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BALANCING THE RISKS: MANAGING TECHNOLOGY AND DANGEROUS CLIMATE CHANGE

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Alexandra B. Klass and Elizabeth J. Wilson

Abstract

While risk is a fact of life, managing risk is complex. This is particularly true today in considering how to address climate change. We know that we must act, and act quickly, to significantly reduce greenhouse gas emissions in order to avoid dangerous climate change. Failure to act risks catastrophic climate impacts. We also know, however, that deploying technologies to significantly cut greenhouse gases will fundamentally change the way society produces and uses energy. Carbon capture and geologic sequestration (CCS) technology promises to provide deep emissions cuts, particularly from coal power generation, but deploying CCS creates risks of its own. This article first considers the risks associated with CCS, which involves capturing CO_2 emissions from industrial sources and power plants, transporting the CO_2 by pipeline, and injecting it underground for permanent sequestration. This article then suggests ways in which these risks can be minimized and managed and considers more broadly when or if CCS should be deployed or whether its use should be limited or rejected in favor of other solutions.

KEYWORDS: carbon capture, sequestration, climate change, risk, global warming

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INTRODUCTION

While risk is a fact of life, managing risk is complex. This is particularly true today in considering how to address climate change. We know that we must act, and act quickly, to significantly reduce greenhouse gas (GHG) emissions in order to avoid dangerous climate change. Failure to act risks catastrophic climate impacts. We also know, however, that deploying technologies to significantly cut GHG emissions will fundamentally change the way society produces and uses energy. Carbon capture and sequestration (CCS) technology promises to provide deep emissions cuts, particularly from coal power generation, but deploying CCS creates risks of its own. This Essay considers the risks associated with CCS, which involves capturing CO_2 emissions from industrial sources and power plants and transporting the CO_2 and injecting it underground for permanent, geologic sequestration. It then suggests ways in which these risks can be minimized and managed and considers more broadly when or if CCS should be deployed or whether its use should be limited or rejected in favor of other solutions.

The risks associated with CCS can be placed into four main categories. First, there are risks to human health and the environment associated with the unintended release of CO_2 into the atmosphere during the process of transporting CO_2 by pipeline to storage sites, the injection of CO_2 into the subsurface, or accidental leakage to the surface after injection is complete. These risks are both geologic and operational—i.e., they can result from problems associated with improper transportation, poor site selection, leaking wells, unanticipated problems with the subsurface geologic strata in which CO_2 is injected, or a failure to properly monitor and manage CO_2 once it is injected into the subsurface. Minimizing and managing these risks will require regulatory authorities to create the right incentives for project operators through existing and future regulations to optimize good site selection, management, and monitoring for CCS projects.

Second, there are financial risks associated with firms using CCS. These financial risks arise with the significant start-up costs associated with CCS—particularly associated with capture—as well as the liability risks firms may be forced to assume if CCS projects harm human health and the environment. Minimizing financial risks may involve government funding to encourage CCS deployment and creating appropriate liability and funding structures through financial responsibility requirements, potentially using private insurance, bonding, or creation of public or private funds to compensate injured parties or resource-owners in case of harm from CCS projects.

Third, there are climate risks. If CCS becomes a part of any state or federal CO_2 cap-and-trade system, incorporating CCS into industrial operations accrues associated credits for reducing CO_2 through CCS technology. There is the risk, however, that CO_2 injected into the subsurface may, at some point in the future, leak back into the atmosphere, limiting the long-term climate change benefit. How do we address potential future CCS leakage of CO_2 within a cap-and-trade framework? Addressing this risk could require tailored legislation, regulation, and institutional structures which consider how to value future, uncertain leakage within a larger climate policy context. Structuring financial or operational sanctions and remedial requirements for leaking CCS projects will be linked to national and international climate policy agreements.

Fourth, there are risks of inaction in not accepting the risks associated with CCS or other technologies to reduce GHG emissions. With regard to CCS, there are arguments that CCS associated with fossil fuel production is not "sustainable" in that it allows the United States and the rest of the world to remain dependent on coal when what is really needed is a complete transition to sustainable energy. Indeed, the environmental community is currently split over the role that CCS could or should play. Some groups argue that it is an important technology to broker a politically feasible climate policy, while others argue that CCS merely perpetuates the problem—dependence on hydrocarbons. Minimizing the risks of inaction involves a more careful look at CCS within a larger energy and climate policy context to determine whether a coal-enabling technology can work as a transition technology so long as sufficient funding and support is provided to encourage other, non-coal-based sources of energy.

I. Climate Change, Coal Combustion, and the Potential Role of CCS

According to research by the National Oceanic and Atmospheric Administration, preindustrial levels of atmospheric CO_2 did not vary more than 7 ppm during the 800 years between 1000 and 1800 A.D.[1] Since the industrial revolution, emissions of CO_2 have increased more than 80 percent[2]—primarily from fossil fuel combustion—and now atmospheric concentrations of CO_2 are 100 ppm higher than preindustrial levels (385 ppm vs 278 ppm).[3] Because CO_2 lasts for roughly a century in the atmosphere, even if global GHG emissions were stabilized immediately, atmospheric levels of GHGs would continue to rise.[4]

Despite the increased media attention and public awareness of climate change and concern about GHG emissions, these emissions continue to increase

[1] NOAA News Online, After Two Large Gains, Rate of Atmospheric CO2 Increase Returns to Average, March 31, 2005, http://www.noaanews.noaa.gov/stories2005/s2412.htm.

[2] CLIMATE CHANGE 2007 SYNTHESIS REPORT: SUMMARY FOR POLICY MAKERS, APPROVED IN DETAIL AT IPCC PLENARY XXVII (Valencia, Spain, 12-17 November 2007), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf. [hereinafter "CLIMATE CHANGE 2007 SYNTHESIS REPORT"].

[3] *See* CO_2 Now, Current Data for Atmospheric CO_2, http://co2now.org/index.php/Current-CO2/CO2-Now/current-data-atmospheric-co2.html (last visited Apr. 21, 2009).

[4] CLIMATE CHANGE 2007 SYNTHESIS REPORT, *supra* note 2.

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as growing global energy demand is satisfied in part with coal-based electric power. Currently the United States emits roughly 1.5 billion tons of CO_2 per year by burning coal in electric power plants.[5] Fossil fuels are predicted to remain the "mainstay" in energy production for decades to come, in the U.S. and around the world, thereby steadily increasing atmospheric CO_2.[6] Global emissions of CO_2 are projected to grow slightly more than half again by 2030 from today's annual emissions.[7]

Of the more than 4 billion Megawatt hours (MWh) of electricity generation produced in the United States annually,[8] roughly half comes from coal-fired power.[9] Despite slowing the modeled increase in coal consumption in its regular Annual Energy Outlook report for 2009 by comparison to earlier reports, the Energy Information Administration (EIA) continues to expect coal consumption in the United States to rise nearly twenty percent by 2030.[10] Although the United States Geological Service (USGS) is currently updating its national coal assessments,[11] the EIA has estimated coal resources in the United States to be sufficient for over 200 years at current rates of consumption.[12] The United States is thought to have by far the largest share of economically-recoverable coal in the world with approximately 29 percent of the total proven recoverable reserves (Russia, China and India follow respectively).[13] The

[5] MIT, THE FUTURE OF COAL, ix (2007), *available at* http://web.mit.edu/coal/The_Future_of_Coal_Summary_Report.pdf.
[6] U.S. EPA, Proposed Rule, Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells, 73 Fed. Reg. 43491, 43495 (July 25, 2008) [hereinafter "EPA Proposed Rule"].
[7] *See* ENERGY INFORMATION ADMINISTRATION (EIA), INTERNATIONAL ENERGY OUTLOOK 2008, at 5 (2008), http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2008).pdf (stating that growth will be "from 28.1 billion metric tons in 2005 to 34.3 billion metric tons in 2015 and 42.3 billion metric tons in 2030—an increase of 51 percent over the projection period").
[8] *See* EIA, State Electricity Profiles 2006 (2007), http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.
[9] *See id.* at 262 (ranging from 52.5% in 1990 to 49% in 2006).
[10] *See* EIA, Annual Energy Outlook 2009, at 7 (2009), http://www.eia.doe.gov/oiaf/aeo/pdf/overview.pdf.
[11] *See* United State Geological Survey (USGS), Coal Resources, http://energy.usgs.gov/coal.html (last visited Apr. 21, 2009).
[12] *See* ASSESSING THE COAL RESOURCES IN THE UNITED STATES, USGS FACT SHEET FS-197-96 (July 1996), *available at* http://energy.usgs.gov/factsheets/nca/nca.html (estimating over 250 years of recoverable coal). *See also* Cathy Booth Thomas, *Is Coal Golden?*, TIME, Oct. 2, 2006, *available at* http://www.time.com/time/magazine/article/0,9171,1541270-1,00.html (estimating over 200 years of economically recoverable coal).
[13] *See* BP, BP STATISTICAL REVIEW OF WORLD ENERGY 2008, at 32 (2008), http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/downloads/pdf/statistical_review_of_world_energy_full_review_2008.pdf (United States 28.6 percent, Russian Federation 18.5 percent, China 13.5 percent, India 6.7 percent).

National Mining Association estimates coal reserves are 95 percent of the fossil energy reserves in the U.S.[14] Because the current electricity portfolio in the U.S. is dominated by coal—though this varies significantly by region—and there do not seem to be any near-term supply-limiting factors, coal is expected by many to continue to play a prominent role in the U.S. electricity system. Efforts to address current transportation fuel challenges—either through the electrification of vehicles or through the use of coal-to-liquids based transportation fuels—may only further increase the use of coal and exacerbate the need to address the associated CO_2 emissions.

