differ in its ranking of the final three obstacle categories. As shown in Figure 5.3, survey respondents named public resistance to CCS least often in response to this open-ended question, whereas it was the fifth-highest ranked obstacle in the ranking questions. Otherwise, the percentage of responses from this open-ended question tracks with the way respondents rated those obstacles in the ranking portion of the survey.

Figure 5.3: % of Open-Ended Responses Identifying Barriers as "Most Significant" to CCS Commercialization



[262] Percentages of responses to open-ended questions were calculated after blank, "don't know," and "other" responses (those that fit into no coded category) were excluded. The number of "other" responses was minor. Where a response identified more than one obstacle, all obstacles were coded.

Second, the "obstacle ranking" scores for the broad "catchall" questions can be compared against the mean ranking scores for the entire category, including all of that barrier's subcategories. For instance, while respondents were asked to rank the catchall "cost of CCS" as an obstacle, they also were asked to rank more specific related obstacles such as the "cost of CO_2 capture," the "cost of CO_2 storage," and the "cost of CO_2 transportation." Similarly granular subcategory questions were asked for each of the different broad obstacle categories.[263] Comparing the average score of all questions in the category against the score for the "catchall" question ensures that the catchall score is reliable, preventing over-emphasis on the catchall score where respondents gave much different scores to the obstacle's more discrete parts.

Importantly, this cross-check reveals a similar pattern to what the catchall ranking questions showed. Although using the category-wide ranking scores drops one obstacle, cost, from the first to the third most important CCS barrier—and raises another obstacle, the lack of comprehensive CCS regulation, from fourth to second—the overall pattern is nearly the same. Using the category-wide mean scores, the top four obstacles are the same as they were using either the "catchall" ranking scores or the open-ended answer percentages. The bottom three obstacles also remain the same. Further, it is hardly surprising that "CCS cost" is reshuffled from first to third once its category-wide score is considered. It is widely acknowledged that the primary cost of commercializing CCS is likely to come from CO_2 capture.[264] Thus, when other, likely less expensive portions of the CCS process are averaged into this obstacle's score, it should be expected to drop

[263] The number of subcategories varied by obstacle. Refer to Appendix B for a list of the broad categories and their corresponding subcategories.
[264] *See supra* Section II.A.1.

somewhat in ranking. A full comparison of the obstacle rankings by each of these three scoring methods is shown in Table 5.1 below.

Table 5.1: Comparison of CCS Commercialization Barrier Rankings

Potential Barrier	Mean "Catcall" Obstacle Score (Rank)*	Percentage of Responses in Open-Ended Questions (Rank)	Mean Aggregated Category-Wide Score (Rank)*
CCS cost	**4.32 (1)**	38.4% (1)	3.73 (3)
Lack of/uncertainty about climate change legislation	**4.21 (2)**	21.0% (2)	**4.06 (1)**
CCS liability	**4.02 (3)**	13.0% (3)	3.53 (4)
Lack of comprehensive CCS regulation	**3.97 (4)**	11.7% (4)	**3.80 (2)**
Public resistance to CCS	**3.68 (5)**	2.9% (7)	3.30 (5)
Lack of proven commercial-scale CCS operations	3.46 (6)	9.2% (5)	**2.87 (6)**
Lack of information about sequestration site geology/capacity	**2.82 (7)**	3.8% (6)	2.75 (7)

*Values in bold are statistically significant ($p \leq .05$) when compared to the mean overall barrier ranking of 3.35.[278]

Notably, obstacle significance varies little by the type of survey respondent. The survey participants broke down into six categories: CO_2 emitters, CCS operators, consultants, regulators, researchers, and nonprofit interest groups. As shown in Table 5.2, all respondent categories placed the lack of a carbon price or other CCS financial

incentive first when the category-wide scoring metric is used. Likewise, all respondent categories put CCS liability fourth as an obstacle and public resistance fifth. The only differences were that some respondent classes switched CCS cost and lack of CCS regulation between second and third, and regulators and researchers flipped the order of lack of CCS technology and insufficient CO_2 storage site information between sixth and seventh.

Table 5.2: Obstacle Ranking by Respondent Category

Category-wide CCS Obstacles (rank)	CO_2 emitters	CCS Operators	Consultants	Regulators	Researchers	Non-profits
Lack of/uncertainty about climate change legislation	1	1	1	1	1	1
Lack of comprehensive CCS regulation	2	2	3	3	2	3
CCS cost	3	3	2	2	3	2
CCS liability	4	4	4	4	4	4
Public resistance to CCS	5	5	5	5	5	5
Lack of proven commercial-scale CCS operations	6	6	6	7	6	6
Lack of information about sequestration site geology/capacity	7	7	7	6	7	7

The survey data, however, do show some difference in how often respondents have exposure to CCS technology and policy. Those who deal with CCS technology or policy on a daily basis rank barriers to commercialization differently than those who self-report as dealing with these issues only "occasionally." As shown in Table 5.3, those

who deal with CCS more often tend to view the lack of CCS regulation as more problematic than those who deal with CCS less often. Respondents dealing with CCS daily also see the lack of a certain carbon price or financial incentive for CCS use as more problematic than do those who have less exposure to CCS; the latter category of respondents puts greater emphasis on the cost of CCS as a barrier to commercialization. Indeed, respondents with less frequent involvement with CCS technology or law and policy give higher mean values to almost all barriers when compared to their more involved colleagues. This tends to suggest that familiarity tends to reduce concern. Statistically significant ($p \leq .05$) mean aggregated category-wide scores are shown in bold.[265]

[265] Daily involvement with CCS technology was tested against occasional involvement with CCS technology, and daily involvement with CCS law and policy was tested against occasional involvement with CCS law and policy. Involvement with technology was not tested against involvement with law and policy.

Table 5.3: Mean Obstacle Ranking by Frequency of Involvement with CCS*

Mean Aggregated Category-Wide [Score (Rank)]	Daily Involvement with CCS Technology	Occasional Involvement with CCS Technology	Daily Involvement with CCS Law and Policy	Occasional Involvement with CCS Law and Policy
Lack of/uncertainty about climate change legislation	**4.17 (1)**	**3.85 (2)**	3.96 (1)	4.16 (1)
Lack of comprehensive CCS regulation	3.87 (2)	3.81 (3)	3.67 (2)	4.00 (2)
CCS cost	**3.64 (3)**	**3.95 (1)**	**3.67 (3)**	**3.98 (3)**
CCS liability	3.43 (4)	3.61 (4)	**3.37 (4)**	**3.78 (4)**
Public resistance to CCS	3.21 (5)	3.39 (5)	3.33 (5)	3.40 (5)
Lack of proven commercial-scale CCS operations	**2.69 (6)**	**3.28 (6)**	**2.50 (7)**	**3.25 (6)**
Lack of information about sequestration site geology/capacity	**2.58 (7)**	**2.98 (7)**	2.59 (6)	2.76 (7)

*Values in bold are statistically significant ($p \leq .05$) when compared to the mean overall barrier ranking of 3.35.

The remainder of this Subsection discusses more detailed survey findings with respect to five of the CCS commercialization barriers: cost, liability, public resistance, technology, and geology. The following two Subsections address survey results on the other two obstacles: government incentives for CCS use and CCS regulation.

a. Cost

The survey results reveal three interesting findings with respect to cost as a CCS barrier. The first is not surprising. Cost is, by far, the most important barrier to CCS use. As stated by one survey respondent, "The most significant barrier is the potential impact on energy costs for our customers." Another respondent put it this way: "[CCS's] impact on power price [is the biggest barrier to CCS]. [L]ow carbon power is more expensive than conventional power yet there is no requirement or incentive to purchase it . . . The policy makers are so focused on renewables that they are overlooking or crowding out the much-needed potential for baseload low carbon CCS power that would serve to firm up the intermittent power." In fact, as shown in Figure 5.3 above, the percentage of respondents who identified CCS cost as the "most significant" barrier to the technology's commercialization dwarfed other barriers identified in open-ended questions: Thirty-eight percent of respondents cited this as the greatest barrier. The next closest barrier was lack of a carbon price signal, which notched 21% of responses. Similarly, in response to the question "What is the most significant financial or business-related barrier to commercial-scale GCS deployment?," 42% of responses identified cost. By comparison, 23% of responses identified the lack of a carbon price or other financial incentive for CCS use, 11% identified liability, and 10% named uncertainty of one kind or another.

The second finding on cost is equally unsurprising. The "energy penalty" associated with CO_2 capture repeatedly has been noted as the key driver for the relatively

Table 5.4: Mean CCS Technology Costs Obstacle Rankings*

Potential Barrier	The cost of GCS	CO_2 Capture	Retrofitting CO_2 emission sources	CO_2 storage	GCS site monitoring	CO_2 transport
Obstacle Score	4.32	4.12	3.99	3.20	2.87	2.84

*Values in bold are statistically significant (p.≤.05) when compared to the mean overall barrier ranking of 3.35.

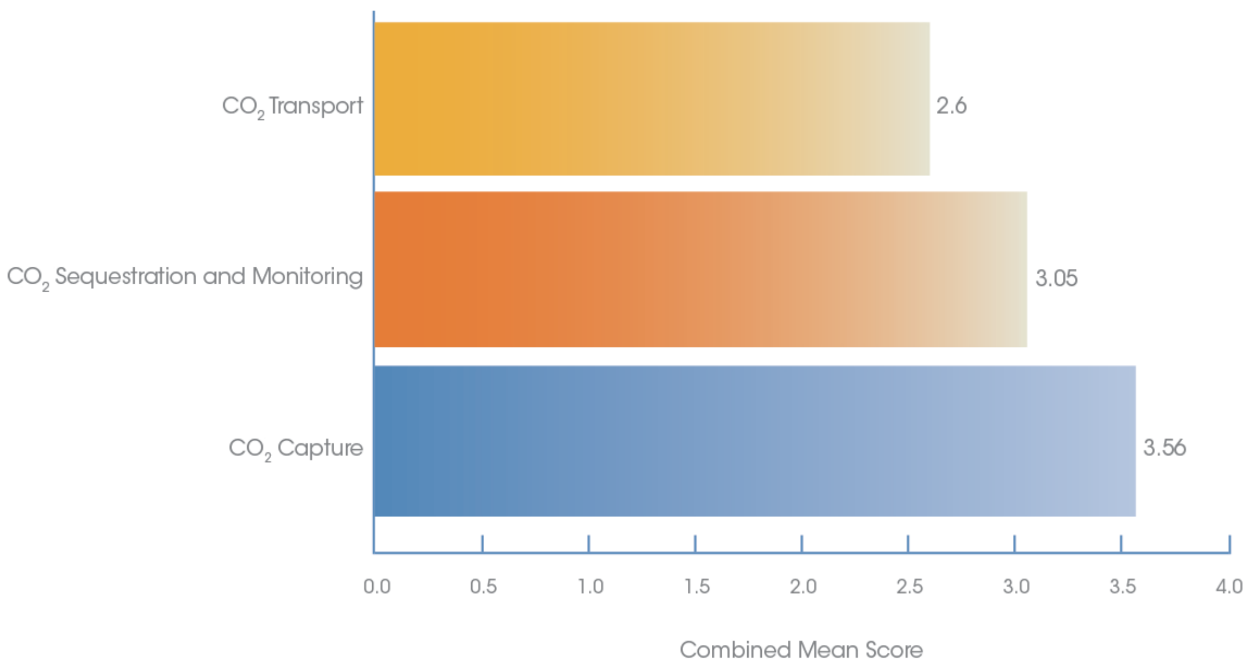
high cost of CCS.[266] Our survey supports this. The cost of CO_2 capture received a higher mean score in the ranking questions—4.12—than any other factor except "the cost of GCS" itself. Likewise, the "cost of retrofitting existing CO_2 emission sources" received the third highest mean score among these cost barriers, 3.99. By contrast, those factors not related to carbon capture received much lower obstacle scores. The cost of CO_2 storage, site monitoring, and transportation all ranked notably lower than carbon capture or retrofit: means of 3.20, 2.87, and 2.84, respectively. *See* Table 5.4 (mean response values that are statistically different ($p \leq .05$) from the overall mean barrier rating of 3.35 are shown in bold).

Likewise, analysis of the various obstacle subcategories related to the three technological phases of the CCS process—CO_2 capture, transport, and storage—shows that respondents see CO_2 capture as the most challenging aspect of CCS. To perform this analysis, the different cost- and technology-related obstacle scores for each phase of CCS were summed and averaged. That analysis, as reproduced in Figure 5.4, makes plain that

[266] *See supra* Sections IV.A and IV.A.1.

CO_2 capture is perceived as more of a barrier to CCS commercialization than transport or storage.

