A REGULATORY FRAMEWORK FOR CARBON SEQUESTRATION: RISKS, SAFETY, AND SOCIAL RESPONSIBILITY

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Abstract:

Carbon capture and storage is being proposed as one of many mitigation options for climate change, in large part because of its potential impacts on the coal industry in the U.S. This novel technology, however, comes with many risks that must be considered in formulating its regulatory framework. Sequestering CO_2 underground for long periods of time poses potential hazards to human health and the environment. Existing regulatory frameworks like hazardous waste injection and natural gas storage deal with many of those risks, and such analogs can be used for implementing the safest possible framework for CCS. In addition to geological risks, however, a comprehensive policy for CCS must include issues such as liability and financial mechanisms, which ensure the long-term integrity and maintenance of a storage site. Here again regulatory analogs such as Superfund and RCRA provide a useful background for the success of such mechanisms in other frameworks. Finally, there are many additional concerns to consider in the regulation of CCS: public education, climate policy, property rights, financial incentives, research and development, and more. The incorporation of all of these topics makes it clear that the best policy approach to CCS is a unified interdepartmental approach on the behalf of the federal government.

INTRODUCTION

Climate change is arguably the number one environmental challenge in the twenty-first century. Although several strategies have been proposed for mitigation, one that has received considerable attention is carbon capture and storage (CCS), a method of capturing carbon dioxide from point sources, compressing it, and injecting it underground for permanent storage. CCS is one of many mitigation approaches, but it is particularly significant because of its linkage to the coal industry: the adoption and deployment of CCS would allow coal-fired power plants, one of the largest global sources of carbon emissions, to reduce (or rather displace) their emissions. Although this technology is controversial as a strategy for mitigation, it is favored by many, including several government officials, as a way to allow the continued use of coal, an integral part of the U.S. economy and an abundant source of cheap energy. This paper investigates the actions that should be taken if CCS is accepted as a climate change mitigation strategy by the federal government. Indeed, the large research and development funds devoted to CCS by the Department of Energy, as well as the recently proposed regulations issued by the Environmental Protection Agency suggest that the U.S. government is already moving forward to promote its national deployment.

Carbon storage, however, comes with several risks, which are part of the controversy associated with the technology. These risks include the inability of a geological storage site to contain the trapped carbon dioxide, the hazards of CO_2 contaminating drinking water or disrupting ecosystems, and even increased likelihood of earthquakes. Given these risks, there need to be certain regulations in place to protect the safety of people and the environment. Additionally, beyond the basic regulations protecting humans and ecosystems, there should be regulation ensuring that corporations that pursue CCS do so in a socially responsible manner.

This paper looks at the regulation of carbon storage, specifically in saline aquifers, in three different sections: geological risks, social responsibility, and additional concerns that will affect regulation. The first part looks at the hazards associated with underground seequestration of carbon dioxide and the regulatory framework necessary to ensure safety and minimal risks, both to humans and the environment. Using regulatory analogs of geologically similar technologies, it analyzes the necessary precautions that must be taken, and compares them with the recently proposed regulatory framework of the EPA. The second section assumes that a regulatory framework that comprehensively covers the geological risks and safety issues is already in place; it addresses aspects of a regulatory framework that might be considered "social responsibility" – particularly the liability and financial mechanism components. These components look at the long-term responsibilities of the private sector and its role within the several hundred years of project existence. Finally, the last section looks beyond the geological risks and long-term aspects of CCS and briefly examines other policy concerns and how they may be addressed. Such concerns involve public education, climate change policy and even property rights. These wide-ranging topics demonstrate the inter-disciplinary nature of CCS, and the multiple departments and regulations that will be involved in its regulation.

OBJECTIVES

The purpose of this paper is to analyze of the type of regulation needed for carbon sequestration, both to ensure its safety and its long-term accountability. Relevant literature often provides scientific information regarding the geological mechanisms of storage and regulatory analogs to similar technologies. The first part of this paper analyzes these arguments and answers the following questions:

- What are the risks associated with geological carbon sequestration?
- If possible, what type of regulation is necessary to minimize those risks?
- Where have these risks been seen before (regulatory analogs) and how have they been dealt with?
- And finally, how does the EPA's proposed rule incorporate this existing knowledge, and does it contain the necessary components for minimizing risks?