Although the U.S. has been a long-time developer and user of coal-fired electric power, rapid growth in developing countries—particularly China and India—is significantly escalating CO_2 emissions. Since 2000, China has doubled its use of coal-fired power and is expected to represent over 70 percent of the growth in coal-fired power internationally over the next decades.[15] China likely surpassed the United States as the global leader in CO_2 emissions in 2006,[16] roughly a decade before expected.[17] China's annual coal capacity addition is equivalent in size to the entire United Kingdom grid.[18] Because coal is abundant and remains affordable, these emission trends are likely to continue.[19] Additionally as these large coal reserves are cheaply available they are often seen as a key component for national development agendas and energy security goals. As a result, socio-economic and political considerations make eliminating coal use completely in the short-term an unrealistic goal.[20] Every new conventional combustion coal plant has an average life span of 30-50 years, locking in the associated carbon emissions and climate liability for decades to come. Closing down coal plants and ceasing operations before they are fully amortized could leave billions of dollars of stranded assets, and place tremendous strains on regional economies.[21] Moreover as the CO_2 emitted today will remain in the

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[14] Chiara Trabucchi & Lindene Patton, *Storing Carbon: Options for Liability Risk Management, Financial Responsibility*, Daily Envt. Rep. (BNA) No. 70 at 7 (Sept. 3, 2008).

[15] *See* EIA, International Energy Outlook 2008 Highlights (June 2008), http://www.eia.doe.gov/oiaf/ieo/highlights.html.

[16] *See* John Vidal & David Adam, *China Overtakes U.S. as World's Biggest CO_2 Emitter*, GUARDIAN, June 19, 2007, *available at* http://www.guardian.co.uk/environment/2007/jun/19/china.usnews.

[17] *See* Peter Fairley, *China's Coal Future*, TECHNOLOGY REVIEW, Jan. 1, 2007, *available at* http://www.technologyreview.com/Energy/18069/.

[18] THE FUTURE OF COAL, *supra* note 5, at ix.

[19] *Id.*

[20] Trabucchi & Patton, *supra* note 14, at 6.

[21] *Id.*

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atmosphere for roughly a century, current infrastructure choices will commit the globe to the associated warming even if dramatic emissions reductions follow.[22]

CCS technology offers the option of continued and future use of fossil fuels in power plants and industrial sources, while substantially minimizing the associated CO_2 emissions. The technology captures CO_2 emissions at the point source and injects the captured CO_2 deep underground (roughly 1 km), effectively preventing emissions into the atmosphere where they contribute to climate change. Areas for potential CO_2 sequestration include oil and gas fields, saline aquifers, and, potentially, deep coal seams. Existing geologic formations containing crude oil, natural gas, brine, and CO_2 could have storage capacity for thousands of years.[23] A U.S. Department of Energy (DOE) report released March 27, 2007 indicates potential underground storage capacity of 3,500 billion metric tons across the U.S. and Canada for storing CO_2 and other GHGs produced at power plants and other industrial sources.[24] Even when compared to the 1.5 billion tons of CO_2 emitted in the U.S. each year, storage capacity is plentiful.[25] Some electric power industry representatives believe that CCS could reduce emissions from electric power plants by one-quarter in 2030.[26] The director of the National Energy Technology Laboratory (NETL) recently testified in Congress that at the current rate of production and use, the United States and Canada have the capacity to store all of the CO_2 emissions they produce for the next 175 to 500 years.[27] The International Panel on Climate Change (IPCC) models project that

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[22] *See Global Warming Will Persist at Least a Century Even if Emissions Curbed Now*, SCIENCE DAILY, Feb. 18, 2002, http://www.sciencedaily.com/releases/2002/02/020218094427.htm; *see also Change Largely Irreversible For Next 1,000 Years, NOAA Reports*, SCIENCE DAILY Jan. 28, 2009, http://www.sciencedaily.com/releases/2009/01/090127163403.htm.

[23] *See* WORKING GROUP III OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE (Cambridge Univ. Press 2005), *available at* http://www.ipcc.ch/ipccreports/special-reports.htm [hereinafter "IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE"].

[24] *See* U.S. DEPARTMENT OF ENERGY, CARBON SEQUESTRATION ATLAS OF THE U.S. AND CANADA (2007), http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html; Lawrence J. Speer, *DOE Finds Large Capacity for Storing Carbon Dioxide Across U.S., Canada*, Daily Env't. Rep. (BNA) No. 60 at A-5 (March 29, 2007). *See also* Eric Williams, et al., *Carbon Capture, Pipeline and Storage: A Viable Option for North Carolina Utilities?*, (Nicholas Inst. for Envtl. Pol'y Solutions & Ctr. on Global Change, Duke Univ., Working Paper No. 07-01, 2007), www.nicholas.duke.edu/institute/carboncapture.pdf.

[25] *See* EPA Proposed Rule, *supra* note 6, at 43496 (stating that worldwide "there appears to be significant capacity in subsurface formations both on land and under the seafloor to sequester CO_2 for hundreds, if not thousands of years.").

[26] Steven D. Cook, *Power Industry Officials Disagree on Future, Feasibility of Carbon Capture, Storage*, Daily Env't. Rep. (BNA) No. 186 at A-1 (Sept. 26, 2007).

[27] *Id.*

CCS could provide anywhere from 10 percent to 55 percent of the total carbon mitigation effort until year 2100.[28]

Deployment of CCS will require CO_2 capture, transport, and sequestration to be both effective and economically efficient.[29] The CO_2 will likely be injected as a dense supercritical fluid[30] into porous sedimentary formations usually at depths greater than one kilometer.[31] Once injected into the formation, the CO_2 flows through the rock to occupy the permeable pore space with any buoyant flow trapped by less permeable rock layers—the 'cap rock'—which impede upward migration. Due to geological heterogeneity, CO_2 behavior in the subsurface will vary between and within sequestration sites. Importantly, after active injection of CO_2 ceases, and reservoir pressures begin to decrease, CO_2 storage sites are predicted to become more secure over time as the CO_2 is trapped in rock capillaries and as geochemical reactions dissolve CO_2 in formation waters and eventually convert it to minerals.[32] Thus, an effectively selected and managed geologic sequestration site has the potential to keep large volumes of a buoyant fluid underground for centuries to millennia.

Although the idea of injecting CO_2 into the subsurface for the purpose of controlling GHG emissions may be new, the practice of injecting CO_2 into the subsurface for other purposes is not. For decades, oil producers have injected CO_2 into the subsurface to increase oil production. This process, known as "enhanced oil recovery" or EOR, is in widespread use in West Texas, where approximately 30 million tons of CO_2 are injected into the ground annually, resulting in a total of 600 million tons injected—though not stored for sequestration—in that area since 1985.[33] While supporters of CCS hold up the success and safety of CO_2 injection for EOR purposes, it is clear that CO_2 storage

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[28] *See* IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23.

[29] *See* Minh Ha-Duong & David W. Keith, *Carbon Storage: The Economic Efficiency of Storing CO_2 in Leaky Reservoirs, in* 5 CLEAN TECH. & ENVTL. POLICY 181 (2003). *See also* Stephen Pacala, *Global Constraints on Reservoir Leakage*, *in* SIXTH INTERNATIONAL CONFERENCE ON GREENHOUSE GAS CONTROL TECHNOLOGIES (John Gale & Yoichi Kaya eds., 2002).

[30] CO_2 is considered a supercritical fluid at temperatures greater than 31.1°C and 7.38 MPa (critical point). *See* CRC HANDBOOK OF CHEMISTRY AND PHYSICS 6-39 (David R. Lide ed., 88th ed. 2008), *available at* http://www.hbcpnetbase.com/articles/06_20_88.pdf; Robert G. Bruant et al., *Safe Storage of CO_2 in Deep Saline Aquifers,* 36 ENVTL. SCI. & TECH. 240A-245A (2002).

[31] *See* Ha-Duong & Keith, *supra* note 29 (discussing benefits of sequestration of shorter timeframes). *See also* IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 247.

[32] *See* Kartsen Preuss et al., *Numerical Modeling of Aquifer Disposal of CO_2*, 8 SOC'Y OF PETROLEUM ENGINEERS J. 49, 52-53 (2003).

[33] RICHARD C. MAXWELL ET AL., OIL AND GAS 13-14 (8th ed. 2007) (discussing enhanced recovery technology); Steven D. Cook, *Researchers Optimistic on Prospects for Successful Carbon Capture, Storage*, Daily Env't. Rep. (BNA) No. 94, at A-1 (May 16, 2007) (discussing the use of enhanced oil recovery in Texas as a current example of subsurface injection of CO_2).

for purposes of controlling GHG levels in the atmosphere will have different risks and be several orders of magnitude larger.[34] The MIT "Future of Coal" study states: "[i]f 60% of the CO_2 produced from U.S. coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would about equal the total U.S. oil consumption of 20 million barrels per day,"[35] highlighting the massive volumes of CO_2 involved in a large-scale carbon capture program.