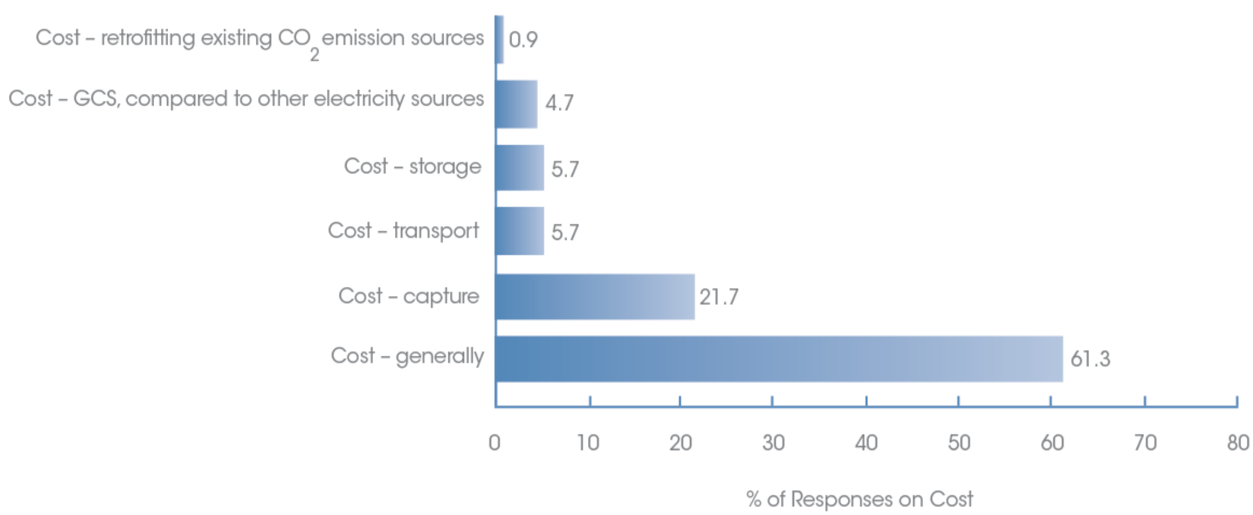
Figure 5.4: Mean Combined Technology-Cost Obstacle Ratings



Both of these results, moreover, were consistent with the open-ended question responses. Responses identifying the cost of carbon capture as a barrier to CCS deployment were ubiquitous. "The high cost of CO_2 capture (capital and operating, which includes parasitic power loss) are the most immediate barriers" to commercial-scale CCS deployment, one survey respondent wrote. A different participant sounded a similar refrain: "Cost. Capturing CO_2 is expensive." Wrote another, "At this time the

capture technology is not [feasible] and is too costly. Once the capture [technology] is developed at reasonable cost," how to address other barriers to CCS commercialization will follow. Of those responses identifying cost as a key financial or business-related barrier in the open-ended questions, in fact, more mentioned capture specifically—by almost two times—than named storage and transport combined. *See* Figure 5.5.

Figure 5.5: % of Open-Ended Responses Discussing CCS Cost Types



The survey's third finding on cost is that uncertainty about cost recovery appears to be more important than other CCS cost risks. While survey respondents rated the cost of CO_2 capture higher than any other cost subcategory, concerns about the ability to recover those investments also rated highly. "Public resistance to higher commodity and electricity prices" received a mean obstacle score of 4.00. Likewise, "uncertainty

regarding utilities' ability to recover costs for using GCS" scored 3.96. And "public utility commission reluctance to pass along GCS costs to ratepayers" came in at 3.79. Contrast these "significant"-level obstacle ratings with the "measurable"-level mean scores of 3.20, 2.87, and 2.84 for CO_2 storage, site monitoring, and transportation costs, and the perceived risk of being a first mover on CCS becomes clear. Although the cost of CO_2 capture is an important barrier to CCS commercialization, so too is companies' ability to recoup their investments. This implies that one important element of a CCS regulatory regime may be cost recovery assurances of some kind.

Table 5.5: Mean CCS Cost Risks Obstacle Rankings

Potential Barrier	CO_2 Capture	Public resistance to higher prices	Uncertainty of utility cost recovery for CCS use	PUC resistance to passing along CCS costs	CO_2 storage	GCS site monitoring	CO_2 transport
Obstacle Score	**4.12**	**4.00**	**3.96**	**3.79**	3.2	**2.87**	**2.84**

*Values in bold are statistically significant ($p. \leq .05$) when compared to the mean overall barrier ranking of 3.35.

b. Liability

That CCS liability also ranked highly as a commercialization obstacle was not unexpected. Liability risks are one of the leading factors cited for reluctance to CCS.[267] What is notable about this finding is that long-term liability is considered much more problematic than liability for CCS transport. The mean obstacle score for "liability for CO_2 pipeline operators" was 2.82. No other liability-related subcategory received a mean

[267] *See supra* Sections IV.A and IV.A.2.

obstacle score lower than 3.43, and those for CO_2 storage liability and the lack of a statutory liability cap for CCS had means of 4.02 and 3.85, respectively.

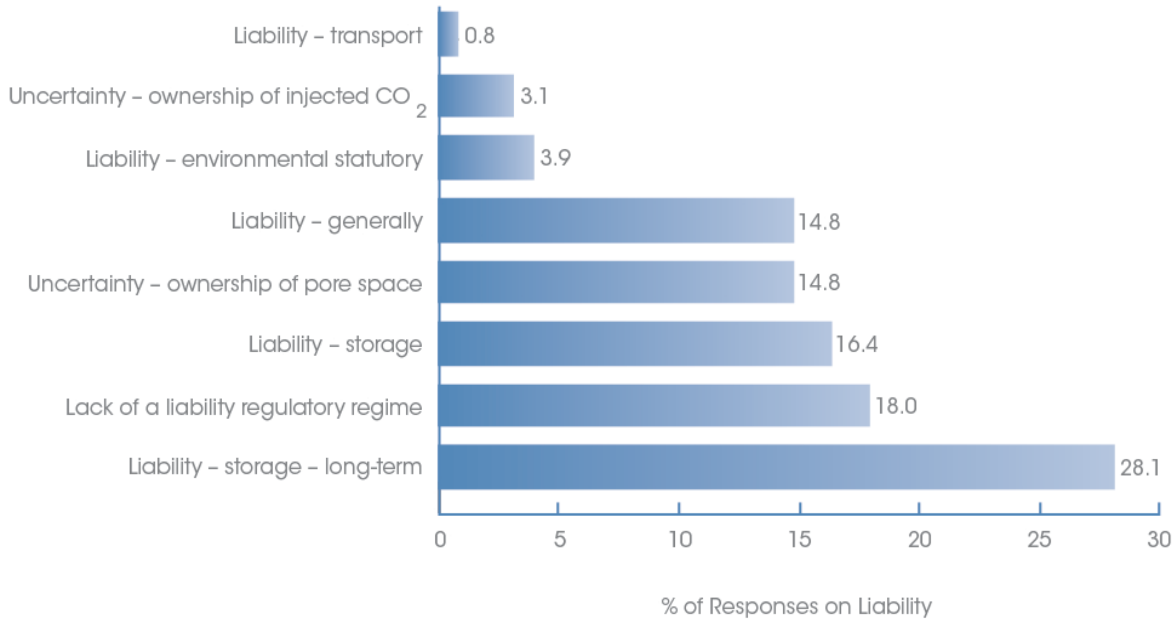
Table 5.6: Mean CCS Liability Obstacle Rankings

Potential Barrier	Liability for CO_2 storage	Lack of a statutory liability cap for CCS	Uncertainty about pore space ownership	Lack of insurance or bonding for sequestered CO_2	Uncertainty about injected CO_2 ownership	Liability for CO_2 pipeline operators
Obstacle Score	**4.02**	**3.85**	**3.52**	**3.51**	3.43	**2.82**

*Values in bold are statistically significant ($p \leq .05$) when compared to the mean overall barrier ranking of 3.35.

Liability's high obstacle rankings are consistent with the open-ended responses. One question asked, "What is the most significant legal or policy barrier to commercial-scale GCS deployment?" In response, 128 participants identified liability as an obstacle. Of those, 66% identified some kind of liability related to CO_2 storage. Another 18% identified the lack of a regulatory regime alleviating liability concerns, and nearly 15% identified liability generally as an obstacle. However, as shown in Figure 5.6, less than 1% of these responses named liability associated with CO_2 transport as a CCS obstacle.

Figure 5.6: % of Open-Ended Responses Discussing CCS Liabilty Type



c. Public Resistance

Survey results concerning public resistance to CCS further confirm the findings on liability. Survey respondents reported a markedly higher concern for public resistance to long-term CO_2 storage sites than they did for other CCS activities. Respondents gave "public resistance to GCS" a mean rating of 3.68. "Public resistance to GCS storage facilities" received a similarly high mean value of 3.42, placing it within the "measurable" category. In contrast, respondents rated public resistance to "CO_2 pipelines" and "retrofitting existing CO_2 emission sources" much lower: at means of 2.82

and 2.56, respectively. Such differentials in the ranking of these possible obstacles is consistent with the survey results showing that liability concerns are most closely associated with the storage phase of CCS.

Table 5.7: Mean CCS Public Resistance Obstacle Rankings

Potential Barrier	Public resistance to higher commodity and electricity prices	Public resistance to CCS	Public resistance to CCS storage facilities	Public resistance to CO_2 pipelines	Public resistance to retrofitting existing CO_2 emission sources
Obstacle Score	**4.00**	**3.68**	3.42	**2.82**	**2.56**

*Values in bold are statistically significant ($p \leq .05$) when compared to the mean overall barrier ranking of 3.35.

Notably, however, none of the "public resistance" obstacle subcategories received more than a negligible number of responses to the three open-ended questions on CCS barriers: As shown in Figure 5.3 above, fewer than 4% of responses identified any form of public resistance to CCS as the "most significant" obstacle to CCS commercialization. This comports with the general ranking of public resistance as less of an obstacle to CCS commercialization than others. It also raises a question about whether the cost element of public resistance skews this category's ranking score, making it appear somewhat higher than it may actually be.

d. Technology Adequacy

Beyond the fact that the lack of adequate CCS technology ranked much lower than other CCS obstacles, perhaps the most notable finding here is the clear difference

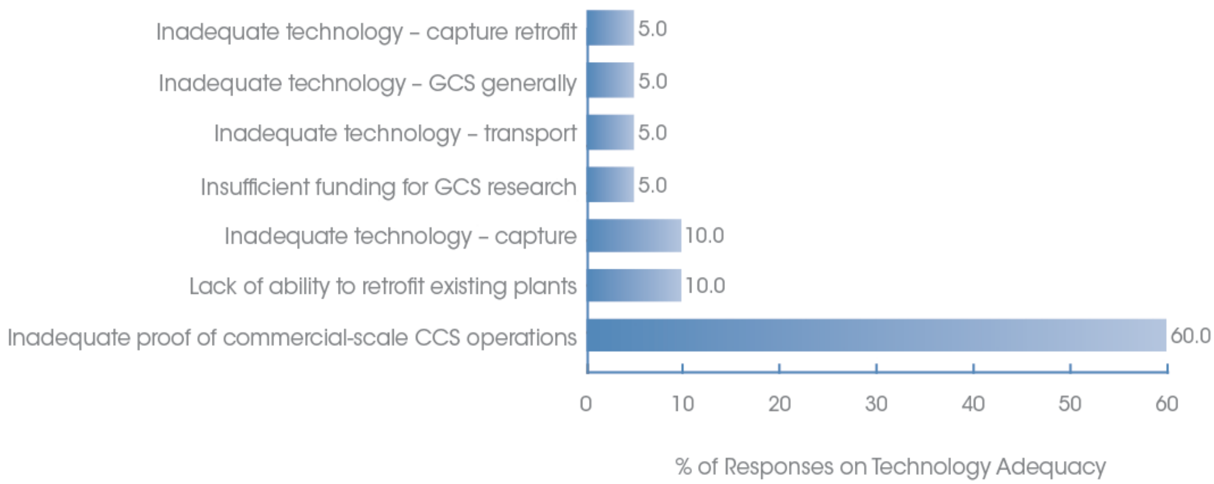
between how survey respondents view the adequacy of CCS technology and how they perceive the risk of being a "first mover" who uses it.

The barrier "lack of proven commercial-scale GCS operations" ranked comparatively high as a CCS obstacle, receiving a solid "measurable" obstacle mean of 3.46. Likewise, almost a tenth of responses identified CCS technology inadequacy of some kind as the "most significant" obstacle to commercialization. On its face, this data implies that even though CCS technology is available, industry is not confident that it can be deployed yet at a commercial scale.

Parsing the data more carefully, however, reveals a more complex story. While "lack of proven commercial-scale GCS operations" did receive a comparatively high mean obstacle score of 3.46, the possible barrier "inadequate GCS technology" received a notably lower mean score: 2.84. Likewise, when asked for the most significant "financial or business-related" obstacle to CCS use, a mere 6% of responses identified technology inadequacy of any kind. More importantly, of those responses, only 35% identified actual CCS technologies as inadequate—rather than merely pointing to a general lack of proof of successful commercial operations. This is shown in Figure 5.7. A similar, slightly less pronounced trend appears in the responses to the "most significant" obstacle open-ended question.[268]

[268] For the "most significant" CCS obstacle question, just over 9% of responses identified some type of technology inadequacy as a barrier. Of those, 43% named lack of proven commercial-scale CCS operations, 25% named inadequate CCS technology generally, 25% identified inadequate CO_2 capture technology, and roughly 3.5% each named insufficient CCS research funding and a lack of the ability to retrofit existing CO_2 sources.

Figure 5.7: % of Open-Ended Responses Discussing CCS Technology Adequacy



These data suggest that there is a possible disconnect between the actual feasibility of CCS technology and the risk industry perceives in employing it. That is, those familiar with CCS appear confident that CCS technology will work at a commercial scale, but no one wants to be the first to assume the business risk of deploying it commercially. This reading is consistent with (1) the survey results underscoring CCS's cost as a barrier to commercialization, (2) respondents' corresponding concern that there is no regulatory mechanism ensuring CCS investment recovery, and (3) concerns over long-term liability.