Although the geological risks and safety of CCS get the most attention, there are other contentious elements of the regulatory framework for CCS, namely liability and the financial mechanisms. A majority of the literature proposes certain action to be taken in terms of these components. This paper looks at multiple approaches, principally those used in other regulations, and evaluates their effectiveness and relevance to CCS. In this second section, the questions that will be answered are:

- Why are liability and financial mechanisms important components of CCS?
- What do these components need to include to serve that purpose?
- Where have similar components been used before (regulatory analogs) and how effective were

they?

- Lastly, how can an analysis of the various available frameworks be incorporated into the EPA proposed rule or another similar regulation for CCS?

Part of the complexity of CCS regulation involves the multiple components that will be necessary for a comprehensive regulatory framework. Although the literature addresses such issues as property rights and incentives, few authors look at the impact of such issues on the policy framework for this technology. By briefly examining a few of these issues, the final section of the paper attempts to address the following questions:

- How do issues such as property rights, public education, financial incentives, research funds and even climate policy relate to CCS?
- What are some options for addressing each of these components in the context of CCS regulation?
- How do these components and their broad nature affect the regulatory choices for deploying carbon sequestration, and what are some solutions to address these issues?

BACKGROUND

The Intergovernmental Panel on Climate Change reported in 2007 that global greenhouse gas emissions must peak shortly after 2015 to avoid catastrophic climatic changes.[1] A key contributor to emissions, however, is also an integral part of our economy and energy supply: coal. Coal provides an important source of power, supplying around 50% of the U.S.'s electricity needs, and a growing portion of the world's as well. However, coal is the dirtiest fossil fuel in terms of CO_2 emissions as well as other pollutants. Coal-fired power plants are an enormous source of greenhouse gases, with slightly over 4,000 point sources (600 of which are located in the United States)[2] responsible for 38% of annual global CO_2 emissions.[3] To address this, many scientists, companies, and government officials are now proposing carbon capture and storage as a mitigation strategy: capturing carbon dioxide emissions from coal-fired power plants, and storing them underground permanently.

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[1] Fourth assessment report climate change 2007: Synthesis report, 2007, Intergovernmental Panel on Climate Change., 66.
[2] Coal vs. Wind, , 2/24/2009 2009 <http://www.ucsusa.org/clean_energy/coalvswind/c01.html>.
[3] Bette Hileman and Jeff Johnson, "Government & Policy - Driving CO2 Underground," Chemical & Engineering News 85.39 (2007) 2/7/2009., 74.

Carbon Capture and Storage Technology

There are three main components to carbon capture and storage (CCS): 1) capturing carbon dioxide, usually by separating it from the flue gas stream of the power plant, and then compressing it to a much denser state; 2) transporting it to the storage site via pipelines, tankers, or other transport; and 3) storing it, which can be underground (geological) or in the ocean. The entire process and all of the technology employed in capturing, compressing, transporting, and storing the stream of CO_2 is considered CCS. While each component technology currently exists and a complete CCS system could be constructed from them, not all components have reached the same technological maturity. There is very limited experience with the combined use of all the different technologies to capture, transport and sequester CO_2 for long periods of time.[4]

To capture carbon dioxide requires separating it from the gas stream. This is done by "scrubbing" the gas with chemical solvents, which can be done pre- or post-combustion.[5] Scrubbing typically captures between 85 to 98% of the carbon dioxide emitted.[6] Capturing and compressing CO_2 is a very energy intensive process, and can decrease the generating output of the plant by as much as 40%.[7] To transport the gas, it must be compressed to a supercritical or liquid state; this reduces the volume to about 0.2% of the space occupied by CO_2 gas at room pressure and temperature, which makes it cheaper and easier to transport.[8] Although ship and road tankers are used frequently for transportation of CO_2, pipelines are the most likely choice for CCS. There are currently 3,600 miles of pipelines for CO_2 in the U.S., mostly used for enhanced oil recovery, although this would have to be significantly expanded.[9] The compressed stream of CO_2 then reaches the sequestration site, where it is stored away from the atmosphere.