Several CCS projects are underway in Norway, Algeria, and Canada and more are planned in the United States, China, Australia, and other European countries.[36] Today four CCS projects are already active, each injecting roughly one million metric tons of CO_2 per year. The Dakota Gasification Company (DGC) plant in Beulah, North Dakota, for example, captures and transports the CO_2 by pipeline over 200 miles and an international border to the Canadian Weyburn oil field for tertiary oil recovery.[37] The DOE has funded seven regional carbon sequestration partnerships with the aim of long-term research and development of the technology as well as six of seven anticipated large scale pilot projects to store 1 million tons or more of CO_2 in various geologic formations across the country.[38] More recently, the American Recovery and Reinvestment Act has allocated an additional $3.4 billion for CCS demonstration projects.[39]

At the same time, state legislatures and federal agencies are developing the early stages of a statutory and regulatory framework to govern CCS deployment. The U.S. EPA manages the Underground Injection Control (UIC) program to regulate underground injection of fluids to protect potential sources of drinking

[34] *See* U.S. Environmental Protection Agency, Using Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects, UIC Program Guidance (UICPG #83), at 2 (March 1, 2007), *available at* http://www.epa.gov/region8/states/pdf/Carbon%20Sequestration%20UIC%20Guide%20Final%20Mar%2007.pdf ("While injection of fluids, including CO_2 into the subsurface, e.g., for enhanced oil recovery (EOR) and enhanced gas recovery (EGR), is a long-standing practice, injection of CO_2 [for CCS] is an experimental application of this existing technology.").

[35] THE FUTURE OF COAL, *supra* note 5 at xi.

[36] *See* The International Energy Agency (IEA), CO_2 Capture and Storage R,D&D Database, http://www.co2captureandstorage.info/search.php (last visited Apr. 21, 2009).

[37] *Id. See also* Dakota Gasification Company, http://www.dakotagas.com/Companyinfo/index.html (last visited Apr. 21, 2009). Three current CCS projects capture and inject the CO_2 produced from natural gas production projects: Sleipner in the North Sea and Snøvhit in the Barents Sea inject deep below the seafloor CO_2 captured from produced natural gas; and In Salah, in Algeria, injects the captured CO_2 into a deep gas formation. The fourth project, in Saskatchewan, injects and monitors CO_2 for the Weyburn enhanced oil recovery project in Beulah, North Dakota.

[38] *See* U.S. Dept. of Energy, Carbon Sequestration Regional Partnerships, http://fossil.energy.gov/sequestration/partnerships/index.html (last visited Apr. 20, 2009).

[39] *See* Summary: American Recovery and Reinvestment Act Conference Agreement, at 4 (2009), http://appropriations.house.gov/pdf/PressSummary02-13-09.pdf.

water and will regulate future CCS permits.[40] Under the EPA's proposed rule for CO_2 sequestration, many of the risks associated with ground water, pressure effects and long-term stewardship are addressed. Because the Rule was promulgated under the EPA's authority through the Safe Drinking Water Act, however, many of the risks addressed in this article—to human health and the environment and for climate change mitigation—are not covered by the rule.[41]

Meanwhile, many states are enacting legislation regulating CCS, GHG emissions, or both. Washington passed a "Mitigating the Impacts of Climate Change" bill in May 2007 that sets both GHG reduction targets and directs the Department of Ecology to develop rules for geologic sequestration.[42] One of two adopted rules in June 2008 sets performance standards for geologic sequestration including that 99 percent of the stored CO_2 must remain underground for at least one thousand years.[43] The other rule governs the injection of the CO_2. Kansas has proposed rules governing CCS but has not yet set a state-wide climate policy or goal. In March 2007 the Kansas legislature passed a law directing the Kansas Corporation Commission to develop rules for geologic sequestration; created a fund for regulatory, remedial, and monitoring costs; and created a tax incentive structure for CCS.[44] The proposed rules include requirements for construction and storage permits.[45] Other states have not yet specifically addressed CCS, but are moving forward on significant climate legislation. Massachusetts, for example, enacted legislation in August 2008 which, in part, requires an 80 percent reduction below 1990 levels of CO_2 by 2050.[46] Table 1 contains a summary of existing state legislation relevant to CCS.

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[40] *See* EPA Proposed Rule, *supra* note 6.
[41] *Id.*
[42] *See* WASH. REV. CODE ANN. § 80.80.040 (West Supp. 2009). California has enacted similar legislation. *See* CA. PUB. UTIL. CODE § 8341(d)(5) (West Supp. 2009).
[43] *See* Melisa Pollack & Elizabeth Wilson, *Regulating Geologic Sequestration in the US: Early Rules Take Divergent Approaches*, 43 ENVTL. SCI. & TECH. 3035 (2009), *available at* http://pubs.acs.org/doi/full/10.1021/es803094f (citing legislation).
[44] *Id.* at 5 (citing Carbon Dioxide Reduction Act, KS HB 2419).
[45] *Id.*
[46] Climate Protection and Green Economy Act of 2008, MASS. GEN. LAWS ANN. ch. 21N, § 1 (2008).

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Table 1: Adopted State Geologic Sequestration Policies as of 2008[47]

State	Policy	Year	Description
Kansas	HB 2419	2007	Requests agency establish rules for geologic sequestration. Creates fund to pay for regulatory costs, remediation, long-term stewardship
	KAR 82-3-1100-1120	under review	Sets requirements for CO_2 storage facility operating permits
Massachusetts	SB 2768	2008	Instructs agency to set sequestration definitions and standards
New Mexico	EO 2006-69	2006	Requires agency to study statutory and regulatory requirements for GS
Oklahoma	SB 1765	2008	Declares CO_2 a commodity. Declares existing rules apply to EOR; creates a task force to make recommendations on CCS
Utah	SB 202	2008	Task force to recommend rules for GS by Jan. 1, 2011; interim report by July 1, 2009
Washington	ESSB 6001	2007	Authorizes agency to set rules for GS; specifies that GS can be used to meet GHG emission reduction goals
	WAC 173-218-115	2008	Revises Washington UIC rules for GS
	WAC 173-407-110	2008	Sets performance standard for GS
Wyoming	HB 0089	2008	Declares pores space the property of surface owner
	HB 0090	2008	Agency to propose rules for GS permitting; no set date. Working group to recommend financial assurance and post closure care by Sept. 30, 2009

II. Risks to Human Health and the Environment

Risks to human health and the environment associated with CCS can be separated into two areas: (1) risks arising from leakage to the surface or near surface; and (2) subsurface risks created by direct contact with the underground plume of CO_2 or the subsurface pressure it creates. Both sets of risks are discussed below.

A. Surface or Near-Surface Risks

Among the least likely but most dramatic concerns regarding CCS is that a substantial leak could cause widespread but localized asphyxiation of people, plants, and animals. Carbon dioxide can affect the central nervous system of humans in varying ways depending on the concentrations.[48] The EPA states that human exposure to concentrations ranging from 17-30 percent and upwards "can

[47] *See* Pollak & Wilson, *supra* note 43.
[48] U.S. EPA, CARBON DIOXIDE AS A FIRE SUPPRESSANT: EXAMINING THE RISKS (Appendix B) (2000), *available at* http://epa.gov/ozone/snap/fire/co2/appendixb.pdf.

quickly (within 1 minute) lead to loss of controlled and purposeful activity, unconsciousness, coma, convulsions, and death."[49] Slightly longer exposures at concentrations between 10 and 15 percent can lead to dizziness, drowsiness, muscle problems, and unconsciousness.[50] Even at much lower levels, undesirable symptoms have been observed at exposures anywhere from a few minutes to an hour.[51] The IPCC has estimated that ambient concentrations of CO_2 above 2 percent can have strong effects on respiratory physiology and levels near 10 percent can cause unconsciousness and death.[52]

Critics of CCS have often pointed to two disastrous events in the 1980s in Cameroon as caution in proceeding forward with CCS.[53] Both events, however, involved limnic eruptions in tropical lakes, where lakes saturated with CO_2 suddenly turned over and release large amounts of CO_2.[54] In 1984 Lake Monuon suddenly emitted a large plume of CO_2 that killed 37 people and only two years later Lake Nyos emitted a large plume of CO_2 asphyxiating approximately 1,700 hundred people and 3,500 livestock in nearby villages.[55] Both lakes overlie an active volcanic area where the persistent emission of CO_2 from magma or volcanic vents accumulates in the lake as dissolved HCO_3. Because the CO_2 remains dissolved in high pressure situations, a sudden shift in pressure can cause the rapid release of the accumulated CO_2. These are two of the three[56] known lakes in the world to have such high concentrations of dissolved CO_2 and the disastrous events described above are thought to be extremely rare.[57]

There are significant differences between what happed in Cameroon and the risks of CO_2 release from CCS. First, the Cameroon tragedies took place because slow and continuous accumulation of CO_2 was suddenly released from

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[49] *Id.*
[50] *Id.*
[51] *Id.* (including "headaches, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing, mental depression, shaking and visual and hearing dysfunction").
[52] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 246.
[53] *See* GREENPEACE, FALSE HOPE: WHY CARBON CAPTURE AND STORAGE WON'T SAVE THE CLIMATE 30 (2008), *available at* http://www.greenpeace.org/raw/content/usa/press-center/reports4/false-hope-why-carbon-capture.pdf.
[54] USGS, Volcanic Lakes and Gas Releases USGS/Cascades Volcano Observatory, Vancouver, Washington, http://vulcan.wr.usgs.gov/Glossary/Lakes/description_volcanic_lakes_gas_release.html (last visited Apr. 21, 2009).
[55] *See* Mark Anthony de Figueiredo, The Liability of Carbon Dioxide Storage 185-191 (Jan. 12, 2007) (unpublished Ph.D. dissertation, MIT), *available at* http://esd.mit.edu/people/dissertations/defigueiredo_mark.pdf. *See also* EPA Proposed Rule, *supra* note 6, at 43498 (discussing Lake Nyos incident and similar incident in the 1980s at Lake Monoun in Cameroon).
[56] The other is Lake Kivu in East Africa and has not yet experienced a similar limnic eruption.
[57] *See* USGS, Volcanic Lakes and Gas Releases USGS/Cascades Volcano Observatory, Vancouver, *supra* note 54.