In fact, the survey responses confirm general industry confidence in the readiness of CCS technology, despite a fear of employing it on a commercial level. Each of the mean obstacle scores for the different technological phases of CCS was markedly lower than the score for the generalized "lack of proven commercial-scale GCS operations." Whereas lack of proven commercial operations scored a mean of 3.46, each of the scores for actual CCS technologies was in the mid- to low-2 range—showing "measurable" to "minor" obstacles for CCS commercialization—with the exception of CCS capture and retrofit technologies. *See* Table 5.8.

Table 5.8: Mean CCS Technology Obstacle Rankings

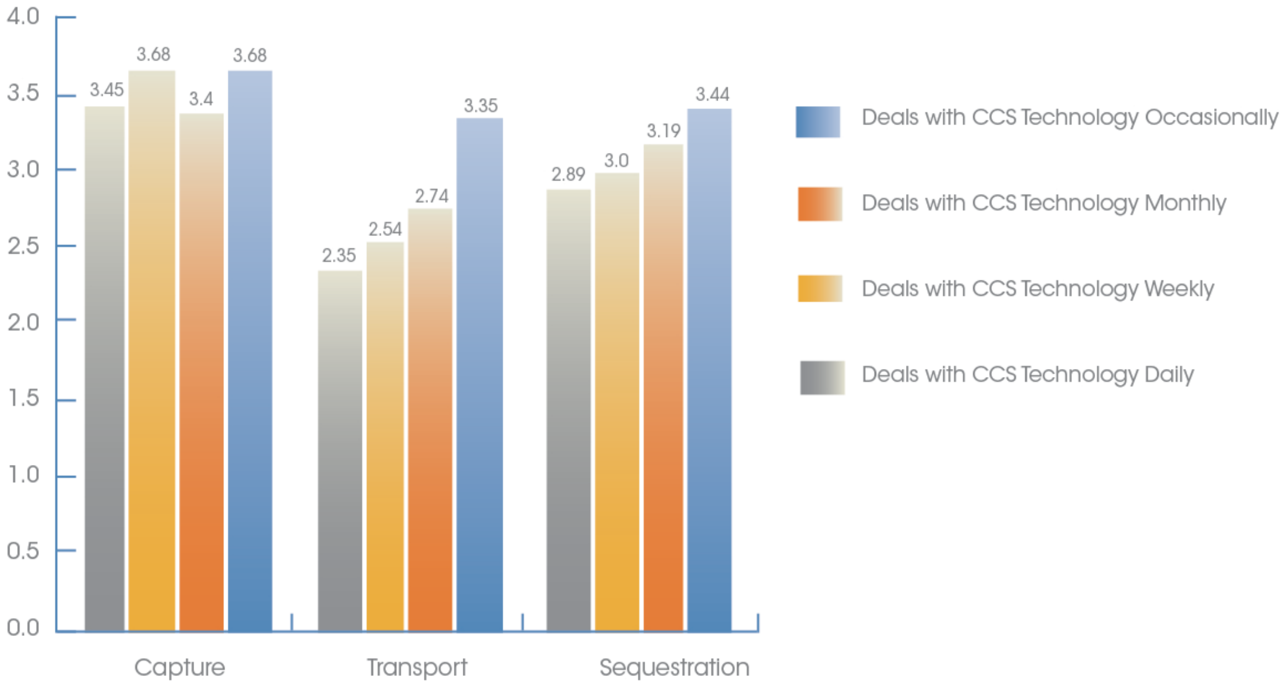
Potential Barrier	Lack of proven commercial-scale CCS operations	Inadequate CO_2 capture technology	Inadequate CO_2 capture retrofitting technology	Inadequate CCS technology	Inadequate CO_2 sequestration technology	Inadequate CO_2 monitoring technology for storage sites	Inadequate CO_2 transport technology
Obstacle Score	3.46	**3.07**	**3.05**	**2.84**	2.62	2.6	**1.97**

*Values in bold are statistically significant ($p. \leq .05$) when compared to the mean overall barrier ranking of 3.35.

Further evidence of this disconnect is seen elsewhere in the survey data. As noted, those who deal regularly with CCS technology and policy tend to have less pessimistic views of CCS barriers than those who deal with it less often. That trend applies to confidence in CCS technology. Respondents who self-report as dealing with CCS daily had markedly lower mean combined technology-cost barrier scores for all three segments of the CCS process than those who do not have as regular of exposure to

the technology. As shown in Figure 5.8, this implies that concerns about the adequacy of CCS technology—and transportation and sequestration in particular—may be knowledge-dependent. Lack of familiarity with the technology may breed unwarranted doubt about its feasibility.

Figure 5.8: Combined Mean CCS Technology Process Obstacle Scores by Level of Respondent Involvement



e.   Geology and Capacity

The most important observation about the physical capacity to store CO_2 geologically may be how little of a barrier this appears to be. Survey respondents seemed confident that both storage capacity and geological information about those sites is

available, or is at least obtainable. None of the possible obstacles listed under this category scored higher than 2.82, and all of them bunched between 2.66 and 2.82. Thus, while this qualifies each of these subcategories as "measurable" obstacles to CCS use, none rises to the "significant" or "critical" level, and some are nearly as close to the "minor" obstacle level as they are to "measurable." Lower concern over storage capacity is also consistent with the open-ended data, which recorded a meager 3.8% of responses in this category to the "most significant" and "most significant legal or policy" barrier questions. Storage capacity and geological information earned an even smaller 1.2% of responses to the "most significant financial or business-related" open-answer question.

2. Incentives for CCS Deployment

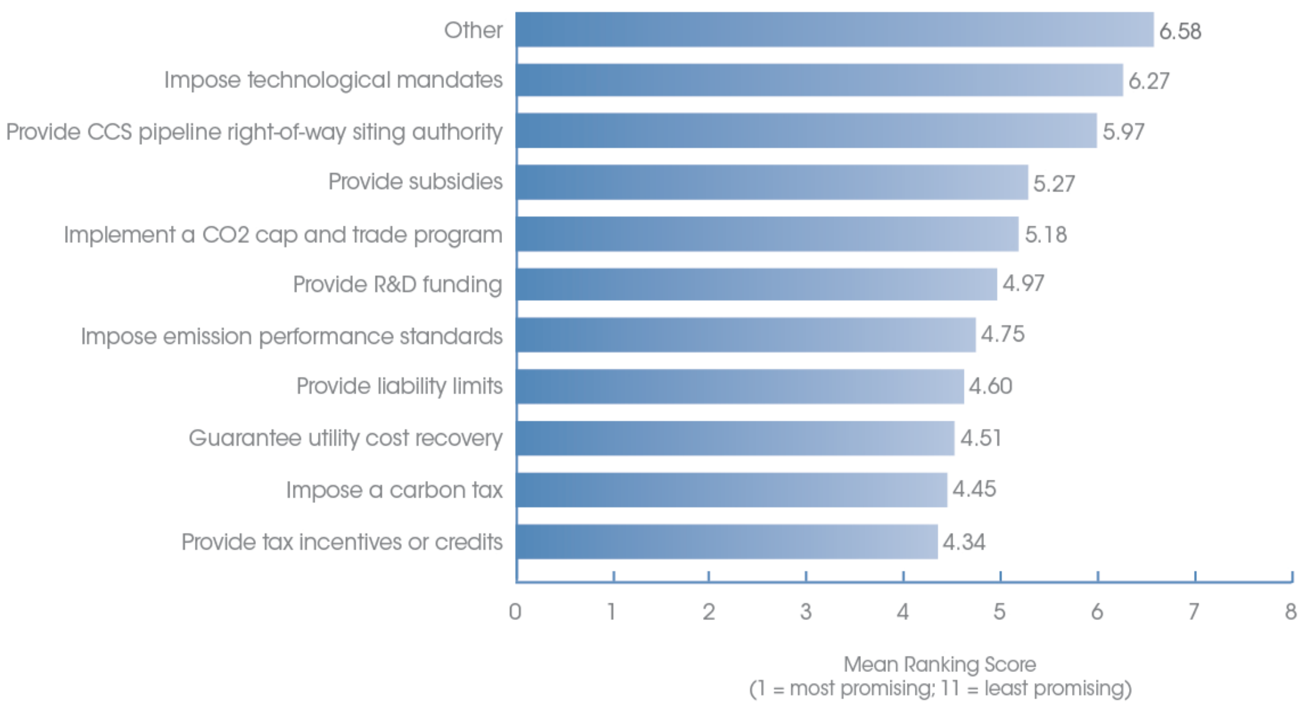
Findings regarding possible government actions to promote CCS parallel the survey results on CCS barriers. Just as the cost of using CCS and the risk of not recovering those costs are the key obstacles to CCS deployment, policy measures aimed at alleviating those concerns prevail as the preferred governmental incentives for CCS commercialization. Precisely which of these measures is most preferred is less certain. Different metrics yielded different results on this front. It appears clear, however, that some combination of tax incentives, a carbon price, and liability limits are preferred. Research and development funding, and guarantees for utility cost recovery, also are viewed favorably.

We asked survey respondents to rank ten options for promoting CCS on a 1-to-11 scale, from "most promising" (1) to "least promising" (11). In addition, we asked two open-ended questions: "What is the most important step that government can take to promote commercial-scale GCS deployment?" and "Are there other important steps that

government should take to promote commercial-scale GCS deployment? If so, what are they?"

In the ranking question, respondents overwhelmingly favored policy incentives that address CCS costs. The most favored policy incentive was "tax incentives or credits" for CCS, earning a mean score of 4.35 among all survey participants. Close behind was imposing a carbon tax, with a mean score of 4.46. Following these options were "guarantee[ing] utility cost recovery" (mean score 4.53) and "provid[ing] liability limits" (4.58). *See* Figure 5.9. Notably, these four policy options closely match the four largest barriers to CCS use identified by survey respondents. The mean response values for the policy options ranged from 4.28 (provide tax incentives or credits) to 6.12 (impose technology mandates). Responses to the ten questions generated 1,753 data points and a mean overall value of 4.91. Only three options were significant at the .05 level, indicating that a wide range of policy options would be perceived as potentially effective, even if not optimal.

Figure 5.9: Mean Ranking Scores of Preferred Policy Incentives

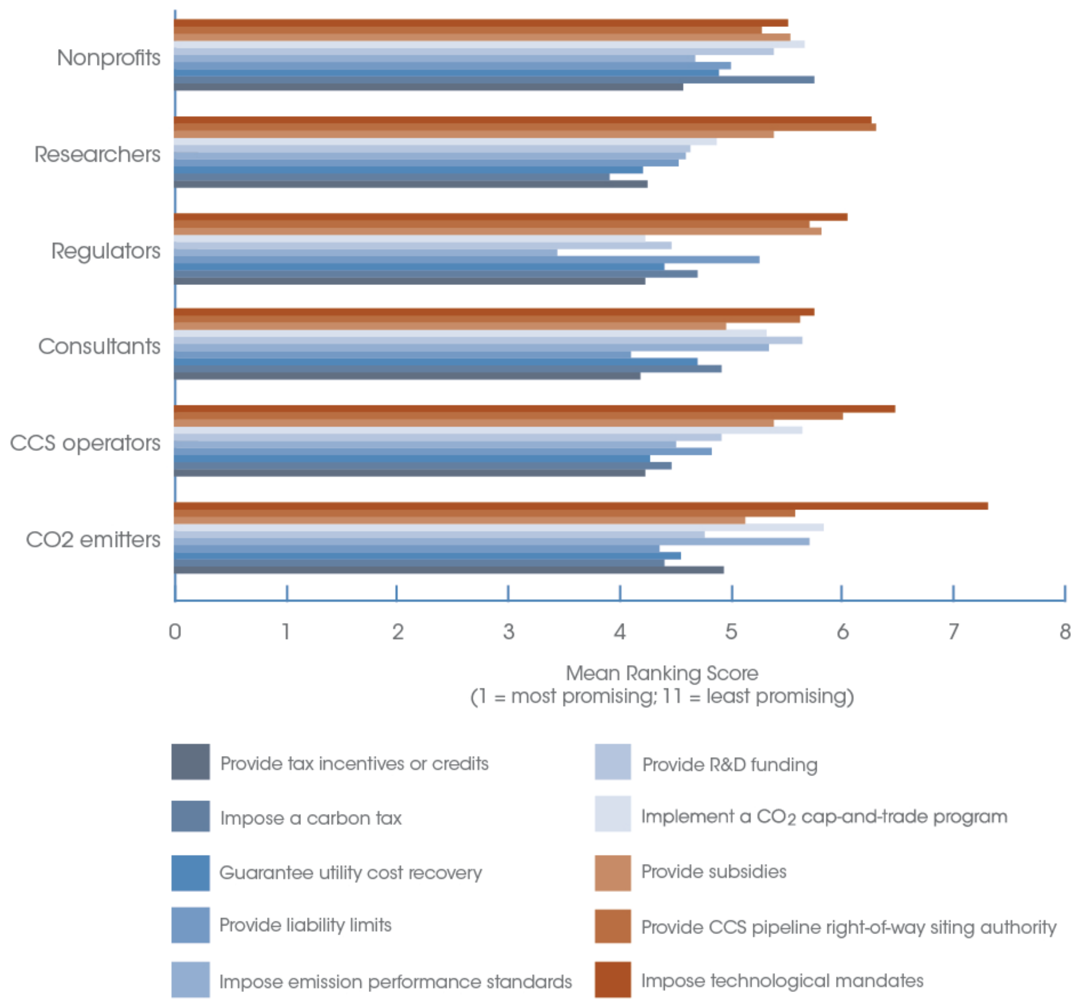


The least preferred policy options under the ranking question also correspond to barriers that survey respondents found least troublesome: Providing research and development funding falls in the middle of the ranking pack with a mean score of 4.99, and giving right-of-way authority to CCS pipelines came in next to last with a mean score of 5.95. Interestingly, however, the option of "implement[ing] a CO_2 cap and trade policy" fell substantially below the comparable policy option of "impos[ing] a carbon tax." Also noteworthy, the option of "impos[ing] technological mandates" scored last in the ranking question (with a mean of 6.28), despite the fact that it would force CCS use directly, irrespective of cost.

