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# Understanding barriers to commercial-scale carbon capture and sequestration in the United States: An empirical assessment

Lincoln L. Davies [a,b], Kirsten Uchitel [a,b,*], John Ruple [a,b]

[a] Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, USA
[b] Wallace Stegner Center for Land, Resources, and the Environment, S.J. Quinney College of Law, University of Utah, Salt Lake City, UT, USA

## HIGHLIGHTS

- We developed and distributed a unique CCS opinion survey.
- Our analysis confirmed cost and liability as primary barriers to CCS deployment.
- We identified regulatory barriers to CCS not previously singled out in the literature.
- We address the need for comprehensive rather than piecemeal CCS regulation.

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## ABSTRACT

Although a potentially useful climate change mitigation tool, carbon capture and sequestration (CCS) efforts in the United States remain mired in demonstration and development. Prior studies suggest numerous reasons for this stagnation. This article empirically assesses those claims. Using an anonymous opinion survey completed by 229 CCS experts, we identified four primary barriers to CCS commercialization: (1) cost and cost recovery, (2) lack of a price signal or financial incentive, (3) long-term liability risks, and (4) lack of a comprehensive regulatory regime. These results give empirical weight to previous studies suggesting that CCS cost (and cost recovery) and liability risks are primary barriers to the technology. However, the need for comprehensive rather than piecemeal CCS regulation represents an emerging concern not previously singled out in the literature. Our results clearly show that the CCS community sees fragmented regulation as one of the most significant barriers to CCS deployment. Specifically, industry is united in its preference for a federal regulatory floor that is subject to state-level administration and sensitive to local conditions. Likewise, CCS experts share broad confidence in the technology's readiness, despite continued calls for commercial-scale demonstration projects before CCS is widely deployed.



## 1. Introduction

Coal consumption rests at the intersection of energy policy's threefold objectives: providing (1) ample, secure supplies that are (2) low cost and (3) environmentally sustainable (Lyster and Bradbrook, 2006). Coal is abundantly used in the United States, providing nearly half of the nation's electricity production (EIA, 2012), but it is also linked to climate change. Worldwide anthropogenic carbon dioxide ($CO_2$) emissions currently total more than 33 billion tons annually (PBL, 2011), a level now recognized as unsustainable (IPCC, 2007). Concerns over climate change and national energy security have prompted a reexamination of fossil fuel use, including coal.

Carbon capture and sequestration (CCS) is one possible strategy for tapping the energy security benefits of coal while simultaneously mitigating climate change emissions. CCS is the process of capturing $CO_2$ and injecting that $CO_2$ deep underground for permanent storage and sequestration.[1] CCS can be used with other fossil fuel combustion processes, such as natural gas, but it is most closely linked with coal-fired electricity generation.

Despite extensive governmental backing, CCS development has proceeded in halting starts and stops in the United States. According to the Global CCS Institute, as of September 2012, the

* Corresponding author at: Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, USA. Tel.: +1 801 585 5609; fax: +1 801 585 1456.
*E-mail address:* kirsten.uchitel@law.utah.edu (K. Uchitel).

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[1] Our survey used the terms carbon capture and sequestration (CCS) and geologic carbon sequestration (GCS). The latter refers specifically to the land-based sequestration phase of CCS operations, while CCS sometimes refers more broadly to capture, transport, injection, and permanent sequestration in land- or non-land-based storage. To minimize confusion, this article uses CCS and GCS interchangeably.

United States had twenty-four large-scale CCS projects in the planning or operational stages. Only four of these projects, however, were operational, and these were connected to enhanced oil recovery efforts. Moreover, these twenty-four projects represent a decreasing effort in large-scale CCS efforts, down from thirty-one large-scale CCS projects underway in 2010 (Global CCS Institute, 2012).

Prior studies have suggested numerous reasons for this stagnation, but these explanations have been subjected to limited empirical testing. This article seeks to advance the discussion by presenting empirical data on both CCS impediments and potential policy responses to CCS commercialization barriers. To do so, we conducted an anonymous opinion survey of 229 stakeholders in CCS technology development, $CO_2$ emitting industries, CCS regulation, and other areas of CCS expertise. The survey had five goals: (1) to identify perceived barriers to commercial-scale CCS deployment, (2) to rate the significance of those barriers, (3) to compare the severity of perceived barriers across sectors, (4) to identify discrepancies between perceived barriers and CCS policies, and (5) to provide a basis for future CCS policy recommendations.

The survey data provide new insight into how CCS policy might be shaped. They also confirm prior studies' emphasis on cost and liability concerns as primary barriers to CCS implementation. Thus, to help CCS reach widespread commercial use, a carbon price or other significant financial incentive is needed, and the liability risks of long-term $CO_2$ storage must be addressed. Moreover, the CCS community craves a predictable, comprehensive regulatory regime—something overlooked by the extant scholarly literature, which has tended to focus on discrete legal and regulatory issues. The survey data suggest that this regime should employ a dynamic, or cooperative, federalist model of regulation—that is, one where national regulators set minimum legal requirements but state officials craft the specific implementation measures for those rules to account for local conditions. This regime would likely include eventual federal ownership of stored $CO_2$ and control over interstate $CO_2$ transport, pipelines, and all aspects of off-shore CCS, but would not disturb traditional areas of state control (*e.g.*, property rights, pore space ownership, mineral rights unitization, and eminent domain). It also would not place first priority on commercial-scale demonstration projects, and would instead emphasize tax credits and incentives over other options, such as technological mandates, subsidies, and funding for research and development.