lower lying high-pressure zones of the lake to the near surface, allowing it to be released from solution into the air.[58] With CCS projects, CO_2 will be injected and trapped within a rock matrix, and release rates will be limited. Additionally, cap rock trapping layers above will reduce the ability of CO_2 to migrate upwards. Even in the event of a well blowout, the volume of CO_2 which can escape to the surface is much smaller than the lake release incidents.[59] Indeed, the EPA Proposed Rule on CCS notes that geologic confining systems do not experience the kind of rapid CO_2 release as the two known lake turnover incidents. CO_2 stored in a geologic formation would also tend to diffuse rather than concentrate.[60] Perhaps most importantly, CCS storage sites will be selected specifically to minimize leakage potential and will be carefully monitored.[61]

Although the risks of sudden and undetected CO_2 release should be very low for CCS, slow, persistent leakage could pose risks to human health and the environment through undetected faults or drilling activity in the area after site abandonment if proper precautions are not in place.[62] Careful monitoring will be important not only in avoiding significant releases of CO_2 but also in avoiding less grave but potentially harmful effects of slow leaks to the surface. As noted earlier, concentrations of a few percent over long periods of time can affect human health. A natural volcanic CO_2 seep in Italy, for example, releases roughly 200 tons of CO_2 per day through soil degassing and has been linked to the deaths of 10 people over a 20-year period.[63] The fact that the dense CO_2 is heavier than air potentially concentrating in topographic depressions in the absence of a small breeze can exacerbate such effects for communities situated in low lying areas.

Slow leaks of CO_2 that migrate toward the surface can also lead to elevated levels of CO_2 concentration in soils that can be lethal to plants and subsurface animals.[64] Elevated concentrations of CO_2 in soils can inhibit root respiration and thereby adversely affect the plant's photosynthesis rates, nutrient uptake, and survival.[65] Where CO_2 concentrations typically range from 0.2-4 percent in soils, concentrations at or above 20 percent can be phototoxic and lead

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[58] *Id.*
[59] EPA Proposed Rule, *supra* note 6, at 43498.
[60] DE FIGUEREDO, *supra* note 55, at 186.
[61] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 211.
[62] *Id.* at 247.
[63] *See* IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 247. While such concentrations that can impact human health can build up in depressions, most will easily disperse with even a small breeze. *See also* Curtis Oldenberg, *Migration Mechanisms and Potential Impact of CO_2 Seepage, in* CARBON CAPTURE AND SEQUESTRATION 127-40 (Elizabeth J. Wilson & David Gerard eds. 2007).
[64] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 248.
[65] Jingen Qi, et al., *High Soil Carbon Dioxide Concentrations Inhibit Root Respiration of Douglas Fir*, 128 NEW PHYTOLOGIST 435 (Nov. 1994).

to noticeable die-off.[66] After a resurgence of volcanic activity, soil CO_2 concentrations in Mammoth Mountain, California increased up to 95 percent, eventually creating a 40 hectare tree die off.[67] Thus, CCS involves surface risks to human health and the environment that must be managed in any regulatory program governing CCS.

B. Subsurface Risks

CCS also may present subsurface risks. The injected CO_2 will likely fill formation pore spaces that are rarely, if ever, empty. The pore spaces are filled primarily with brine formation waters, some of which will be displaced by the CO_2 injection and pressure effects from CO_2 injection. Even as a supercritical fluid, the CO_2 will generally be less dense than the brine present in the reservoir.[68] Because injected CO_2 will initially be more buoyant than the formation brines, the injected CO_2 will have the tendency to move both upwards and outwards in the subsurface, making caprock integrity a key consideration. This subsurface behavior is a critical consideration for modeling and monitoring CO_2 plume migration and the subsurface pressure gradient and the development of risk management plans.

A major concern over injecting CO_2 deep underground is that it be monitored to avoid adverse affects on underground drinking water. There are three primary risks to underground drinking water from CCS. First, the pressure created by the CO_2 plume could push native brines into freshwater systems and cause potable water to become more saline. Second, the CO_2 and associated contaminants in the CO_2 stream (e.g., SO_2 or H_2S) could directly affect water quality. In some formations, this could create a third problem if undesirable minerals or compounds are leached into the ground water supplies. This third problem could also be made worse by the presence of undesirable compounds in an impure CO_2 stream. Other subsurface risks include ground heave, induced seismicity, and damage to hydrocarbon resources, all of which have been managed for other injection activities. If injection pressures are not properly managed, the injected CO_2 could be at a higher pressure than the surrounding formation pressure and cause the formation rock to fracture from the increased stress.[69]

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[66] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 248.
[67] *Id.*
[68] Stefan Bachu, *Sequestration of CO_2 in Geological Media: Criteria and Approach for Site Selection in Response to Climate Change*, 41 ENERGY CONVERSION MGMT. 953, 967 (2000).
[69] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 227.

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C. Managing Risks

The IPCC estimates that for well-selected, designed, operated, and monitored sites, over 99 percent of injected CO_2 is very likely (probability between 90 to 99 percent) to remain underground for over 100 years and likely to remain underground for over 1000 years.[70] First and foremost, careful site characterization should effectively evaluate the prospective host formation to ensure its safety and suitability for long-term CO_2 injection. Because of the geochemical and geophysical heterogeneity of the various host formations and the investment (in terms of human, natural, and financial capital) in getting the site characterization right, every potential site will need to be carefully evaluated, modeled, and planned given the site-specific characteristics. This includes geologic, geophysical, and engineering analyses and close assessment of the overlying rock formation's ability to confine the CO_2 from upward migration through faults or other pathways.[71]

A large and very rapid release of CO_2 to the atmosphere is unlikely as it will be trapped in a rock matrix well below the surface.[72] The other most direct path to the surface is through human well infrastructure or undetected transmissive faults. Active well infrastructure should be heavily monitored and have quick remediation systems in place. Unknown and abandoned well bores on the other hand, might be among the most substantial concerns for CO_2 leakage.[73] Abandoned wells are generally plugged with cement, but if faulty, CO_2 could seep between the well casing and the cement or through the plug itself.[74] Out of roughly 470 natural gas storage facilities in the United States, there have been nine documented problems of significant leakage, five of them through wellbores.[75] CCS is expected to have even less risk of such releases as the CO_2

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[70] *See* Elizabeth J. Wilson, Timothy L. Johnson, & David W. Keith, *Regulating the Ultimate Sink: Managing the Risks of Geologic CO_2 Storage*, 37 ENVTL. SCI. & TECH. 3476, 3477 (2003); IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 14 ("Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years. For well-selected, designed and managed geological storage sites, the vast majority of the CO_2 will gradually be immobilized by various trapping mechanisms and, in that case, could be retained for up to millions of years. Because of these mechanisms, storage could become more secure over longer timeframes.").

[71] U.S. EPA, Geologic CO_2 Sequestration Technology and Cost Analysis (June 2008), *available at* http://www.epa.gov/ogwdw/uic/pdfs/support_uic_co2_technologyandcostanalysis.pdf.

[72] 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).

[73] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 244.

[74] *Id.*

[75] *Id.* at 245.

will dissolve in pore water and the projects will not be designed for rapid pressure cycling as are the natural gas storage projects.[76] Nevertheless, the risk of wellbore leakage must be managed and is best addressed up front.

Once the site has been selected and injection initiated, regular in situ monitoring of CO_2 behavior must be instituted and integrated with site modeling to ensure against large or small leakage.[77] The EPA has identified different technologies to monitor sites for CO_2 fluctuations in the subsurface soil or ambient air so long as proper baseline measurements have been made available. They are designed specifically for the smaller, persistent leakage rates that are much more likely and, when taken cumulatively, could pose a greater risk to human health, the environment, and climate stabilization. Eddy covariance, for example, is used to measure ambient CO_2 concentration above a sequestration site. It combines measurements from an infra-red gas analyzer and an anemometer sensitive to wind direction and speed. Surface CO_2 flux monitoring (measuring the amount and movement of CO_2 concentrations in air within the soil or subsurface) and vadose zone sampling (sampling CO_2 concentrations over time from various depths in the vadose zone – or the unsaturated area beneath the surface) can also help monitor long-term and potentially slow leakage.[78] Despite methods being available to monitor even slow or small leakages, some argue that the sheer volume of CO_2, the large areas, and the unpredictability of geological formations will "preclude direct measurement of surface leakage for the entire large land area overlying a formation in which CO_2 is sequestered."[79] Evidence of vegetative changes or stress could help direct more targeted surface monitoring.[80]

III. Investment and Liability Risks

CCS could play an important role in helping to meet GHG emission reduction targets, but the technology will not become economically viable without policies committed to dramatic CO_2 emission reductions as well as mechanisms to address potential liability for CCS operators in the case of CO_2 leakage causing harm to human health or the environment.[81] Cost estimates of CCS on electric power

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[76] *Id.*

[77] *See* WRI Guidelines for Carbon Dioxide Capture, Transport and Storage 67 (Nov. 2008), *available at* http://www.wri.org/publication/ccs-guidelines.

[78] U.S. EPA, Geologic CO_2 Sequestration Technology and Cost Analysis, *supra* note 71, at 13-14.

[79] *See* Robert Nordhaus, *Treatment of CCS under a Domestic Greenhouse Gas Regulatory Program, in* CARBON CAPTURE AND SEQUESTRATION: FRAMING THE ISSUES FOR REGULATION 133 (CCSReg Project Interim Report 2009), *available at* http://www.ccsreg.org/pdf/CCSReg_3_9.pdf.

[80] *Id.* (this is also dependent on the confidence that no significant leaks would occur, only small isolated and slow leaks).