There was less consensus among survey respondent categories on which CCS incentive is most preferable. CO_2 emitters and consultants prefer liability limits (mean values of 4.37 and 4.10, respectively), while CCS facility operators prefer tax incentives or credits (mean value 4.23). Regulators strongly prefer emission performance standards (mean value 3.44), researchers have a fairly strong preference for a carbon tax (3.91), and non-profit interest groups strongly prefer some other undefined option (mean value 3.00). Interest in another, undefined option is notable because this was the least popular option overall (mean value of 6.58) and the last choice for CO_2 emitters, CCS facility operators, consultants, and researchers. Notably, the frequency with which the respondents deal with either CCS technology or CCS law and policy appears to have no bearing on their preferred incentive.

This lack of consensus was repeated elsewhere in both the ranking and the open-ended data. Reviewing policy preferences by respondent type reveals a very mixed picture. No policy option had a majority of respondents rank it as either the most, or as the least, promising. And only one of the named options—imposing a carbon tax—had even a third of respondents rank it as most or least promising. Indeed, as shown in Figure 5.10, every category of respondents had their own ranking of these policy options from most to least promising.

Figure 5.10: Mean Ranking Scores of Preferred CCS Policy Incentives by Respondent Type

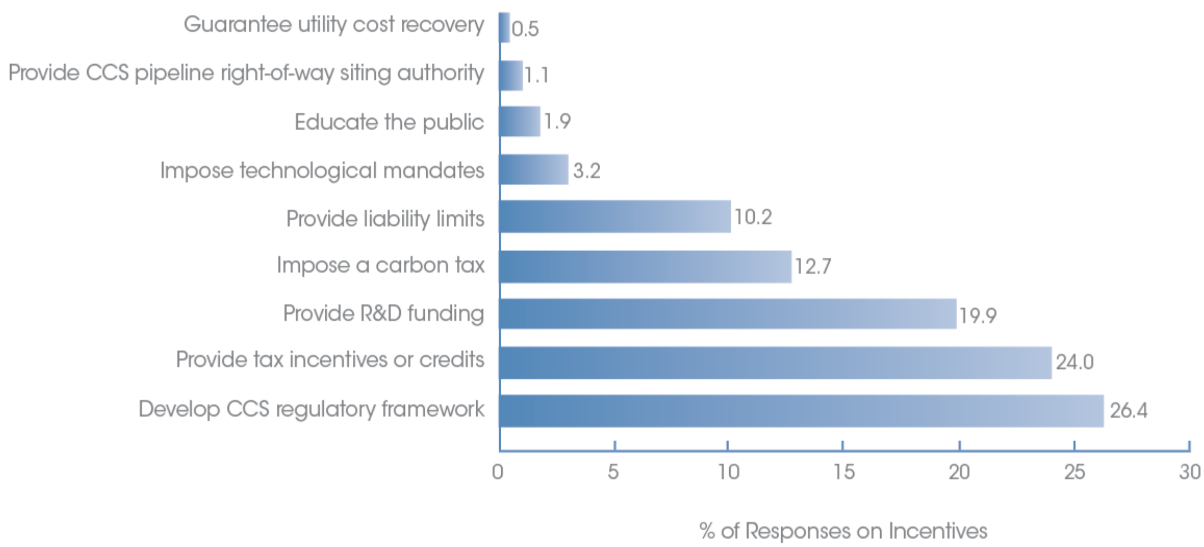


Responses to the open-ended questions reflected a similar, but not identical, pattern. Asked what the "most important" step is that government can take to "promote commercial-scale GCS deployment," references to both reducing cost and addressing liability abounded: Government should "[s]upport the cost of the initial projects which cannot/will not proceed on pure economic fundamentals." Government must "[c]over

long-term liability and provide a value for sequestration." Another participant summed up, "[CCS needs f]unding like nuclear receives[; c]ost remains an important barrier to wider commercial deployment."

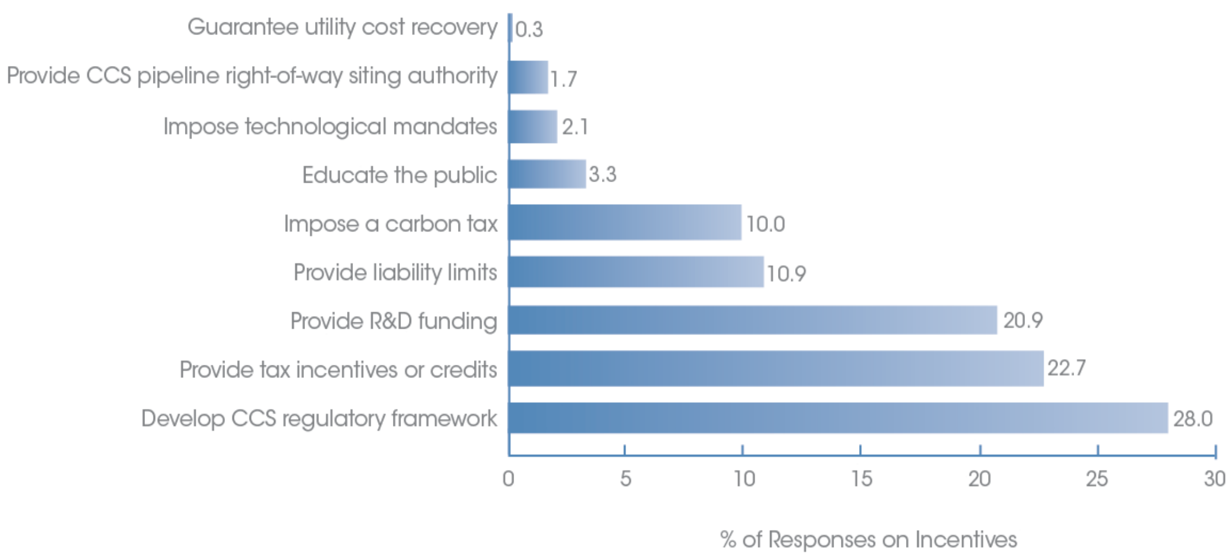
More often, however, survey participants cited a need for CCS regulation as the best way to promote the technology. As shown in Figure 5.11, the order of preferred CCS incentives changes when considered from the perspective of the open-ended questions rather than the ranking questions. Not only does the need for CCS regulation predominate (26.4%), but research and development funding moves up in the rankings from sixth to third (19.9%), as does the preference for technological mandates (from last to sixth). Suggestions of public education also emerge, and the weight placed on utility cost recovery measures plummets (from third to last). Likewise, emissions performance standards, which fell squarely in the middle of the policy options in the ranking draft, drop off the chart entirely when the open-ended question data is used. Not a single respondent mentioned this as a way to promote CCS.

Figure 5.11: % of Open-Ended Responses Identifying Preferred CCS Incentive



Nevertheless, using either set of data—ranking or open-ended—three policy options group together as the highest scoring CCS incentives: tax/financial incentives, a carbon tax, and liability protections. Likewise, under either set of data, granting right-of-way authority for CO_2 pipelines has limited appeal. Little changes when the additional responses to the open-ended question "Are there other important steps that government should take to promote commercial-scale GCS deployment?" are included. In this iteration of the incentives analysis, protecting companies from open-ended liability moves up from fifth to fourth, as does public education from seventh to sixth. Otherwise, the open-ended rankings remain the same. *See* Figure 5.12.

Figure 5.12: % of Combined Open-Ended Responses Indentifying Preferred CCS Incentive



One potential explanation for the lack of consensus is that respondents understand that the various policy options are not mutually exclusive and, indeed, the survey did not ask participants to treat them as such. A CCS regulatory framework would presumably include either a mandate to adopt CCS, a carbon tax, or other incentive to deploy technology, as well as liability clarification. Such mandates would indirectly address cost recovery issues because public utility commissions would presumably approve rate changes that reflect statutory obligations.

At bottom, however, the survey results suggest two take-home messages on CCS incentives. First, there is no pure consensus on which policy preference is “best” for CCS promotion. Second, tax/financial incentives, liability limits, a CCS regulatory frame, and a carbon tax all are clearly favored as the top options, in some kind of combination. After that, the next most preferred policy may be either R&D funding

or cost recovery guarantees, although the data point in both directions on these potential measures.

In other words, the survey data make clear that the CCS community desires strong incentives. It simply is not as clear which incentive the community desires most—and it may well be that industry views more than one as necessary. As one participant wrote, the government should "[e]stablish financial incentives that address [both the] capital and long-term operating costs of CCS projects. [What we need is to a]llow multiple financial tools to be applied to a single project." From how the survey data reads, the same may well be said of CCS as a whole.

3. CCS Policy Design

The survey data also lay bare several lessons about what CCS regulation should entail. The first has already been discussed: The CCS community sees clarifying the regulatory landscape as one of the best ways to promote CCS use. Beyond this fundamental message, the survey responses also speak to the substance of CCS regulation (what areas the regulation should address) as well as its structure (who should regulate). Here, the data are unambiguous. Respondents are most concerned about liability. Survey respondents also favor a cooperative federalism approach—where the federal government sets regulatory limits and the states implement them—over other possible regulatory options.

a. Substance

The clearest message on CCS policy design is that respondents are very concerned about liability. After that, the most conspicuous message is that participants

are not confident in the clarity or substance of existing regulations for almost any part of the CCS process.

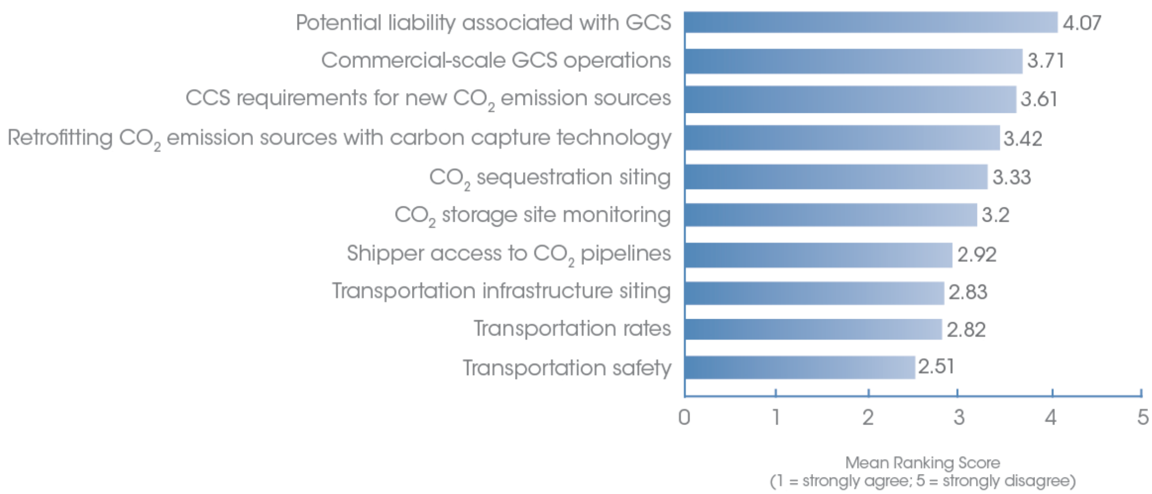
Survey participants were asked to rank their level of agreement with ten different statements about CCS regulation. Each statement began, "Existing legal structures are adequate to address . . . " and concluded with a reference to an area of regulation. Those areas included a catchall for "commercial-scale GCS operations," a category for liability, and various questions on the capture, transport, and storage portions of the CCS process. For each of the statements, respondents could give a rating of "strongly agree" (a score of 1), "agree" (2), "neutral" (3), "disagree" (4), or "strongly disagree" (5). Responses to the ten regulatory questions generated 1,733 data points and a mean overall score of 3.25.

Tellingly, respondents gave no area of existing regulation a mean rating equivalent to an "agree" (lower than 2.5) or "strongly agree" (lower than 1.5) score. This suggests that the CCS community lacks confidence that existing regulations are sufficient for any area of CCS operations.

Most areas earned neutral (2.5 to 3.49) mean rankings. As shown in Figure 5.13, those include transportation safety regulation, which respondents seem to have the most confidence in (a mean score of 2.51); transportation rates (2.82); transportation infrastructure siting (2.83); shipper access to CO_2 pipelines (2.92); CO_2 storage site monitoring (3.2); storage siting (3.33); and capture retrofitting (3.42). It is notable that mean values for seven of the ten areas of existing regulation fall within the "neutral" category. This may indicate that the CCS community does not feel strongly about the substance or quality of regulation today for most stages of the CCS process. Neutral responses might be expected given the current absence of a comprehensive CCS

framework. Nevertheless, that not one area of regulation earned even an “agree” ranking is hardly a ringing endorsement of the sufficiency of current CCS regulation.