## 2. Possible barriers to CCS commercialization

Although prior CCS studies are numerous, the scholarly literature has not yet systematically assessed the barriers to commercial-scale CCS deployment in the United States. Instead, scholarly empirical studies have focused primarily on Europe (Anderson et al., 2007; Evar, 2011; Hansson and Bryngelsson, 2009; ICF, 2007; Johnsson et al., 2010; Ramírez et al., 2008; Sala and Oltra, 2011; Stigson et al., 2012; van Alphen et al., 2007; Wallquist et al., 2010). Within the United States, CCS studies tend to focus on qualitatively outlining impediments that CCS commercialization faces, without any empirical evaluation. Other authors have highlighted government incentives, concentrating on options for promoting CCS (DeCesar, 2010; Flatt, 2009; Som, 2008). Still others have zeroed in on public perception of CCS and climate change (Bradbury et al., 2009; Curry, 2004). While often recognizing that regulatory uncertainty acts as an impediment to CCS commercialization, most of the law and policy literature has emphasized specific legal issues, such as potential CCS liability mitigation regimes, pore space ownership, or $CO_2$ pipeline regulation.

Potential barriers to CCS commercialization identified in prior studies include cost, the need for commercial-scale demonstration projects, liability and property rights issues associated with long-term CCS storage, safety and siting concerns, and the need for greater geologic knowledge and predictive modeling capabilities (Carnegie-Mellon, 2009; Folger, 2009; GAO, 2008; IEA, 2007, 2010; IPCC, 2005a; IRGC, 2008; Melzer, 2008; NETL, 2006; Parker et al., 2009; Pew Center, 2008; University of Houston, 2008; WRI, 2007, 2008). Scholars have also noted the general public's limited knowledge about CCS and the technologies involved (Bradbury et al., 2009; Curry, 2004), while others have suggested that public outreach is necessary to build trust between communities and project developers, and to counteract what has been characterized as a "pessimistic" public attitude about CCS (Carnegie-Mellon, 2009; DOE, 2010; WRI, 2008).

Of these various barriers, the higher cost of CCS-based electricity production, associated largely with the energy penalty from the $CO_2$ capture phase of CCS, has received the greatest attention (Der, 2010; GAO, 2008; Melzer, 2008; Pew Center, 2008). Estimates place the cost of retrofitting an existing power plant with CCS technology, as reflected by the increased cost of electricity, at 50–80% above existing costs (Carbon Capture and Storage Technologies Hearing, 2008; FutureGen Program Hearing, 2008). The absence of any financial incentive for CCS, such as a carbon price, is thus viewed as a fundamental barrier to CCS deployment (DOE, 2010; GAO, 2008; Pew Center, 2008). This relationship may create a Catch-22 of sorts. As Folger observes, "To achieve commercialization, [CCS] must… meet a market demand—a demand created either through a price mechanism or a regulatory requirement (demand-pull mechanisms)" (Folger, 2009). The failure of the United States to create a market reflecting the true price of carbon therefore serves as a disincentive for CCS deployment (Der, 2010; Pew Center, 2008), leading some commentators to suggest that CCS is unlikely to be economically favorable in the United States for at least two decades (JP Morgan, 2007). Focusing on price, the literature also advocates for research and development to increase CCS cost-effectiveness (GAO, 2008), along with addressing the capital costs that the extensive pipeline infrastructure that broad-scale CCS would entail (DOE, 2010; WRI, 2008).

After cost, liability receives the greatest attention as an impediment to CCS deployment (Antanasio, 2009; Bidlack, 2010; DOE, 2010; Hoffman, 2010; Klass and Wilson, 2008; Som, 2008). Liability for $CO_2$ storage is unclear. Two groups potentially bear the primary long-term legal risks for post-injection $CO_2$ management: private companies that take on CCS projects and the government/taxpayers. Which group ultimately will bear the risk is an open question (Carbon Capture and Storage Technologies Hearing, 2008). Accordingly, numerous observers have highlighted the uncertainty surrounding potential liability for carbon storage as a key source of industry reluctance for CCS investment (Carbon Capture and Storage Technologies Hearing, 2008; Carnegie-Mellon, 2009; Chestney, 2009; DOE, 2010). To address this barrier, observers have proposed a number of possible liability strategies, including traditional bonding and insurance, statutory liability limits, imposing responsibility on states, mandating federal ownership for stored $CO_2$, and various hybrid private–public solutions (Carnegie-Mellon, 2009; DOE, 2010; Flatt, 2009; WRI, 2008).

Policy studies have also observed CCS's need for continuous monitoring, especially via risk assessment and mitigation measures following $CO_2$ injection (DOE, 2011; NETL, 2009). 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 for wide-scale CCS deployment (DOE, 2011; NETL, 2009). This is in part because of CCS's potential for groundwater contamination and displacement