There are several storage options for carbon dioxide, including oceanic and geological sequestration. Ocean storage would dispose of carbon dioxide into deep ocean waters where it could remain for hundreds of years as a "pool" of liquid CO_2 on the ocean floor; this approach is

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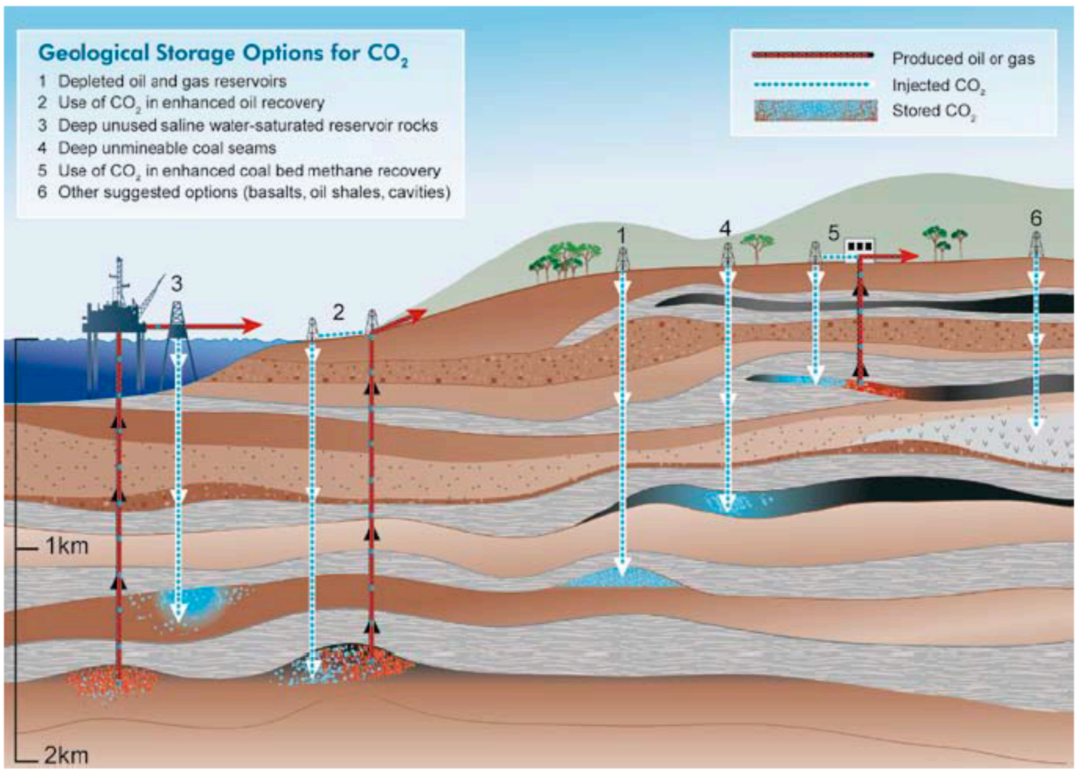
[4] Fernando Hiranya, et al, Capturing King Coal: Deploying Carbon Capture and Storage Systems in the U.S. at Scale (Washington, D.C.: World Resources Institute, 2008) 10.
[5] Bert Metz, et al, Carbon dioxide capture and storage : IPCC special report. Summary for policymakers, a report of Working Group III of the IPCC ; and, Technical summary, a report accepted by Working Group III of the IPCC but not approved in detail (Geneva: World Meteorological Organization ; United Nations Environment Programme, 2006) 59.
[6] *Ibid*, 107
[7] Intergovernmental Panel on Climate Change., IPCC special report on carbon dioxide capture and storage: Summary for policymakers (S.l.: IPCC, 2005) 3. (CCS Report: Summary for Policy Makers)
[8] Metz, et al, 59
[9] Hiranya, et al, 12