[81] Jim McFarland, Howard Herzog, & John Reilly, Economic Modeling of Carbon Cature and Sequestration Technologies, *available at*

plants vary but estimates suggest that the cost of power production will increase 20 to 90 percent above current energy production costs with the introduction of the new technology.[82] The MIT "Future of Coal" study estimates that CCS might be economic—competitive with conventional coal plants forced to pay for carbon emissions—at a CO_2 price of $30/ton. By contrast, they argue that if the price of carbon starts much lower, at $7/ton, and increases roughly 5 percent per year, it will take roughly 25 years for CCS to become economic.[83] Thus, the current uncertainty over the future cost of carbon emissions leads to financial uncertainty regarding the feasibility of CCS under a cap and trade emissions reduction system and suggests that emissions performance standards may be necessary for actually deploying CCS.

In addition to the uncertainty about the future cost of carbon emissions, the specter of legal liability from leaking CO_2 creates financial risks for CCS operators and investors. Given the high capital costs and long-term investment, short-term policy incentives may be necessary to encourage early investment in the event of initially low carbon allowance prices.[84] Those investing in CCS need to have a long-term capital horizon, something not often associated with a high tolerance for risk and the unexpected.[85] An investment risk that is difficult to quantify is future CCS operator legal liability if CO_2 leakage harms human health and the environment.

In an earlier article,[86] we outlined potential sources of existing legal liability for CO_2 leakage from CCS operations. These sources include the federal environmental laws and state common law. We then proceeded to discuss different approaches to manage the risk of liability through insurance, pooled federal funding, bonding, and other mechanisms. This management of liability risk is critical. For CCS to play a role in addressing climate change, utility customers will need to be willing to pay for the increased cost of CCS, policy makers and insurers will need to be able to balance the potential costs through risk management mechanisms, and the market will have to eventually confirm that CCS technology is financially viable despite these risks.[87]

The clarity, certainty, and extent of legal liability can heavily affect technology adoption, particularly new technology deployment. Companies considering adopting new technology are adverse to unknown or potentially unlimited liability associated with technological problems new to commercial-

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http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/2c3.pdf.

[82] *See* IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 247.

[83] *See* THE FUTURE OF COAL, *supra* note 5, at x.

[84] *See* Nordhaus, *supra* note 79 (noting that a certified CCS project under the Dingell-Boucher bill before Congress would be allocated "bonus allowances from calendar years 2012 through 2025.").

[85] Trabucchi & Patton, *supra* note 14, at 8.

[86] Klass & Wilson, *supra* note 72.

[87] Trabucchi & Patton, *supra* note 14, at 8.

scale deployment. Stable and certain liability terms help guide company investment as well as shareholder and financial community expectations. Legal liability is also important for government actors wishing to promote a technology because it can ensure the party with the most information about risks and solutions takes appropriate measures to avoid problematic consequences. And finally, clear and transparent liability regimes help the public understand and have confidence that risks to human health and the surrounding environment will be actively managed and, in the event of an accident, effectively remediated and compensated.

Liability will be largely linked to risk and driven by the behavior of the injected CO_2 as described in Part II. Of key import as risk factors are: (1) the volume of CO_2 to be injected—millions of tons per project; (2) initial buoyancy of injected CO_2; and (3) the need for injected CO_2 to remain in the subsurface for hundreds to thousands of years. The risks from CCS are associated both with the sheer amount of injected material as well as the specific physical properties of CO_2 and where the CO_2 will be injected. CCS risks will vary through the lifecycle of a CCS project and are affected by local and regional geology and site history; they will likely decrease after injection ceases as formation pressures naturally decrease.[88] Additionally, risk profiles will be different if the CO_2 stream contains other contaminants (e.g. hydrogen sulfide (H_2S)).

CCS will be deployed into an existing framework of laws, regulations, and legal precedent which will vary significantly across jurisdictions. Moreover, individual CCS projects could cross both state and national boundaries, further complicating the potential legal liability scenario. Although existing statutory and common law are sub-optimal tools for assigning fault or rapidly compensating parties damaged by CCS projects, they provide a foundation to understand potential legal liability and can help ensure appropriate site selection, negotiate overall public acceptance of the technology, and fill in gaps in any future comprehensive framework for CCS.

The following sections discuss the existing federal environmental laws and state common law doctrines that may apply to the release of CO_2 in connection with CCS, the importance of ensuring that CCS operators are subject to legal liability for harm associated with CCS, and, finally, financial mechanisms for minimizing the risk of legal liability while still ensuring the law will provide appropriate incentives for safe site management and compensation for harm.

[88] *See* Klass & Wilson, *supra* note 72, at 117-19.

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A. Federal Statutory Liability for Release of CO_2

Overarching U.S. federal legislation may impact CCS in several different ways. Since the 1970s, Congress and state legislatures have enacted far-reaching legislation to reduce or eliminate air and water pollution; govern the generation, storage, and disposal of solid and hazardous waste; and create a regulatory system to review, classify, and regulate a host of pollutants and hazardous chemicals. The two statutes that may have the most direct application to recovery of harm associated with CO_2 storage include the Resource Conservation and Recovery Act (RCRA)[89] and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[90]

RCRA was enacted in 1976 to provide a comprehensive "cradle-to-grave" regulatory system for identifying, listing, and tracking hazardous wastes; setting standards for the generation, handling, storage, and disposal of hazardous wastes; and assisting states with the management of solid wastes from active facilities. Section 7002 of RCRA authorizes citizen suits against anyone who contributes to the past or present handling of solid or hazardous waste that endangers human health or the environment.[91] RCRA's provisions may provide liability for harm arising from CO_2 storage, if stored CO_2 is determined to be a solid or a hazardous waste; in which case it would impose stringent handling, storage, and disposal requirements on the CCS process. RCRA defines solid waste as including "any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid or contained gaseous materials, resulting from industrial, commercial, mining, and agricultural operations, and from community activities."[92] Stored CO_2 in connection with CCS operations may be a solid waste because it is arguably "discarded material," is in "gaseous" or "liquid" form, and results from industrial or commercial activities. Hazardous waste is essentially defined as that which exhibits a hazardous characteristic (including ignitability, corrosivity, reactivity, and toxicity) or is listed by the EPA as hazardous.[93] CO_2 is not currently a listed hazardous waste. Co-injection of CO_2 with other waste stream constituents (e.g. hydrogen sulfide (H_2S)), however, could cause it to exhibit hazardous characteristics and be so defined.[94] The EPA could also, however, expressly exclude stored CO_2 from the definition of hazardous waste, as it has done with incinerator ash and wastes produced during the exploration, development, and production of crude oil, natural gas, and geothermal energy.

[89] 42 U.S.C. §§ 6901-6992k (2000).
[90] 42 U.S.C. §§ 9601-9675 (2000).
[91] 42 U.S.C. § 6972(a) (2000).
[92] 42 U.S.C. § 6903(27) (2000).
[93] 42 U.S.C. § 6904(5) (2000).
[94] *See* EPA Proposed Rule, *supra* note 6, at 43492.

Industry has also made an effort to classify CO_2 as a "commodity," which would bring it outside the scope of RCRA altogether by avoiding a classification as a "waste."[95]

CERCLA, also known as "Superfund"[96] was enacted in 1980 to create a federal framework to address the problems associated with the existence of hazardous substances in the environment. Unlike other environmental laws that govern the generation, management, and disposal of hazardous materials and waste, CERCLA provides a vehicle for the federal government, state and local governments, and private parties to recover costs associated with contamination that occurred in the past. Liability under CERCLA is retroactive, joint, and several and is imposed on current as well as past owners and operators of "facilities" where there has been a release of a hazardous substance, as well as on those who have generated or transported hazardous substances.[97] It limits recovery by private parties to expenditures related to investigation and remediation of a release of hazardous substances; it does not allow private parties to recover damages associated with lost profits, diminution in value to property, personal injury, lost rents, punitive damages, or other harm associated with contamination of property or the environment, and allows only state and federal governments to recover for harm to natural resources.

In order for CERCLA to apply to any releases of CO_2, the stored CO_2 must be considered a "hazardous substance." CO_2 is not considered hazardous by any environmental statute or agency classification, although the EPA has stated that if the injected CO_2 stream contains mercury or other hazardous substances or were to react with groundwater to create hazardous substances, it might be subject to CERCLA liability.[98] Given CO_2 is non-toxic at low concentrations and is not a listed waste, CERCLA likely does not apply to current CO_2 injection activities unless recognized hazardous substances are present. If CCS is associated with hydrocarbon production, it might also fall under the CERCLA "petroleum exclusion" which states that petroleum and natural gas are not hazardous substances. Finally, CERCLA typically does not apply to hazardous substances sold as "useful products" (as opposed to those for disposal) which would mean that, like RCRA, CO_2 classified as a "commodity" rather than a waste might not be covered under CERCLA.[99]

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95 Klass & Wilson, *supra* note 72, at 126.
96 The term "Superfund" is from the five-year, $1.6 billion Hazardous Substances Response Trust Fund created to finance cleanups at CERCLA's inception. *See* 28 U.S.C. § 9507 (establishing fund).
97 *See* 42 U.S.C. § 9607(a) (2000).
98 *See* EPA Proposed Rule, *supra* note 6, at 43504.
99 Klass & Wilson, *supra* note 72, at 130.