Figure 5.13: Mean Confidence Ranking in Existing CCS Regulatory Structures("Existing legal structures are adequate to address . . . ")

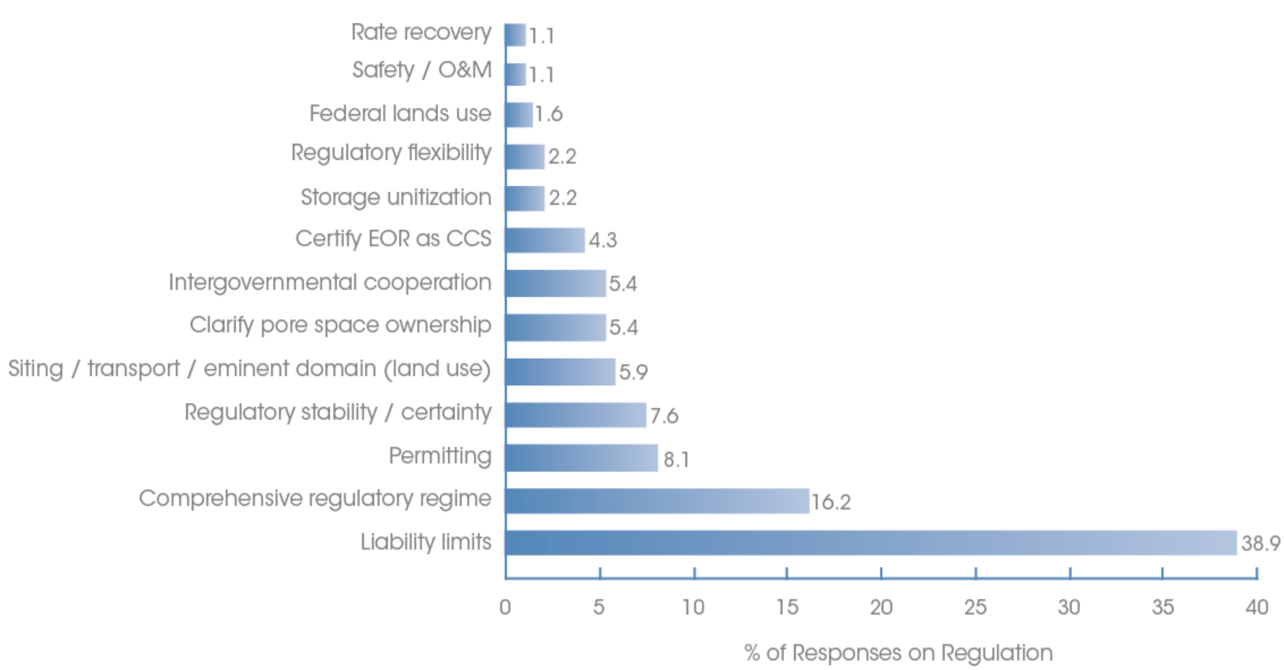


Indeed, while most areas of regulation earned a “neutral” score, the statement “Existing legal structures are adequate to address commercial-scale GCS regulations” was ranked at 3.71, noting clear disagreement with this statement. Respondents’ displeasure with how CCS is regulated overall would seem to indicate a general need for a more comprehensive, certain, and transparent regulatory structure.

Other survey data support this conclusion. As discussed at more length above, in response to the open-ended questions on CCS incentives, the need to develop a CCS regulatory regime accounted for more responses than any other possible incentive: Regulation was mentioned in more than 30% of the responses to the query regarding the

"most important" step that government can take to promote CCS, and 28% of the combined responses to both of the open-ended incentive questions. Answers such as "the lack of full spectrum legal and regulatory infrastructure that enables GCS" and "[i]t seems that regulations have not been set" were common responses to these questions. As shown in Figure 5.14, over 16% of these open-ended responses named the need for comprehensive CCS regulation as one of the best ways to incentive CCS use. The only more common answer also was consistent with the policy ranking data: limiting liability, which notched roughly 39% of the responses.

Figure 5.14: % of Open-Ended Responses Identifying CCS Regulation Area

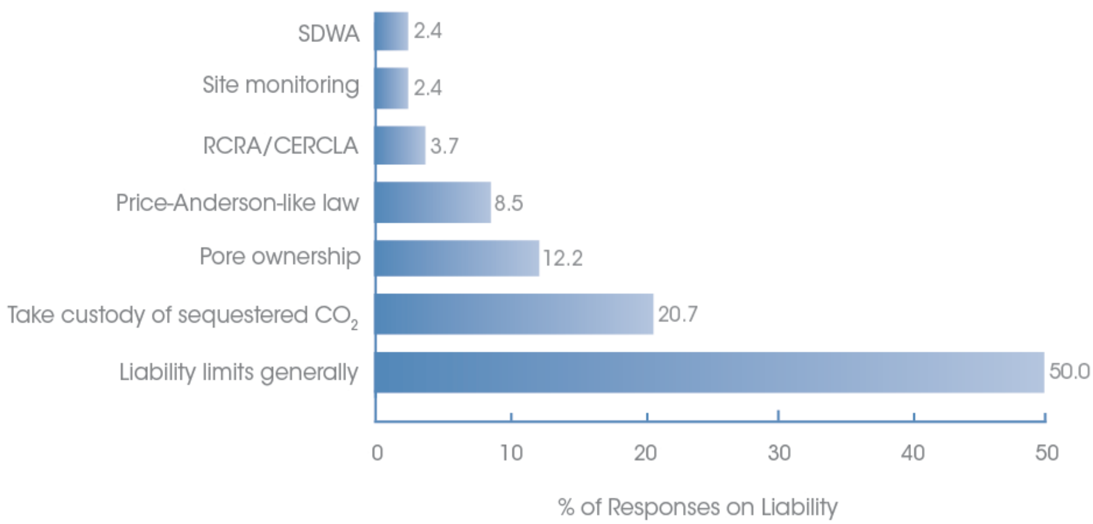


One other trend bears noting. There is a clear hierarchy in how comfortable respondents are with existing regulations for the different parts of the CCS process. This hierarchy maps closely to the pattern for respondent confidence in CCS technology itself. Respondents report most confidence in existing regulations for CCS transport, somewhat less confidence in regulations for CCS storage, and the least confidence in those for CO_2 capture. One explanation for this may be that the oil and gas industry has an established history of dealing with CO_2 pipelines for enhanced oil recovery. Experience with regulation of this part of the CCS process thus may breed additional assurance and comfort.

Overall, survey responses evince two consistent patterns. Respondents express greater confidence in the regulatory framework for transport than for storage, and respondents express greater confidence in the regulatory framework for storage than for capture. The sole exception to these expressions of confidence is concern over liability. No matter how the data is categorized, calls for liability limits outweigh those for any other type of CCS regulation. In terms of open-ended responses, liability dwarfs any other option, accounting for almost 39% of the responses compared to 16% for the next most common response (the need for comprehensive CCS regulation). In the ranking data, CCS liability regulation earned a 4.07 mean score compared to the 3.71 mean score for regulation of commercial-scale CCS operations. Both of these observations point heavily toward the need for any CCS regulatory regime to address liability concerns. As one survey participant noted, industry considers the "lack of a definitive liability framework, such as that offered for hazardous waste disposal," to be a key impediment to CCS commercialization. Another respondent put this even more starkly, "[T]he

government needs to develop a way to take the long-term liability. No company is going to invest in an activity with liability in perpetuity. It's simply not a risk worth taking."

Figure 5.15: % of Open-Ended Responses Identifying CCS Liability Type



With respect to the type of liability regulation that respondents prefer, the data are less clear. Half of the respondents who called for liability limits in their open-ended responses simply identified the need in general. A number of respondents, however, named more concrete preferences. The most common was a desire for the government to take custody of CO_2 following sequestration. As Figure 5.15 shows, 20.7% of responses called for federal custody provisions. If combined with calls for a Price-Anderson-like liability law (8.5% of responses), this policy option might be considered to account for nearly a third of the responses. After that, 12.2% of responses asked for clarification of pore space ownership, and much smaller percentages of respondents—under 4% each—

asked for limits on environmental statutory and site monitoring liability. Thus, a comprehensive liability strategy may require more than one of these options.

b. Structure

Two points emerge regarding how CCS regulation should be structured. First, survey respondents strongly favor cooperative federalism over an entirely federal or solely state-by-state approach. Second, respondents appear to strongly favor the status quo on federal and state jurisdiction, preferring that regulatory primacy remain with the governmental entity that already regulating the area today.

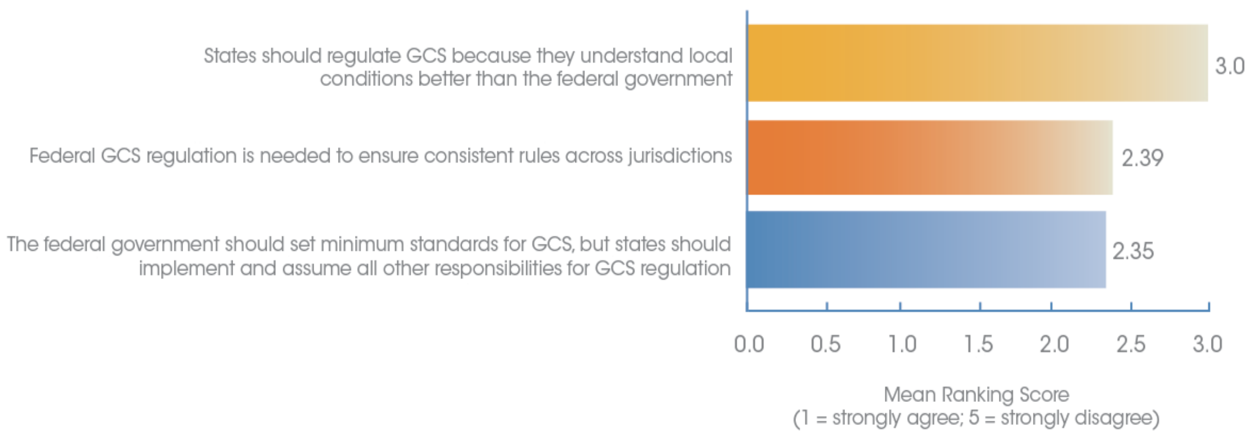
Respondents' preference for cooperative federalism is plain. Ranking questions asked participants to score three statements on the 1-to-5, "strongly agree"-to-"strongly disagree" scale:

- "The federal government should set minimum standards for GCS, but states should implement and assume all other responsibilities for GCS regulation."
- "Federal GCS regulation is needed to ensure consistent rules across jurisdictions."
- "States should regulate GCS because they understand local conditions better than the federal government."

There was little difference in the mean scores for these statements. However, as shown in Figure 5.16, the statement about the federal government instituting minimum standards and the states implementing them—known in legal and policy circles as "cooperative," "dual," or "dynamic" federalism—outscored the other two statements. Cooperative federalism earned a mean "agree" rating of 2.35, whereas the notion that states should be the primary CCS regulators came in at a solidly neutral 3.00. The statement about

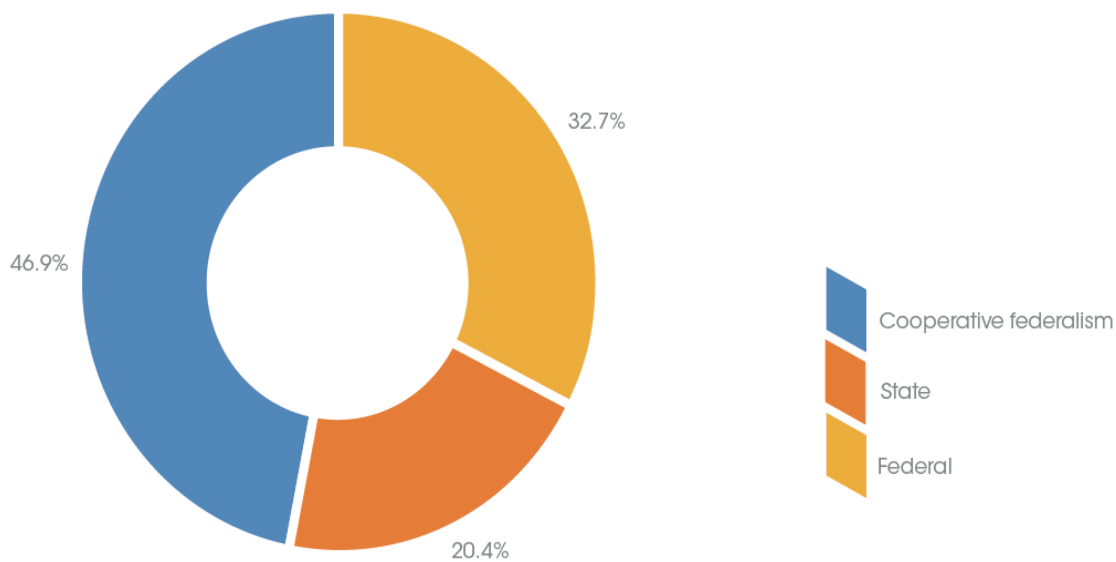
ensuring consistency through federal regulation followed closely behind cooperative federalism at 2.39.

Figure 5.16: Mean Ranking Scores for Who Should Regulate



These ranking scores are consistent with the open-answer data. Two of the open-ended questions asked "what areas" of CCS regulation are "more appropriate" for federal or state regulation. The responses reflected the same order of preferences for who regulates as the ranking scores. *See* Figure 5.17. Cooperative federalism is preferred first, with 46.9% of the responses; federal regulation second, with 32.7%; and exclusively state regulation last, with 20.4%. Together, these data make clear that the CCS community would prefer a system of cooperative regulation with uniform national requirements but state implementation.