still in the research phase but is vulnerable to public criticism for its known impacts on deep-ocean biology.[10] Geological storage involves the injection of CO_2 into permeable rock formations, like deep coal seams, depleted oil and gas reservoirs, and saline aquifers.[11] (See Figure 1) Wells are used to inject the CO_2 to depths where it remains as a supercritical fluid. All formation options involve the "permanent" storage of the carbon dioxide, and require monitoring and verification after injection ceases to maintain the safety and permanence of the storage site.

Figure 1 – Geological storage options for carbon sequestration (Metz, et. al)



Geological Sequestration and Storage Processes and Mechanisms

Although there are several technologies associated with CCS, this paper will focus primarily on geological sequestration. This choice was made because sequestration can easily be considered the most important step in the CCS process. It is the aspect of CCS that allows for climate change mitigation: without effective and permanent trapping of the carbon dioxide, CCS

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[10] Metz, et al, 279

[11] Enhanced oil recovery, while not a geological formation, is a method of injecting CO_2 that is used to recovery hydrocarbons in depleted reservoirs, which therefore provides an economic incentive to sequestration. This method of sequestration will not be covered in this paper.

has no benefit and carbon capture has no purpose. Support from the federal government in the form of research funds and proposed regulation also suggests that geological sequestration, versus oceanic, might be pursued by the government as a more feasible climate change mitigation strategy.[12]

A more detailed look at the processes and mechanisms involved in storing compressed CO_2 underground is required before moving forward. To start with, the different options for geological storage vary vastly. Coal seams are deep coal deposits that cannot be mined due to technological or economic constraints. These seams have pores between the coal fractures that allow for the trapping of gas.[13] Depleted oil and gas reservoirs are favorable for sequestration of CO_2 because they are well characterized, and they have proven their impermeability by storing natural gas or oil for geologically significant amounts of time. Saline aquifers are deep sedimentary rocks saturated with brines and salty water, which are unfit for agricultural or human consumption.[14] To keep the carbon dioxide contained underground in these various formations, the most basic and necessary feature of the site is an overlying impermeable caprock.[15] For this reason, and to ensure that the site has sufficient storage capacity, site selection is key for geological sequestration in any formation.

To further narrow down the discussion of geological sequestration, especially in light of the considerable differences between storage options, this paper will focus specifically on sequestration in saline aquifers. Saline aquifers have the greatest known storage capacity. According to the IPCC, deep saline aquifers contain between 1,000 to 10,000 $GtCO_2$ of storage capacity. With annual global carbon dioxide emissions from coal totaling about 11.5 $GtCO_2$, the capacity of saline aquifers is enough to store 86 to 860 years worth of coal emissions.[16] The second largest storage option, depleted oil and gas reservoirs, has an estimated capacity of 675 to

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[12] Negative public perception can decrease the feasibility of a project and is considered a critical component of success for carbon sequestration. See generally: Climate change federal actions will greatly affect the viability of carbon capture and storage as a key mitigation option : report to the Chairman of the Select Committee on Energy Independence and Global Warming, House of Representatives, 2008, U.S. Govt. Accountability Office. (Carbon Capture and Storage Report)
[13] Metz, et al, 217
[14] *Ibid,* 217
[15] Hiranya, et al, 13
[16] International Energy Outlook 2008-Energy-Related Carbon Dioxide Emissions, June 2008 2008, 1/27/2009 2009 <http://www.eia.doe.gov/oiaf/ieo/emissions.html>.
Calculations were made using the following information: the EIA states that global carbon dioxide emissions are 28.1 gigatons with 41 percent of emissions from coal in 2005.

900 $GtCO_2$,[17] or 58 to 78 years of emissions from coal.[18] Although both capacities are quite large, this difference is formidable, and if geological sequestration of carbon dioxide moves forward, it is probable that saline aquifers will be a key storage option.