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B. State Common Law Liability for Release of CO_2

In comparison to federal environmental statutes, state law, and particularly state common law, has the potential to provide non-federal actors more comprehensive relief from harm related to the long-term storage of CO_2, but also is at most risk of federal preemption by any forthcoming federal regulatory framework on CCS.[100] Unlike the federal environmental statutes, which either do not give states or private parties the right to seek monetary recovery or, in the case of CERCLA, allow only for recovery of response costs, the state common law claims are available to private parties, local governments, and states to recover for a fuller range of harms associated with leakage from stored CO_2. Potential claims of trespass, negligence, negligence per se, nuisance, and strict liability offer the possibility of compensatory and punitive damages and injunctive relief not available under most federal and state environmental statutes.[101]

Trespass requires that the plaintiff establish an unauthorized invasion of private property where the entry is intended by the defendant, caused by the defendant's negligence or recklessness, or the result of the defendant's engaging in an ultra-hazardous activity.[102] In order to establish a claim for negligence, the plaintiff must prove that the defendant owed a duty of care to the plaintiff, that the defendant breached that duty of care, that the breach of the duty of care was the actual and proximate cause of the plaintiff's harm, and that the plaintiff suffered damages to person or property.[103] Under negligence per se, a plaintiff can establish negligence if he or she can show the defendant violated a statute "designed to protect against the type of accident the actor's conduct causes and if the accident victim is within the class of persons the statute was designed to protect."[104] Although few statutes and regulations exist today that set specific standards of conduct for CO_2 storage, Congress, state legislatures, and federal and state agencies are likely to create a significant body of law in this area. In the absence of such statutes the release of CO_2 to the surface or subsurface may

[100] For a discussion of federal preemption of state statutory law and common law relating to CCS, see Klass & Wilson, *supra* note 72, at 133, 155-58.
[101] *See, e.g.*, Michael D. Axline, *The Limits of Statutory Law and the Wisdom of Common Law, in* CREATIVE COMMON LAW STRATEGIES FOR PROTECTING THE ENVIRONMENT 63, 67-68 (Denise E. Antolini & Clifford L. Rechtschaffen eds. 2007); Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change, Carbon Sequestration, and Property Rights,* 2010 U. ILL. L. REV. (forthcoming 2010).
[102] *See* JAMES A. HENDERSON, JR. ET AL., THE TORTS PROCESS 380-81 (2003).
[103] *See* 1 DAN B. DOBBS, THE LAW OF TORTS § 114, at 269-70 (2001) (outlining the elements of the prima facie claim of negligence).
[104] *See* RESTATEMENT (THIRD) OF TORTS § 14 (Proposed Final Draft 2005).

constitute a trespass or negligent conduct under traditional common law doctrines.[105]

Nuisance law underlies much of environmental law, and has been used by private and public parties to obtain injunctive and monetary relief for air, water, soil, and noise pollution resulting from industrial and commercial activities such as landfills, sewage treatment plants, oil refineries, quarries and the like.[106] An action in nuisance involves the invasion of the private use and enjoyment of land (private nuisance) or interference with a right common to the public (public nuisance). Like other common law doctrines, the court often balances the benefits of the alleged nuisance activity with the harm caused to determine whether the defendant should pay damages or be enjoined from actions causing the nuisance.[107] Migrating or leaking CO_2 that harms nearby soil, surface water, groundwater, mineral, or other resources, or interferes with human health could constitute either a public or private nuisance. This could result in an injunction requiring remediation of any harm caused by CO_2 or preventing the continued storage of CO_2.[108] It could also result in an award of monetary damages for harm associated with the release. Such injunctive or monetary relief could be awarded under a nuisance theory even if the CCS project or storage area was in full compliance with all federal or state permits.[109]

Strict liability allows for liability even where the defendant did not intend to interfere with a legally protected interest or breach a duty of reasonable care.[110] In most jurisdictions, a defendant is strictly liable for harm to public health or the environment for activities that are deemed "abnormally dangerous," "non-natural" or an "abnormal" use of the land which results in harm.[111] Injecting massive amounts of CO_2 into the subsurface may be readily characterized as either "non-natural" or "abnormal," at least in parts of the country unaccustomed to EOR activities. Courts have held defendants strictly liable for a broad range of related

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[105] *See* Klass & Wilson, *supra* note 72, at 133-39 (discussing case law supporting claims for trespass and negligence that might apply to the release of CO_2).
[106] *See* WILLIAM H. RODGERS, JR., ENVIRONMENTAL LAW § 2.1 at 112-113, 114-15 (2d ed. West 1994).
[107] *See* RESTATEMENT (SECOND) OF TORTS § 936; DAN B. DOBBS, LAW OF REMEDIES § 5.7(2), at 765-71 (2d ed. 1993).
[108] For a discussion of potential difficulties establishing causation for CCS projects, see Klass & Wilson, *supra* note 72, at 137.
[109] *See* Michal D. Axline, *The Limits of Statutory Law and the Wisdom of Common Law, in* CREATIVE COMMON LAW STRATEGIES FOR PROTECTING THE ENVIRONMENT, *supra* note 101, at 74-76; Alexandra B. Klass*, Common Law and Federalism in the Age of the Regulatory State*, 92 IOWA L. REV. 545, 583 & n.215 (2007) (same).
[110] *See* W. PAGE KEETON ET AL., PROSSER & KEETON ON THE LAW OF TORTS § 75, at 534 (5th ed. 1984).
[111] Rylands v. Fletcher, (1868) 3 L.R.E. & I. App. 330 (H.L.); PROSSER & KEETON, *supra* note 110, at 545-46 (discussing *Rylands* case).

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activities including the release of petroleum or oil that contaminated groundwater; seeping salt water from an oil and gas well that contaminated a water supply; the release of pollutants during the blowout of an oil well during drilling; and pollution of water wells by nearby oil wells that percolated on the property.[112] On the other hand, courts often consider the benefits to the community and whether the activity is in an appropriate location in determining whether an activity is subject to strict liability.[113] If CCS is tied closely to national climate change efforts, and injection sites are chosen carefully, those factors may weigh against any application of strict liability. Thus, whether courts will find the long-term storage of CO_2 associated with CCS to be subject to strict liability remains to be seen and, given the significant geologic differences, could likely vary by region or state.

For each of the potential common law claims, apart from establishing the elements of each individual claim, the issue of causation will be challenging for plaintiffs attempting to assert any of these common law torts. For instance, if several parties were simultaneously injecting CO_2 into the same geological formation and influencing formation pressure, assigning blame for harm could prove exceedingly difficult.[114]

As shown above, state common law, like federal statutory environmental law, provides a potentially powerful body of law that may apply to CCS operations and increase the risks associated with operators going forward with investment in this technology. While some have argued that federal or state legislation should simply relieve CCS operators from some or all of the potential legal liability to spur investment,[115] such a "pass" on liability will prevent the law from acting as a powerful incentive to ensure optimal site selection, monitoring, and care by CCS operators. As a result, any future regulatory regime governing CCS should retain the hallmarks of federal and state law that provide incentives for careful operations as well as a mechanism for public and private entities to obtain compensation in the event of harm. Some potential mechanisms to retain but yet manage such legal liability are discussed below.

C. Managing Legal Liability

While existing state common law and federal statutory environmental laws are a useful backstop for managing the risks of CCS, they are relatively crude tools

[112] *See* Alexandra B. Klass, *From Reservoirs to Remediation: The Impact of CERCLA on Common Law Strict Liability Environmental Claims*, 39 WAKE FOREST L. REV. 903, 942-61 (2004) (discussing cases).
[113] *See* RESTATEMENT (SECOND) OF TORTS § 520. *See also* Klass & Wilson, *supra* note 72, at 143.
[114] *See* Klass & Wilson, *supra* note 72, at 137 (discussing causation issues).
[115] *Id*. at 149-55.

compared to a tailored regulatory framework designed explicitly for CCS. The complicated policy and regulatory regimes necessary for safe and successful deployment of CCS would be more efficiently and consistently managed under CCS-specific laws which can incorporate the unique features of CCS, create regulatory safeguards to guide development, and create a permitting and compliance structure appropriate for CCS deployment. If this type of CCS-specific regulatory and statutory regime is not created by federal and state legislatures, however, federal environmental law and state common law can still play a meaningful role in CCS development. RCRA and CERCLA are powerful environmental statutes that have been used to address a wide range of contamination issues since they were enacted over 20 years ago. Common law, for its part, can evolve in a reasoned manner somewhat more insulated from interest groups than the political process; reach decisions based on sworn, scientific testimony rather than the generalities often presented in legislative hearings; and make decisions based on individualized factual circumstances.[116]

Augmenting statutory and common law liability within a CCS-tailored regulatory structure is an important component of integrating risk management of CCS with CCS deployment. Shortcomings of relying solely upon general statutory and common law liability are: (1) the ability to detect and assign blame for harm;[117] (2) the potential lack of necessary financial resources for firms injecting CO_2 to address potential harms; and (3) the time horizon between cause (injection of CO_2) and effect of any damages.[118] Additional financial mechanisms can supplement liability frameworks and help operators manage liability risks associated with the technology.[119]

As the life-time of CCS projects (with storage of CO_2 required for hundreds to thousands of years) is incongruous with the lifetime of a private entity, legislators and regulators must develop institutional structures to fund and manage CCS risks over the long term. The CCS life-cycle will follow a pattern of

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[116] *See* Klass, *supra* note 109, at 582 (discussing benefits of the common law).
[117] This could be especially important given the multiple effects of CO_2 in the subsurface, latency between injection and harm, and challenges in proving a causal link between CO_2 injection and harm. Current monitoring methodologies are limited in scope with only a few states requiring any post-closure site monitoring. This could be especially important if many actors are injecting CO_2 in one basin. *See generally* David W. Keith et al., *Regulating the Underground Injection of CO_2,* 39 ENVTL. SCI. & TECH. 499A (2005).
[118] *See* David Gerard & Elizabeth J. Wilson, *Environmental Bonds and the Challenge of Long-Term Carbon Sequestration*, 90 J. ENVTL. MGMT. 1097 (2009); Steven Shavell, *Liability for Harm Versus Regulation of Safety*, 13 J. LEGAL STUDIES 357 (1984); A. H. Ringleb & S.N. Wiggins, *Liability and Large Scale, Long Term Hazards*, 98 J. POL. ECON. 574 (1990).
[119] *See* de Figueiredo, *supra* note 55, at 67.