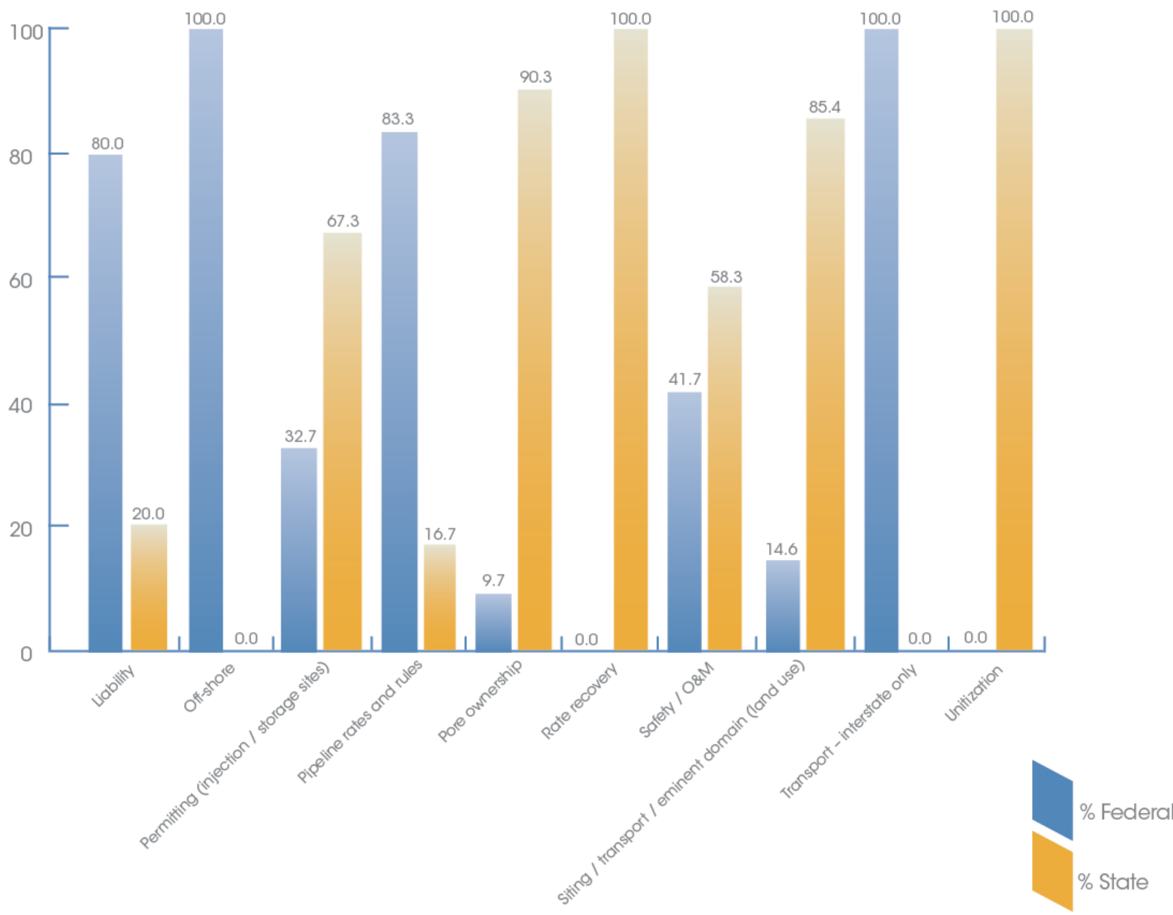
Figure 5.17: % of Open-Ended Responses on Who Should Regulate



Finally, the survey data show provide some insight on who should regulate each aspect of CCS. Although survey participants clearly favor cooperative federalism, they expressed a rather stark preference for maintaining areas of traditionally federal and state regulation. As Figure 5.18 summarizes, responses to the open-ended questions mark a clear divide for which portion of government should have primacy in regulating different parts of CCS. The divide is a largely historical one. Issues of local concern and traditional state regulation, such as permitting, rate recovery, and property rights (including pore ownership), land use, and unitization, received the majority of responses preferring state regulation. By contrast, areas of interstate and traditionally federal

concern, such as off-shore CO_2 storage, pipeline rates and rules, and interstate transport, all received a much higher proportion of responses favoring federal regulation.

Figure 5.18: % of Open-Ended Responses Identifying Preferences on Who Regulates What



The two sole outliers were (1) liability and (2) safety / operation and maintenance of sites. Although both of these might be fairly characterized as primarily local, liability received a full 80% of responses identifying it as preferred for federal regulation—

perhaps because it is potentially such a large an impediment to CCS. Safety and operation and maintenance, on the other hand, still were favored for state regulation, but by a much narrower margin: 58.3% of responses in favor of state regulation, as opposed to 41.7% for federal.

VI. Implications of Survey Findings

The natural question that follows an assessment of CCS barriers, incentives, and potential regulations is, "What next"? What actions should be taken with regard to CCS, based on the CCS community's view of the economic and regulatory landscape? Who should take those actions?

Whether to promote CCS is of course a threshold consideration. There are strong arguments that CCS must become part of the United States' energy portfolio if climate change is to be abated.[269] This is especially true given both electricity production's heavy contribution to domestic greenhouse gas emissions and coal's dominance in electric power production.[270] Commercial-scale deployment of CCS in the United States also could pave the way for greater use of the technology abroad, and could create a first-mover advantage for the United States by building experience designing, implementing, and refining CCS.[271] On the other hand, some observers make the argument that the United States could garner bigger climate emission reductions by focusing on other low-emission sources, such as renewables, demand-side management, and efficiency.[272] Such arguments emphasize the energy penalty associated with CCS and the possibility of providing comparable baseload energy from nuclear power.[273]

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[269] *See, e.g.,* U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT (2010); LARRY PARKER *ET AL*., CONG. RESEARCH SERV., RL34621, CAPTURING CO_2 FROM COAL-FIRED POWER PLANTS: CHALLENGES FOR A COMPREHENSIVE STRATEGY (2009).
[270] *See* Energy Information Administration, ANNUAL ENERGY OUTLOOK 2011, 3-4 (comparing CO_2 emissions across fuels and sectors, and projecting electric generation from coal to increase by 25% from 2009 to 2035).
[271] *See* Heleen de Coninck, *The international race for CO_2 capture and storage: And the winner is…?,* FACET COMMENTARY NO. 12, FORUM FOR ATLANTIC CLIMATE AND ENERGY TALKS (2008).
[272] *See* Pushker A. Karecha, Charles F. Kutscher, James E. Hansen & Edward Mazria, *Options for Near-Term Phaseout of CO2 Emissions from Coal Use in the United States*, 44 ENVIRON. SCI. TECHNOL. 4050 (2010).
[273] *See id.*

Notwithstanding intensifying concerns over climate change, coal (along with other fossil fuels) is likely to remain a substantial part of our energy mix of the foreseeable future.[274] Given this, the more appropriate question may be not whether to promote CCS, but rather, how to speed its commercialization. This Section addresses that question: What did the CCS community tell us about how to move forward in promoting CCS?

The answer is in five chief parts. If the path forward is to be based on the CCS community's views as reflected in our survey, an initial architecture for CCS regulation emerges:

- A financial incentive that will send an appropriately strong signal is imperative if CCS is to be deployed on a commercial scale. Most likely, this should be a carbon price.
- In addition to an economic driver for CCS deployment, the CCS community wants a comprehensive regulatory regime to address CCS implementation, not rules eked out one at a time, statute by statute.
- Ideally, that regulatory scheme will rely primarily on cooperative federalism, with the federal government setting applicable standards and states implementing them. Areas favored for federal regulation include interstate CO_2 transport, pipelines, liability, and all aspects of offshore CCS. Areas favored for state regulation relate to property rights, including pore space ownership and eminent domain.
- Potential liability for CCS use also must be addressed. The CCS community supports a wide array of liability mechanisms but heavily favors government custody of stored CO_2.
- Scholarly concerns about the lack of commercial-scale demonstration projects, lack of information about storage site geology, and public resistance to CCS projects appear overstated. According to the CCS

[274] *See* Energy Information Administration, ANNUAL ENERGY OUTLOOK 2011, 3-4 (2011). Indeed, most cases for climate change mitigation now suggest an "all hands on deck" approach, recognizing that no single strategy is likely to be a "silver bullet" that solves the problem. *See* Rob Socolow & Steven Pacala, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 SCIENCE 968 (2004). In this scenario, fossil fuel-fired electricity does not simply vanish from the landscape.

community, regulators would do well to focus on issues other than these as first steps to promoting CCS deployment.

The remainder of this Section discusses these recommendations in greater detail. It progresses in two Subsections. Subsection VI.A asks which barriers to CCS government action should focus on, and Subsection VI.B outlines what a possible CCS regulatory regime should look like, according to the survey results. Both Subsections proceed by contrasting survey results with existing scholarly literature and government regulation.

A. CCS Barriers and Incentives

Overall, our survey's results confirm what the scholarly literature suggests are the largest barriers to CCS commercialization. Overwhelmingly, the literature has targeted the lack of a carbon price as the primary impediment to CCS deployment. Our survey findings likewise point in this direction. Setting a carbon price is an essential first step. The absence of a price signal and investor reluctance to assume costs that are not mandated by government action—and that thus may not be recoverable—led the list of concerns voiced by our survey respondents.

This is the first take-home message of our survey. Without a sufficiently high carbon price, or some other comparably strong incentive for CCS use, CCS is unlikely to reach commercialization. For longstanding observers of CCS, this conclusion is hardly remarkable. It is important, nonetheless, for its clarity. The survey findings confirm what commentators have repeatedly noted, and do so from the specific vantage of the CCS community. If CCS is to move to broad-scale use, governmental action on climate change, with a meaningful economic component, is not negotiable.

The second way in which both the literature and our survey results align is in their shared emphasis on concerns over liability. Both rank potential CCS liability high as an impediment—immediately after economic barriers/lack of a carbon price. This also, then, should provide an unambiguous message to policymakers. Regardless of how liability risks from CCS use are apportioned, these liabilities must be comprehensively addressed if CCS is to reach commercialization. This is particularly true for liability risks associated with long-term storage.

The third and fourth take-home messages come not from the survey findings' congruence with the scholarly literature, but from their divergence. Prior research has suggested that the lack of CCS technology scale-up, including commercial-scale demonstration projects, is one of the largest barriers to CCS use. Our survey findings suggest otherwise. While survey respondents ranked the lack of commercial-scale projects as a "measurable" barrier to CCS use, that impediment paled in comparison to others. It ranked sixth out of seven possible barriers, when measured either by the category catchall questions or the category-wide ranking scores.[275] This stands in stark contrast to the scholarly literature, which long has suggested that large, commercial-scale projects must be completed in defined, sequential stages before CCS can truly get off the ground.[276] Contrary to this view of commercial-scale demonstration as a necessary condition precedent to CCS deployment, our survey suggests that the CCS industry is confident that the technology can be made fully operational today. "[CCS t]echnology,"

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[275] *See supra* Section V.B.1.

[276] *See, e.g.*, DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION, AN INTERIM REPORT FROM THE CCSREG PROJECT (2009); L. STEPHEN MELZER, DEVELOPMENT OF A POLICY FRAMEWORK FOR CO_2 CARBON CAPTURE AND STORAGE IN THE STATES, PEW CENTER ON GLOBAL CLIMATE CHANGE (2008); GAO, REPORT TO THE CHAIRMAN OF THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING, HOUSE OF REPRESENTATIVES, FEDERAL ACTIONS WILL GREATLY AFFECT THE VIABILITY OF CARBON CAPTURE AND STORAGE AS A KEY MITIGATION OPTION (2008).

one respondent wrote, "is available but costs to deploy at scale are substantially higher than business as usual." This implies that demonstration of CCS technology may have more to do with investor confidence than engineering capacity and technological know-how. As observed by another survey participant, CCS deployment is not hampered by a lack of technology, but rather, by a prevailing "lack of a sufficiently proven technology to facilitate financing"—to show "the true costs of CCS over a 20 year period." Indeed, the survey results underscore that confidence in CCS processes increases with additional exposure to the technology and surrounding issues.[277]

The survey results also appear to discount two barriers that the scholarly literature has held out as critical. The literature has emphasized as tertiary CCS obstacles the lack of knowledge of CO_2 reservoir geology and plume movement, and public discomfort with CCS.[278] The survey results suggest that emphasis on these considerations may be overstated. While these issues registered, respectively, as "measurable" and "significant" barriers in the survey responses, they also ranked among the lowest of potential impediments to CCS use. Specifically, knowledge of reservoir geology and capacity scored thirty-third and thirty-fourth out of forty-one potential CCS barriers. Lack of adequate sequestration sites scored even lower, ranking thirty-sixth. And while lack of public acceptance of CCS came in higher, at fifteenth, much of this ranking score may have to do with CCS's anticipated impacts on price. The survey's direct obstacle scores for public resistance to CCS storage facilities, transportation facilities, and capture technology were much lower: twenty-first, thirty-second, and thirty-ninth, respectively. This suggests that the CCS community is not worried about public opposition to CCS *per*

[277] *See supra* Section V.B.1.
[278] *See supra* Sections IV.A.3 and IV.A.4.

se, but rather, is apprehensive about the public reaction to the costs of greenhouse gas regulation. Thus, while work may be needed to mitigate both the geologic knowledge gaps that now exist and any public resistance to CCS, the survey data strongly imply that these barriers should not be among the first targets for government action, contrary to what the literature might say.