The storage mechanisms exhibited in saline aquifers are consistent with those seen in most other geological formations. Fluids are pumped into saline aquifers as a supercritical fluid.[19] The injection of fluids causes the pressure to rise near the well, which allows the carbon dioxide to enter the pore spaces previously filled with water and brine. CO_2 injected into a saline aquifer is not miscible with water and in fact, is much less dense. This density difference causes strong buoyancy forces to push CO_2 upwards. This particular factor is why the confining caprock in aquifers is so crucial. The carbon dioxide will pool along the underside of the confining layer, and could escape through any cracks or fractures.

The amount of pressure that builds up near the well will depend on the injection rate as well as the permeability of the formation. Once injected, many factors control the spread of the CO_2 within the formation: natural hydraulic gradients, diffusion, mineralization, and permeability.[20] These factors control carbon dioxide's interaction with water, which in turn controls the geochemical trapping mechanisms that take place. Geochemical traps, chemical reactions that result in the relatively permanent storage of CO_2 underground, occur in a number of ways. One way of permanently trapping carbon dioxide in aquifers is called "residual CO_2 trapping" in which the gas gets trapped and immobilized in pore spaces. Another process, which takes decades, is carbon dioxide dissolution into the formation waters, causing carbonic acid (as well as bicarbonate and carbonate ions) to form. The formation of this solution causes the CO_2 to lose buoyancy, which decreases the chances of leakage. The most permanent form of trapping CO_2, and the one that takes the longest (thousands to millions of years) is called "mineral trapping"; this is when a portion of the injected carbon dioxide precipitates into stable carbonate minerals.[21] Essentially, the longer carbon dioxide can stay sequestered, the more secure it becomes as geochemical traps start taking effect. (See Figure 2) This is important when considering the monitoring and long-term security of a site. As the site gets older, less oversight

[17] These figures would increase 25% if undiscovered oil and gas fields were included.
[18] Energy Information Administration; Metz, et al, 221
[19] CO_2 stays as a supercritical liquid due to the pressures and temperatures found at the depth of the geological formation.
[20] Metz, et al, 205
[21] *Ibid.*, 208-09; S. M. Benson and D. R. Cole, "CO2 Sequestration in Deep Sedimentary Formations," Elements. 4.5 (2008).

is necessary to ensure its safety.

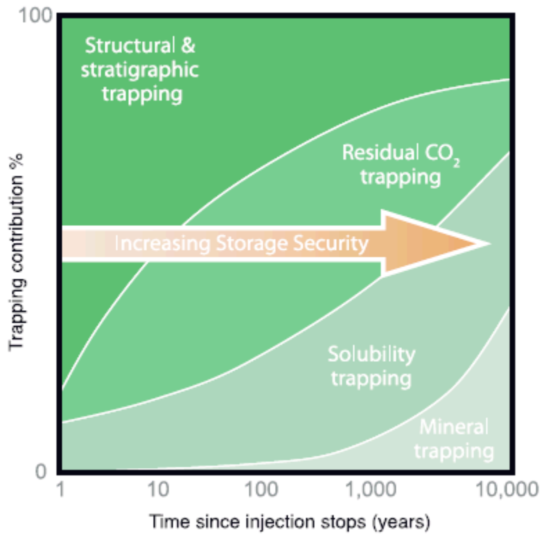

Figure 2 – As geomechanical traps and processes take place over time, the storage security of sequestered CO_2 increases.