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active injection, site closure, post-closure, and long-term stewardship,[120] with monitoring, remediation, and liability responsibility likely shifting from private to third-party (public or possibly a public-private hybrid) ownership with post-closure to long-term stewardship transition.[121] Ensuring adequate funds are available during the post-closure and long-term stewardship phases could follow several different formulae,[122] but any approach must guarantee resources are available to cover public monitoring and potential remediation costs and avoid CCS projects becoming an unfunded public mandate.

A CCS regulatory framework will need to clarify how and under what conditions the transition from private operator to public entity for long-term stewardship will occur. In a previous paper we have proposed a three-tiered payment system that covers: (1) the active CO_2 injection phase; (2) the post-closure period; and (3) long-term stewardship.[123] During active CO_2 injection, the CCS project operator holds insurance and site liability and pays into a central fund as pre-payment for long-term stewardship. In the second phase, the post-closure period, the operator is still responsible for site monitoring, verification, and necessary remediation, and is fully liable for damages. During this phase, bonding or insurance mechanisms could be used to cover monitoring and necessary remediation. These could be held at a project level—again to encourage responsible site operation by the owner/operator, or pooled across different projects if care were taken to manage any moral hazard. If an industry-funded pool were created, potentially at the geologic basin or federal level, these funds could be used to ensure adequate coverage for any damages sustained above individual operator liability caps set within the fund. When the CCS site meets pre-determined performance based measures, the responsibility for the site then transfers to the third or long-term stewardship phase.[124]

Any necessary monitoring, remediation, and damages would be funded from the federal pool, financed during the active injection phase by performance-

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[120] *See* Edward S. Rubin et al., *Regulatory and Policy Needs for Geological Sequestration of Carbon Dioxide, in* PROCEEDINGS OF THE SIXTH ANNUAL CONFERENCE ON CARBON CAPTURE AND SEQUESTRATION, PITTSBURGH, PA; EXCHANGE MONITOR PUBLICATIONS: PITTSBURGH, 14 (2007).

[121] While for this paper we discuss transfer to a public entity, it is possible that a private or semi-private organization with sovereign durability could play this role as well. *See* Wilson et al., *supra* note 70.

[122] *See* INTERSTATE OIL AND GAS COMPACT COMMISSION, CO_2 STORAGE: LEGAL AND REGULATORY GUIDE FOR STATES AND PROVINCES 11 (2007) *available at* http://iogcc.publishpath.com/Websites/iogcc/pdfs/Road-to-a-Greener-Energy-Future.pdf; Christina Ulardich, *Environmental Impairment Liability Insurance for Geological Carbon Sequestration Projects*, *in* INT'L RISK GOVERNANCE COUNCIL, WORKSHOP REPORT ON REGULATION OF CARBON CAPTURE AND STORAGE 19 (2007), *available at* http://www.irgc.org/IMG/pdf/IRGC_CCS_SwissRe07.pdf.

[123] *See* Klass & Wilson, *supra* note 72, at 174.

[124] *See id*.

based fees collected from the project owner/operator, could be administered by a public or semi-private entity, and would be responsible for ensuring management and data of CCS injection sites is supported and available in perpetuity. The advantage of having this pool financed at the federal as opposed to the state or geologic basin level is two-fold. First, risks of leakage or damage may be correlated with certain geologic formations, and this approach would spread the risk more widely. Second, if this pool were linked to a site-specific damage cap, federal standards would provide a regulatory "floor" for environmental and technical standards.[125]

IV. Climate Risks Associated with CCS

The fundamental and long-term purpose of CCS technology is to address climate change by capturing CO_2 emissions from point sources. While regulations need to be in place to ensure safety, reduce risk, and encourage best management and site selection, CCS will not be deployed widely in the absence of a GHG regulatory program.[126] Such regulation can take a variety of forms including: (1) a market-based system whereby a cap is put on GHG emissions and emitters attempt to efficiently trade emission allowances or credits; (2) a GHG or carbon tax which simply imposes a cost on CO_2 or other GHG emissions; (3) a command-and-control regulatory system whereby strict limits and regulations are set for emitters to meet regardless of the cost to any specific plant or company; or (4) a GHG emissions performance standard where GHG emissions per MWh produced are limited.[127]

Addressing climate change is a high priority for the new Obama administration and the eventual regulatory solutions may incorporate a combination of one or more of the above-described options. Although the different approaches may affect the development and deployment of CCS in different ways, we discuss here how the climate risk associated with CCS, namely leakage, might be addressed and incorporated in regulation. Indeed, an important issue for CCS within future climate regulation will be to determine how to monitor and account for surface leakage of CO_2 as wide-spread leakage could threaten the emission reductions gained from deploying CCS.

In its simplest form this is a basic accounting question focused on the quantity of CO_2 emissions reduced or avoided for a given period. While initial accounting will likely focus on the amount of CO_2 avoided or emitted on an annual basis, longer term means of verification will need to be in place to avoid

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[125] For additional discussion on legal, regulatory, and financial mechanisms applied to mitigate CCS risks, see Trabucchi & Patton, *supra* note 14, at 15-30.
[126] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 356.
[127] *See* Nordhaus, *supra* note 79, at 133-145 (discussing climate change regulatory programs).

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later leakage problems that could threaten the climate benefit. Of key import to an emerging accounting system are the volume of CO_2 to be potentially sequestered and the necessary residence time in storage to meet climate goals. Full-scale CCS projects will likely sequester millions of tons of CO_2 annually at each site, with injected CO_2 potentially spreading over tens of square miles for a single project and subsurface pressure effects felt over even greater distances.[128]

A. How Much Leakage is Acceptable?

While CO_2 leakage to the atmosphere from properly selected CCS sites is predicted to be very unlikely, persistent leakage from a large number of sites could compromise climate objectives.[129] The question is what rate of leakage would be acceptable and still meet stated climate goals? Our current climate change problem has arisen because we have been emitting GHGs at a far greater rate than natural attenuation mechanisms, causing an increase of long-lived GHGs in the atmosphere. Because CO_2 persists in the atmosphere for a hundred years or longer, stabilizing atmospheric concentrations of CO_2 requires roughly an 80 percent decrease in emissions. CCS can help slow emissions to the atmosphere even with small amounts of leakage, but the acceptable rate must be linked to the chosen CO_2 stabilization target and the total amount of CO_2 being stored.[130]

From a climate perspective, an acceptable CO_2 leakage rate is widely debated because it rests on so many factors and assumptions. It will depend on what percent of total emissions reductions are based on CCS; the availability, energy penalty, and cost of both CCS and other technologies; and a host of other economic and technical parameters as well as the presumed climate sensitivities and natural attenuation mechanisms. For example, David Hawkins of the Natural Resources Defense Council modeled an extreme case where energy demand continues to grow for the next 100 years and all of the necessary CO_2 reductions are met through CCS alone over the next 200 years. In his projections even a 0.1 percent annual leakage rate would surpass the total annual allowable emissions for stabilization at 450 ppm by 2200.[131] In an earlier paper by Minh Ha-Duong and David Keith, which used an energy-economic model to factor in price and the

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[128] *See* Preuss et al., *supra* note 32, at 52-53.
[129] Pacala, *supra* note 29.
[130] David G. Hawkins, *No Exit: Thinking About Leakage from Geologic Carbon Storage Sites*, 29 ENERGY 1571, 1573 (2004), *available at* http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V2S-4CC7RP3-7-5&_cdi=5710&_user=616288&_orig=search&_coverDate=08%2F31%2F2004&_sk=999709990&view=c&wchp=dGLbVlW-zSkzk&md5=221f1ace8477cf00ce7780bb68764b2c&ie=/sdarticle.pdf.
[131] Hawkins, *supra* note 130, at 1573-74.

potential use of CCS, the authors concluded that while 0.1 percent would be nearly equivalent to perfect storage, a 0.5 percent leakage rate would be unattractive from a climate perspective.[132] This study, however, included not only climate goals but economic efficiency and intergenerational equity in cost-sharing to reach climate goals.[133] Notably, a study by van der Swan and Smekens using a MARKAL bottom-up technology model developed a variety of different CCS deployment assumptions and concluded that while 1 percent leakage annually would defeat climate goals, 0.5 percent would be acceptable.[134] Stephen Pacala of Princeton University's Climate Mitigation Initiative estimates that even at a leakage rate of 1 percent, or residence time of 100 years in storage, stabilization at 450 ppm is possible.[135] He argues that economic and local risk considerations will constrain local leakage rates more tightly than atmospheric CO_2 requirements.[136] The lack of consensus on acceptable leakage rate is rather unsurprising given the range of factors that affect the goal including: (1) the target at which atmospheric concentrations should be stabilized; (2) the point in time by which this target should be met; (3) the expected growth in energy demand over that period; (4) the cost of the changes; and (5) who will pay those costs. While these variables remain in play, all agree that it is critical to focus on minimizing leakage and accounting for the leakage that does occur.