With respect to incentives for CCS deployment, the survey results add substantial detail to a picture that the literature has painted largely in broad strokes. Prior studies point generally to the need for government incentives for CCS deployment, but typically do not parse which incentives might best serve this purpose. The survey results bring more clarity to this question. They show that while the literature is correct that the CCS community heavily supports governmental incentives for CCS, four are most favored: a carbon tax or price, liability limits, tax and other financial incentives, and a comprehensive CCS regulatory scheme. These incentive rankings dovetail with the predominant views expressed in both the CCS literature and our survey concerning CCS roadblocks, namely that the absence of a meaningful carbon price and clear liability limitations stand as the most significant barriers to CCS. The ranking data also show, however, that the CCS community favors tax incentives, such as production tax credits, over numerous other possibilities, such as technological mandates, CCS subsidies, and R&D funding.[279]

Finally, the survey results point to one CCS incentive that has gone largely unnoticed in the literature. Our data show that both a major impediment to CCS deployment and a favored incentive for greater CCS use is the creation of a comprehensive CCS regulatory framework. The survey results on this score contrast

[279] *See supra* Section V.B.2.

sharply with prior studies, which tend to assume that the existing regulatory framework will suffice until CCS scales-up to widespread deployment.[280] Much of the analyses found in the CCS literature zero in on narrow legal questions and regulatory approaches associated with possible CCS use, tending to focus on disparate, existing laws rather than treating CCS holistically.[281] This is thus one of the most important messages of the survey results: The CCS community craves regulatory certainty, and the certainty that is most preferred is a soup-to-nuts regulatory regime. A hodgepodge, statute-by-statute approach is disfavored. As one respondent wrote, what the industry needs the government to do is to "[r]emove regulatory uncertainty by establishing appropriate CCS legal and regulatory frameworks." Such calls for putting "together complete and concise regulations/guidance for applicants" were markedly common in our survey responses. Indeed, as the next Subsection details, the survey results speak not just to the need for comprehensive regulation in general but also more specifically to what that scheme might entail.

B. CCS Regulation—A Preliminary Blueprint

Beyond pointing toward the need for a comprehensive rather than fragmentary, approach to CCS regulation, the survey results offer three important observations for how that regulatory scheme might take shape. The survey data offer valuable insights in this regard, particularly because much of the legal CCS literature has focused specifically on

[280] *See, e.g.,* U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 10 (2010) ("Though early CCS projects can proceed under existing laws, there is limited experience at the Federal and State levels in applying the regulatory framework to CCS. Ongoing EPA efforts will clarify the existing regulatory framework by developing requirements tailored for CCS, which will reduce uncertainty for early projects and help to ensure safe and effective deployment. Experience gained from regulating and permitting the first five to ten CCS projects will further inform potential changes to existing requirements and the need for an enhanced regulatory framework for widespread CCS deployment.").
[281] *See supra* Section IV.

liability and property rights issues rather than holistic CCS regulation.[282] Since Congress has yet to enact CCS legislation, the question of how best to regulate CCS remains an open and extremely relevant query.

First, the survey data strongly indicate a preference for a cooperative federalist approach to CCS regulation, under which the federal government sets standards and allows the states to implement these programs in ways sensitive to local conditions. This is consistent with suggestions for this type of regime in the scholarly literature but, again, adds empirical heft to what previously has remained a largely logical deduction. Indeed, a full 47% of survey respondents indicated a preference for cooperative federalism as the means of effecting CCS regulation. This is a clear signal that impending regulations should be crafted to create uniform standards but allow some flexibility in implementation. Indeed, when considered along with the additional 33% of respondents who favor federal regulatory control, it should be clear that the CCS community favors a federal role in CCS regulation: Together, a full 80% of participants believe that federal law, whether in cooperation with states or standing alone, is beneficial for CCS deployment. This raises, quite pointedly, the question of whether—and how—the federal government will step into the CCS regulatory fray.[283] As it is today, the federal government's most prominent actions on CCS came in the form of CAA and SDWA rules, whereas a number of states have moved well beyond this kind of single-issue

[282] *See supra* Section IV.A.2.
[283] The EPA is in the process of promulgating regulations regarding greenhouse gas emissions from fossil fuel-fired power plants and refineries. *See* http://www.epa.gov/airquality/ghgsettlement.html. When finalized, these regulations could reduce regulatory uncertainty while simultaneously incentivizing CCS deployment.

regulation.[284] The survey responses make clear, however, that the CCS community wants neither outcome: not substantively piecemeal laws nor a state-by-state jumble.

Second, the data do not just highlight a desire for a cooperative federalist approach, they also provide a preliminary outline of what that approach might entail. Our survey results strongly suggest that the CCS community disfavors upsetting traditional lines of regulatory jurisdiction in the United States. Specifically, the survey data show that the CCS community believes that states should retain primacy in four areas: pore space ownership, CO_2 unitization, eminent domain, and utility rate recovery.[285] By contrast, respondents heavily favored continued federal control of four other areas: interstate transportation, pipeline regulation, off-shore permitting, and liability.[286] The split was closer for two final areas—injection and storage area siting, and site safety and operation and maintenance.[287]

These results imply that with respect to areas of regulation related to interstate movement of CO_2, off-shore access, liability, siting, and operation and maintenance, the CCS community believes it may be appropriate for the federal government either to regulate directly or to set regulatory standards that state governments act to implement and enforce. However, for issues related to property law, including pore space ownership and eminent domain, the industry appears to consider state control more appropriate, even though it may lead to conflicting rules and requirements depending on the jurisdiction. Industry tolerance for this kind of regulatory disparity may be founded in respect for traditional state primacy, perhaps due to familiarity with state regulations. Or

[284] *See supra* Section III.B.
[285] *See supra* Section V.B.3.b.
[286] *See id*.
[287] *See id*.

it may be that respondents simply assume that federal resolution of disputes will be available where a significant enough conflict in state law emerges (such as in pore space ownership rules for a storage basin that crosses state lines). In any case, our survey findings add a valuable level of detail on industry preferences not previously cataloged. Indeed, given that perhaps the most well known CCS regulatory roadmap offered to date, that of the Interstate Oil and Gas Compact Commission, advocates for state rather than federal regulation of CCS,[288] our survey data call into question the appropriateness of general deference to state law.

Third, the survey data also provide new granularity on what kind of liability limits may be best suited to an emerging CCS industry. Prior scholarship has considered a wide range of approaches to managing CCS risks and liabilities.[289] While no one liability framework has emerged as the clear favorite, the CCS literature broadly concludes that effecting CCS deployment will require the government to take some role in limiting private parties' exposure to CCS liabilities.[290] Similarly, our survey results show that the CCS community clearly believes that one necessary component of any liability regime is for the government to take custody of sequestered CO_2 after some period of time, once injection and monitoring requirements are met. This differs with the report issued by the

[288] As stated by the IOGCC, "Although the UIC Program may be applicable at the discretion of a state program, the current limitations of the UIC program make it applicable only to the operational phase of the storage project. It would therefore appear that given the ownership issue and the proposed long-term 'care-taker' role of the states, the states are likely to be best positioned to provide the necessary 'cradle to grave' regulatory oversight of geologic storage of CO_2." IOGCC, STORAGE OF CARBON DIOXIDE IN GEOLOGIC STRUCTURES, A LEGAL AND REGULATORY GUIDE FOR STATES AND PROVINCES 12 (2007). For additional discussion of the IOGCC framework and state adoptions of that framework, *see* Section III, *supra*, at pp.12-13. In 2010, the CCSReg Project offered its draft model legislation for a federal CCS regulatory framework that contemplates shared federal and state regulatory authority. DEPARTMENT OF ENGINEERING AND PUBLIC POLICY, CARNEGIE MELLON UNIVERSITY, CCSREG PROJECT, MODEL LEGISLATION: THE CARBON CAPTURE AND SEQUESTRATION REGULATORY ACT OF 2010 (2010). The CCSReg Project framework remains a work in progress. *See* CCSReg Project, http://www.ccsreg.org/index.html.
[289] *See supra* Sections IV.A. and IV.A.2.
[290] *Id*.

Interagency Task Force on Carbon Capture and Storage, which explicitly hedged with regard to whether government ownership of stored CO_2 should be pursued.[291] Rather, that study recommended that government ownership should be considered as one of "four approaches" for addressing "long-term liability and stewardship," including "[r]eliance on the existing framework," "[a]doption of substantive or procedural limitations on claims," "[c]reation of a fund to support long-term stewardship activities and compensate parties . . . after site closure," and "[t]ransfer of liability to the Federal government after site closure (with certain contingencies)."[292] Our survey results contradict this recommendation; a full 42% of survey participants who identified a specific liability limit in their open-answer respondents favor ultimate government custody of sequestered CO_2.[293]

Our survey results show, moreover, that the next most favored approaches to liability are, in order, addressing pore ownership, capping liability as is done for nuclear power operators in the Price-Anderson Act, limiting environmental statutory liability, and clarifying long-term site monitoring requirements.[294] This indicates that the CCS community may be satisfied with a potentially broad range of liability solutions—although it also suggests a fairly ordered list of preferences for how to proceed on this front. Ideally, this kind of additional granularity in stakeholder preferences can help to inform future proposals for CCS regulation, both with respect to how to apportion CCS liabilities and on how government can best incent private investment in CCS.

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[291] U.S. DEP'T OF ENERGY, CCS TASK FORCE REPORT 126-27 (2010).
[292] *Id*.
[293] *See supra* Section V.B.3.a.
[294] *See id.*

Exit this survey

INSTITUTE FOR
Clean and Secure Energy
THE UNIVERSITY OF UTAH

Geologic Carbon Capture and Sequestration Opinion Survey

Introduction

Dear survey participant:

The University of Utah's Institute for Clean and Secure Energy (ICSE) is researching the law, policy, and regulation of geologic carbon capture and sequestration (GCS). The research is sponsored by funding from the United States Department of Energy (DOE).

ICSE is conducting an opinion survey on GCS regulation. The purpose of this study is to determine how regulatory approaches to GCS match up—or do not match up—with the GCS industry's needs for regulation. Our hope is that this study will help inform U.S. energy and climate change policy, specifically policies related to GCS. Results will be submitted to the U.S. Department of Energy and may be included in public presentations or publications.

You were identified as possessing GCS expertise. We value your opinions regarding barriers to GCS development and deployment, and encourage you to complete the survey.

The survey should take approximately 15-20 minutes to complete. If you choose to participate, your identity and the identity of your organization will be kept confidential. ICSE will release only aggregated results and anonymous comments.

Participation in this study is voluntary. You can choose not to take part. You can choose not to finish the questionnaire or omit any question you prefer not to answer without penalty or loss of benefits. By completing this survey, you are giving your consent to participate.

If you have questions regarding this survey, please contact Professor Lincoln Davies (801.581.7338 or lincoln.davies@law.utah.edu) or John Ruple, ICSE Research Fellow (801.585.5197 or john.ruple@law.utah.edu).

If you have questions regarding your rights as a research participant, contact the Institutional Review Board (IRB). You may also contact the IRB if you have questions, complaints, or concerns that you do not feel you can discuss with ICSE. The University of

Utah IRB may be reached by phone at 801.581.3655 or by email at irb@hsc.utah.edu.

Thank you for your participation. Your input plays an important role in identifying barriers to GCS and in formulating practical, effective policy programs.

Sincerely,

Lincoln L. Davies
Associate Professor of Law
University of Utah

14%

Next

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Geologic Carbon Capture and Sequestration Opinion Survey

General Questions

This survey measures barriers to the commercial-scale deployment of carbon capture and geologic sequestration (GCS) technology in the United States. Please answer the questions below based on your personal opinion.

ALL RESPONSES ARE CONFIDENTIAL.

PARTICIPATION IS VOLUNTARY; YOU MAY CHOOSE NOT TO ANSWER ANY QUESTION.

1. Which of the following describe your organization's role in GCS? (check all that apply)

- ☐ We are a CO2 emitter
- ☐ We are engaged in CO2 capture
- ☐ We are engaged in CO2 transportation
- ☐ We are engaged in CO2 sequestration
- ☐ We provide professional services (lobbying, financing, insurance, legal services, etc.) to companies emitting CO2
- ☐ We provide professional services (lobbying, financing, insurance, legal services, etc.) to companies engaged in CO2 capture, transportation, or sequestration
- ☐ We are a governmental agency or regulator
- ☐ We conduct research involved in CO2 capture, transportation, or sequestration
- ☐ We are a non-profit interest group
- ☐ Other (please explain)

2. If involved in CO2 sequestration, is your organization involved in CO2 sequestration that DOES NOT involve enhanced oil recovery?

- No
- Yes

3. What is the most significant barrier to commercial-scale GCS deployment?

4. What is the most significant legal or policy barrier to commercial-scale GCS deployment?

5. What is the most significant financial or business-related barrier to commercial-scale GCS deployment?

29%

Prev Next

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Geologic Carbon Capture and Sequestration Opinion Survey

General Questions

6. What is the most important step that government can take to promote commercial-scale GCS deployment?

7. Are there other important steps that government should take to promote commercial-scale GCS deployment? If so, what are they?

8. Are there areas of GCS regulation that are more appropriate for the federal government than state governments? If so, what areas?

9. Are there areas of GCS regulation that are more appropriate for state governments than the federal government? If so, what areas?

10. Would you prefer large, regional carbon sequestration sites for multiple emission sources, or local sequestration sites for each major CO2 source?

- Regional
- Local

Why?

43%

Prev Next

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Geologic Carbon Capture and Sequestration Opinion Survey

Barriers to GCS

11. This question asks you to rate possible barriers to the commercial-scale deployment of GCS technology. For each factor, please rate the significance of that factor as an obstacle to GCS.