B. Accounting for Leakage

The premium on guarding against CO_2 leakage will be linked to future carbon prices, the importance of CCS in an emissions reduction strategy, and overall GHG targets.[137] Were the climate benefit of the technology to be substantially undermined through many large and leaking sites, there will be little reason to support continued CCS development. Risks associated with CCS leakage, however, will likely peak long after major decisions on deployment are made and as reservoir pressures reach their highest point near the end of the project's active

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[132] Ha-Duong & Keith, *supra* note 29 (discussing benefits of sequestration of shorter timeframes).
[133] *Id.* at 182-188.
[134] *See* Bob van der Zwaan & Koen Smekens, *CO_2 Capture and Storage with Leakage in an Energy-Climate Model,* 14 ENVIRON. MODELING & ASSESS. 135 (2009); Science for Environmental Policy, Carbon Capture and Storage: How Much Leakage is Acceptable? (2008), http://ec.europa.eu/environment/integration/research/newsalert/pdf/105na3.pdf.
[135] Pacala, *supra* note 29.
[136] *Id.*
[137] Ironically one of the most credible among them utilizes CCS but replaces coal as the power source with biomass, meaning all the carbon uptake through the photosynthesis in the plant's lifecycle is not re-released to the atmosphere upon combustion. *See* James S. Rhodes & David W. Keith, *Biomass with Capture: Negative Emissions Within Social and Environmental Constraints*, 87 CLIMATIC CHANGE 321 (2008).

injection phase.[138] If the stored CO_2 leaks to the surface some time well after it has been captured, stored and accounted for, it may raise additional issues for regulatory accounting of CO_2 and possibly additional financial risks for the operator.

Take for example the Lieberman-Warner bill which proposed a downstream (at the point of combustion) cap and trade system for CO_2.[139] While it may create an efficient market-based tool for immediate and annual emissions reductions from the power sector, there is currently no mechanism to adjust sequestration credits to address later leakage.[140] In the near future Congress will almost certainly pass some sort of climate change legislation and it should carefully consider the effects of delayed CCS emissions previously accounted for as avoided. There are number of ways to account for leakage in a future regulatory system, some of which are as follows:

1. No required repayment;

2. No required repayment but amend regulatory system to guard against similar leaks in the future;

3. Repayment based on the amount of CO_2 released;

4. Risk of future leakage is factored into the price of credits or allowances; and

5. Fund a "leakage reserve" through small payments by operators over time.[141]

The first two options do not include substantial financial risks to operators associated with leakage, provided the leaks are relatively minor. The first option allows the operator to retain full credit for the CO_2 avoided but may couple it with research and monitoring to ensure that the leaks were truly de minimis. This would require ensuring that the leaks accumulated over time are also de minimis. The second, which might be best-suited to correcting leaks that might be more pervasive in the industry, would allow the operator to retain the full CO_2 credits but use the problem to amend the regulatory program to prevent further leakage. The EPA or authorized agency would change the program to prospectively account for similar leakage.

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[138] Trabucchi & Patton, *supra* note 14, at 15.
[139] *See* Climate Security Act of 2008 (Liberman-Warner Bill), S. 3036, 110th Cong. (2008).
[140] *See* Nordhaus, *supra* note 79, at 140.
[141] *Id.*

If the regulatory program is more strict or the leakage more substantial, operators might instead be required to account for the losses through financial mechanisms of some sort. One option would be to have the operator simply repay the allowance or credit based on the amount leaked. Perhaps deceptively simple, this option could become increasingly complicated if monitoring technologies are not sufficiently developed, multiple parties are involved, or the injector/operator is not the entity receiving the credit. Another option may be discounting the potential leakage upfront in the price or credit calculation. This too could raise many difficulties including identifying the right discount price and perhaps taking account of the varying risks across different formations. It could also make CCS less economically competitive in the nearer term. Yet another option would be to fund a leakage reserve over time with small portions of allowances to cover unexpected future leakages. Premiums could vary based on site risks and performance standards. Thus, the financial risks of delayed carbon emissions could take a number of different forms under a future carbon limiting regime. If an operator or injector is depending on a price of carbon to make the enterprise economically viable as described above, it should also be prepared to account and pay for some portion of future losses were the CO_2 to leak to the atmosphere. This provision could vary between early demonstration projects, where the government could take an additional role, and later commercial projects where commercial operators would be better suited to take over the funding.

V. The Risk of Ignoring a Key Climate Strategy

The risks of CCS must, of course be weighed against the risks of rejecting CCS as a climate change strategy. A 1998 study estimated that in order to avoid dangerous changes to our climate, we will need at least as much net new carbon-free energy online by 2050 as the sum of global energy produced currently.[142] Thus, the question becomes, if CCS is not deployed to avoid future CO_2 emissions, what other technologies could fill the gap? While there are many viable low-carbon energy technologies available, the sheer volume needed to avoid dangerous climate change is staggering. Even if there were political, economic, and technical consensus to shift away from coal, it is unclear whether there are sufficient alternatives, at least in the near term, to provide low-carbon base-load electricity relatively affordably. A recent study by MIT concluded that CCS was the critical technology needed to meet our growing energy needs while

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[142] *See* Martin I. Hoffert et al., *Energy Implications of Future Stabilization of Atmospheric CO_2 Content*, 395 NATURE 881, 881 (Oct. 29, 1998) ("A standard baseline scenario that assumes no policy intervention to limit greenhouse-gas emissions has 10 TW (10 x 10^{12} watts) of carbon-emission-free power being produced by the year 2050, equivalent to the power provided by all today's energy sources combined.").

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reducing CO_2 emissions significantly.[143] Some environmental groups have put it more forcefully, arguing there is no chance of meeting the necessary global carbon targets without CCS.[144] Thus, the question remains how to create the massive reductions in CO_2 emissions experts say are needed now to limit the effects of global climate change.

Currently in the U.S., hydro electric generation represents roughly 7 percent of the nation's total electricity needs and all of the other renewable sources combined represent less than 3 percent of the nation's electricity.[145] Even accounting for rising fossil fuel prices and increasing technology-forcing policies such as renewable energy standards, the EIA estimates non-hydropower renewable energy will represent under 10 percent of the total U.S. electricity generation by 2030.[146] Wind and biomass technologies, which make up the majority of that percentage,[147] also are constrained somewhat by resource availability (or variability) and competing uses for land. The challenge for solar energy is somewhat different. While wind is affordable but somewhat resource-limited, the available solar resource is virtually inexhaustible but its persistent high cost leads modelers to assume it will likely represent a small fraction of U.S. energy production over the same period.[148]

Another alternative, nuclear power, currently provides the most carbon-free energy in our system.[149] Although there have not been any new orders for nuclear power plants in the United States since the 1970s, new policy incentives and the need for climate-friendly energy technology may foster increased interest in nuclear energy in the coming decades.[150] Even while the EIA predicts an increase in nuclear power, it warns that the industry's future remains highly uncertain because "plant safety, radioactive waste disposal, and the proliferation of nuclear weapons" continue to raise significant concerns.[151] Illustrative of this point is the fact that the United States, after decades of negotiation, has yet to find

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[143] *See* THE FUTURE OF COAL, *supra* note 5, at x.

[144] *See* Armond Cohen, President of the Clean Air Task Force, Presentation to the 2007 Midwest Governor's Summit on Energy and Climate Security, *available at* http://www.midwesterngovernors.org/MGA%20Energy%20Initative/2007%20Summit/Thursday%20Cohen%20Session%202.pdf.

[145] EIA, State Electricity Profiles 2006, *supra* note 8, at 262 (2.4 percent in 2006).

[146] EIA, Annual Energy Outlook 2009, at 74, http://www.eia.doe.gov/oiaf/aeo/pdf/trend_3.pdf.

[147] *Id.*

[148] *See id.* at 74 ("Solar technologies in general remain too costly for grid-connected applications, but demonstration programs and State policies support some growth in central-station solar PV, and small-scale customer sited PV applications grow rapidly.").

[149] *See* EIA, State Electricity Profiles 2006, *supra* note 8 (showing nuclear energy as providing just under 20 percent of the nation's total electricity in 2006).

[150] EIA, Annual Energy Outlook 2009, *supra* note 146, at 73.

[151] EIA, International Energy Outlook 2008, http://www.eia.doe.gov/oiaf/ieo/highlights.html.

a solution for the existing nuclear waste, much less additional waste from added nuclear capacity.[152]

While there are clear reasons to be concerned about the risks associated with large scale deployment of CCS, it is not clear that any alternatives are necessarily less risky or sufficient to stabilize GHG concentrations. As a result, there are good arguments that CCS should be pursued, along with other non-coal-based alternatives, so that all options remain open for reducing CO_2 emissions as soon as possible. This basic assumption, that a diverse portfolio of low-carbon energy technologies that includes coal with CCS is necessary to reach climate goals, is also reflected in the strategic plans of countries currently regulating CO_2 emissions.[153] The IPCC notes that the opportunity cost of not pursuing CCS as part of the problem may simply be too high, and some estimates suggest that using the technology could save tens of billions to trillions of U.S. dollars when compared to other climate strategies.[154] The critical requirement in going forward with CCS, however, will be to ensure that appropriate regulation, legal remedies, and funding mechanisms remain, or are put in place, to ensure that CCS is developed in a manner that minimizes the risk of harm to human health, the environment, and the climate.

[152] *See* Robert Vandenbosch & Susanne Vandenbosch, NUCLEAR WASTE STALEMATE: POLITICAL AND SCIENTIFIC CONTROVERSIES 47 (2007).
[153] *See* EurActive, The EU's Energy Mix: Aiming for Diversity, (April 17, 2007), http://www.euractiv.com/en/energy/eu-energy-mix-aiming-diversity/article-163228.
[154] IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE, *supra* note 23, at 358.

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