	No Obstacle	Minor Obstacle	Measurable Obstacle	Significant Obstacle	Critical Obstacle
Public resistance to GCS	○	○	○	○	○
Public resistance to greenhouse gas regulation	○	○	○	○	○
Public resistance to new coal-fired power plants	○	○	○	○	○
Public resistance to retrofitting existing CO2 emission sources	○	○	○	○	○
Public resistance to higher commodity and electricity prices	○	○	○	○	○
Public resistance to CO2 pipelines	○	○	○	○	○
Public resistance to GCS storage facilities	○	○	○	○	○
Lack of comprehensive GCS regulation	○	○	○	○	○
Lack of CO2 emission limits	○	○	○	○	○
Uncertainty about climate change legislation	○	○	○	○	○
Uncertainty regarding ownership of pore space	○	○	○	○	○

	No Obstacle	Minor Obstacle	Measurable Obstacle	Significant Obstacle	Critical Obstacle
Uncertainty regarding ownership of injected CO_2	○	○	○	○	○
Uncertainty regarding utilities' ability to recover costs for using GCS	○	○	○	○	○
Inconsistent laws or regulations affecting GCS	○	○	○	○	○
Insufficient government incentives for GCS use	○	○	○	○	○
Public utility commission reluctance to pass along GCS costs to ratepayers	○	○	○	○	○
Inadequate GCS technology	○	○	○	○	○
Inadequate technology to capture CO_2	○	○	○	○	○
Inadequate technology to retrofit existing emission sources with GCS technology	○	○	○	○	○
Inadequate technology to transport CO_2	○	○	○	○	○
Inadequate pipeline capacity for CO_2 transportation	○	○	○	○	○
Inadequate technology to geologically sequester CO_2	○	○	○	○	○
Inadequate technology to monitor geological CO_2 storage sites	○	○	○	○	○
Lack of CO_2 sequestration sites	○	○	○	○	○
Lack of information about sequestration site capacity	○	○	○	○	○
Lack of information about sequestration site geology	○	○	○	○	○

	No Obstacle	Minor Obstacle	Measurable Obstacle	Significant Obstacle	Critical Obstacle
Lack of information regarding abandoned wells within potential sequestration sites					
Lack of proven commercial-scale GCS operations					
The cost of GCS					
The cost of GCS, compared to other alternative sources of electricity					
The cost of CO2 capture					
The cost of retrofitting existing CO2 emission sources					
The cost of CO2 transportation					
Liability for CO2 pipeline operators					
The cost of CO2 storage					
Liability for CO2 storage					
The cost of GCS site monitoring					
The cost of complying with GCS regulations					
Lack of adequate private insurance and/or bonding for sequestered CO2					
Lack of a statutory liability cap for GCS					
Insufficient funding for GCS research					

57%

Prev Next

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Geologic Carbon Capture and Sequestration Opinion Survey

Policy Options

12. This question includes a list of policy options. For each option, please rank the values of each option with steps, with 1 representing the most promising option. The most effective means of encouraging commercial-scale GCS development is to:

	Ranking (1=most promising; 11=least promising)
Impose a carbon tax	
Implement a CO2 cap and trade program	
Impose technological mandates	
Impose emission performance standards	
Guarantee utility cost recovery for GCS use	
Provide research and development funding	
Provide subsidies	
Provide tax incentives or credits	
Provide liability limits	
Provide GCS pipeline right-of-way siting authority	
Other (please specify)	

.

13. The best entity to regulate GCS is:

	Ranking (1=best; 7=worst)
The U.S. Congress	
The U.S. EPA	
Different federal agencies for different aspects of GCS	
Individual states	
State implementation of federal programs	
Voluntary industry standards	
Other (please specify)	

.

71%

Prev Next

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Geologic Carbon Capture and Sequestration Opinion Survey

GCS Regulation

14. This question includes statements about GCS. Please rate your level of agreement with each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing legal structures are adequate to address commercial-scale GCS operations	○	○	○	○	○
Existing legal structures are adequate to address GCS requirements for new CO2 emission sources	○	○	○	○	○
Existing legal structures are adequate to address retrofitting CO2 emission sources with carbon capture technology	○	○	○	○	○
Existing legal structures are adequate to address CO2 transportation infrastructure siting	○	○	○	○	○
Existing legal structures are adequate to address CO2 transportation rates	○	○	○	○	○
Existing legal structures are adequate to address shipper access to CO2 pipelines	○	○	○	○	○
Existing legal structures are adequate to address CO2 transportation safety	○	○	○	○	○
Existing legal structures are adequate to address CO2 sequestration siting	○	○	○	○	○
Existing legal structures are adequate to address CO2 storage site monitoring	○	○	○	○	○

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing legal structures are adequate to address potential liability associated with GCS	○	○	○	○	○
Federal GCS regulation is needed to ensure consistent rules across jurisdictions	○	○	○	○	○
States should regulate GCS because they understand local conditions better than the federal government	○	○	○	○	○
The federal government should set minimum standards for GCS, but states should implement and assume all other responsibilities for GCS regulation	○	○	○	○	○
Commercial-scale implementation of GCS is unlikely unless performed in conjunction with enhanced oil recovery (EOR)	○	○	○	○	○
It is difficult to obtain investment funding for GCS	○	○	○	○	○
The lack of sufficient GCS regulation is what makes it difficult to obtain investment funding for GCS	○	○	○	○	○
GCS is a viable means of reducing CO_2 emissions	○	○	○	○	○

86%

Prev Next

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Geologic Carbon Capture and Sequestration Opinion Survey

Your Organization

15. Which of the following best describes your organization? (check all that apply)

- ☐ Our organization operates internationally
- ☐ Our organization operates in the following region(s) of the United States:
- ☐ Northwest
- ☐ Southwest
- ☐ Intermountain West
- ☐ Midwest
- ☐ Southeast
- ☐ Mid-Atlantic
- ☐ Northeast
- ☐ Alaska or Hawaii

16. My organization deals with GCS technology:

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ Occasionally

17. My organization tracks GCS legal, regulatory, and policy developments:

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ Occasionally

Appendix B: CCS Barrier Ranking Data

N.B.: "Catchall" barriers are indicated by shaded rows; barriers included within that obstacle category follow. Bolded cells indicate the obstacle ranking option that received the most responses for that CCS barrier.

Possible CCS Barrier	Number of Responses	No Obstacle Responses	Minor Obstacle Responses	Measurable Obstacle Responses	Significant Obstacle Responses	Critical Obstacle Responses	Mean Score	Obstacle Rank
The cost of GCS	185	1.6% (3)	2.2% (4)	15.7% (29)	23.8% (44)	**56.8% (105)**	4.32	Significant
The cost of CO2 capture	187	2.7% (5)	2.7% (5)	16.6% (31)	35.8% (67)	**42.2% (79)**	4.12	Significant
Public resistance to higher commodity and electricity prices	186	0.5% (1)	5.4% (10)	22.6% (42)	**36.6% (68)**	34.9% (65)	4	Significant
The cost of retrofitting existing CO2 emission sources	184	1.6% (3)	4.3% (8)	20.7% (38)	**39.7% (73)**	33.7% (62)	3.99	Significant
Uncertainty regarding utilities' ability to recover costs for using GCS	185	0.5% (1)	6.5% (12)	25.9% (48)	30.3% (56)	**36.8% (68)**	3.96	Significant
The cost of GCS, compared to other alternative sources of electricity	187	4.3% (8)	9.1% (17)	21.9% (41)	32.1% (60)	**32.6% (61)**	3.8	Significant
Public utility commission reluctance to pass along GCS costs to ratepayers	182	1.6% (3)	8.2% (15)	27.5% (50)	**35.2% (64)**	27.5% (50)	3.79	Significant
The cost of complying with GCS regulations	181	3.9% (7)	21.5% (39)	**32.6% (59)**	27.6% (50)	14.4% (26)	3.27	Measurable
The cost of CO2 storage	184	4.9% (9)	26.1% (48)	**28.8% (53)**	24.5% (45)	15.8% (29)	3.2	Measurable
The cost of GCS site monitoring	184	7.1% (13)	**32.6% (60)**	**32.6% (60)**	21.7% (40)	6.0% (11)	2.87	Measurable
The cost of CO2 transportation	182	10.4% (19)	30.8% (56)	**31.3% (57)**	19.8% (36)	7.7% (14)	2.84	Measurable

Uncertainty about climate change legislation	185	1.6% (3)	3.2% (6)	16.2% (30)	30.3% (56)	**48.6% (90)**	4.21	Significant
Insufficient government incentives for GCS use	184	2.2% (4)	4.9% (9)	19.6% (36)	32.1% (59)	**41.3% (76)**	4.05	Significant
Lack of CO2 emission limits	182	1.1% (2)	9.9% (18)	21.4% (39)	25.8% (47)	**41.8% (76)**	3.97	Significant
Public resistance to greenhouse gas regulation	186	2.2% (4)	14.5% (27)	**38.7% (72)**	31.7% (59)	12.9% (24)	3.39	Moderate
Liability for CO2 storage	182	2.2% (4)	6.6% (12)	17.6% (32)	34.1% (62)	**39.6% (72)**	4.02	Significant
Lack of a statutory liability cap for GCS	181	2.2% (4)	6.6% (12)	27.1% (49)	**32.0% (58)**	**32.0% (58)**	3.85	Significant
Uncertainty regarding ownership of pore space	185	2.2% (4)	13.5% (25)	32.4% (60)	**33.5% (62)**	18.4% (34)	3.52	Significant
Lack of adequate private insurance and/or bonding for sequestered CO2	179	2.8% (5)	13.4% (24)	**33.0% (59)**	31.3% (56)	19.6% (35)	3.51	Significant
Uncertainty regarding ownership of injected CO2	186	3.8% (7)	16.7% (31)	**32.8% (61)**	26.3% (49)	20.4% (38)	3.43	Measurable
Liability for CO2 pipeline operators	180	8.9% (16)	**35.6% (64)**	27.8% (50)	20.6% (37)	7.2% (13)	2.82	Measurable
Lack of comprehensive GCS regulation	183	1.1% (2)	9.3% (17)	20.2% (37)	30.1% (55)	**39.3% (72)**	3.97	Significant
Inconsistent laws or regulations affecting GCS	183	2.2% (4)	14.2% (26)	27.9% (51)	**31.7% (58)**	24.0% (44)	3.61	Significant
Public resistance to higher commodity and electricity prices	186	0.5% (1)	5.4% (10)	22.6% (42)	**36.6% (68)**	34.9% (65)	4	Significant

Public resistance to GCS	186	0.5% (1)	9.1% (17)	33.3% (62)	**36.0% (67)**	21.0% (39)	3.68	Significant
Public resistance to GCS storage facilities	185	1.1% (2)	14.6% (27)	**37.3% (69)**	35.1% (65)	11.9% (22)	3.42	Measurable
Public resistance to CO2 pipelines	186	8.1% (15)	31.7% (59)	**35.5% (66)**	19.4% (36)	5.4% (10)	2.82	Measurable
Public resistance to retrofitting existing CO2 emission sources	179	12.3% (22)	**44.1% (79)**	24.6% (44)	12.8% (23)	6.1% (11)	2.56	Measurable
Lack of proven commercial-scale GCS operations	186	4.8% (9)	16.7% (31)	26.3% (49)	**32.3% (60)**	19.9% (37)	3.46	Measurable
Insufficient funding for GCS research	182	5.5% (10)	19.8% (36)	**33.5% (61)**	24.2% (44)	17.0% (31)	3.27	Measurable
Inadequate technology to capture CO2	182	14.8% (27)	**23.6% (43)**	23.1% (42)	17.0% (31)	21.4% (39)	3.07	Measurable
Inadequate technology to retrofit existing emission sources with GCS technology	182	12.1% (22)	23.6% (43)	**29.1% (53)**	17.6% (32)	17.6% (32)	3.05	Measurable
Inadequate GCS technology	183	15.3% (28)	**29.0% (53)**	26.2% (48)	15.8% (29)	13.7% (25)	2.84	Measurable
Inadequate technology to geologically sequester CO2	183	19.7% (36)	**29.5% (54)**	27.9% (51)	15.3% (28)	7.7% (14)	2.62	Measurable
Inadequate technology to monitor geological CO2 storage sites	183	16.4% (30)	31.7% (58)	**35.0% (64)**	9.8% (18)	7.1% (13)	2.6	Measurable
Inadequate technology to transport CO2	183	**44.3% (81)**	29.0% (53)	15.3% (28)	8.2% (15)	3.3% (6)	1.97	Minor

Lack of information about sequestration site geology	182	10.4% (19)	30.2% (55)	**36.3% (66)**	13.2% (24)	9.9% (18)	2.82	Measurable
Lack of information about sequestration site capacity	182	11.5% (21)	32.4% (59)	**33.0% (60)**	15.9% (29)	7.1% (13)	2.75	Measurable
Lack of information regarding abandoned wells within potential sequestration sites	181	9.4% (17)	31.5% (57)	**41.4% (75)**	12.7% (23)	5.0% (9)	2.72	Measurable
Lack of CO2 sequestration sites	181	18.2% (33)	**29.8% (54)**	**29.8% (54)**	11.6% (21)	10.5% (19)	2.66	Measurable
Public resistance to new coal-fired power plants	181	3.9% (7)	10.5% (19)	**37.0% (67)**	33.1% (60)	15.5% (28)	3.46	Moderate
Inadequate pipeline capacity for CO2 transportation	180	11.7% (21)	25.0% (45)	**38.9% (70)**	20.0% (36)	4.4% (8)	2.81	Measurable