Metz, et. al, 208

Current CO_2 Sequestration Projects

Currently, several geological storage projects are taking place around the world. The majority of commercial projects are associated with gas production facilities; they separate CO_2 from natural gas before pumping the stream of carbon dioxide underground. The most well known of such projects include Sleipner in the North Sea, Snohvit in the Barents Sea, and In Salah in Algeria.[22] Sleipner and Snohvit both utilize aquifer formations underneath the ocean floor for storage. Sleipner, located in Norway, is operated by Statoil and has been operating since 1996, pumping about 3,000 tons of CO_2 underground per day. Snohvit, also operated by Statoil and located in Norway, operates on a slightly smaller scale than Sleipner, pumping about 2,000 tons of CO_2 into a saline formation since 2006. In Salah is a joint venture between Sonatrach, BP, and Statoil, and sequesters the CO_2 stream in a gas reservoir, the largest project in existence to do so. Although no commercial carbon capture and sequestration plants are in existence yet, the IPCC's 2006 Special Report on CCS lists 18 geological storage projects in operation and development, 17 of which were operating as of 2007. Of these operating projects, seven plants are using saline formations and aquifers for storage, with the rest utilizing sequestration technology for enhanced oil recovery, including the largest sequestration project in existence, the Weyburn Project in Saskatchewan, Canada.[23]

CCS as Strategy for Climate Change Mitigation

There are several factors to consider when deciding whether CCS should play a role in mitigating climate change: the environmental impacts, social consequences of using the

[22] Metz, et al, 200
[23] United States Government Accountability Office (Carbon Capture and Storage Report), 17; Metz, et al, 201

technology, cost of emission reductions, demand for certain energy sources, range of applicability, and efficacy of storage.[24] In reports about CCS, there are two obvious sides to the debate: arguments for CCS as a mitigation strategy, and arguments against it. While this paper will not look at the merit of CCS in this light, understanding the different arguments will be helpful in understanding the coming analysis.

Arguments against CCS tend to rely on four general points for why the technology should not be deployed.[25] Firstly, there is the argument that carbon capture and sequestration cannot deliver in time to be a viable strategy for climate change mitigation. This is based on the World Business Council for Sustainable Development's estimate that the *earliest* commercial implementation for CCS can be expected is 2026.[26] With the IPCC's warning that emissions need to decrease shortly after 2015, this would be "far too late to help the world avoid dangerous climate change."[27] Secondly, opponents present the case that CCS wastes energy, facing a 10 – 40% energy penalty (depending on the technology used) for capturing CO_2.[28] Reductions in efficiency will require increased coal inputs, increasing the environmental impacts observed from more mining, burning, transport, and waste disposal. Thirdly, there is concern over safety and the risks associated with underground storage of CO_2. Because permanent storage cannot be proven, and any leakage may diminish the gains achieved from storing the CO_2, many opponents believe that the risk is not worth taking. Finally, the argument is made that CCS is too expensive, and would divert resources from other mitigation options like renewable energy sources. This point is supported by the recent increase in funding for CCS in the Department of Energy's 2009 budget; it calls for a 26% increase in CCS-related funding, but simultaneously scaled back budgets for renewable energy and efficiency research.[29] Additionally, CCS plants used for generating power are likely to increase electricity prices around 65%, the cost of which is likely to be borne by the consumer.[30] These four large reasons are the foundation for most arguments against carbon capture and storage.

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[24] Metz, et al, 53
[25] Greenpeace: False Hope arguments will be used as a general overview here.
[26] World Business Council for Sustainable Development (WBCSD), Facts and Trends: Carbon Capture and Storage (CCS), 2006) 2.
[27] United Nations Development Program (UNDP), Avoiding Dangerous Climate Change: Strategies for Mitigation, 2007) 145-46.
[28] Intergovernmental Panel on Climate Change. (CCS Report: Summary for Policy Makers), 3
[29] U.S. Department of Energy, Fiscal Year 2009 Congressional Budget Request, 2008.
[30] The EPRI Energy Technology Assessment Center, The Power to Reduce CO2 Emissions: The Full Portfolio, 2007) 28.

Arguments in favor of CCS tend to take a very different approach, assuming the continued use of coal, and from that standpoint arguing for the widespread deployment of CCS. Coal currently accounts for around half of the U.S. domestic electricity production; China, the largest producer of greenhouse gases, is constructing the equivalent of 2 500-megawatt coal-fired power plants per week, and the energy demand around the world is growing.[31] Armed with this information, supporters of CCS view coal as indispensable. Additionally, according to MIT's report, the Future of Coal, this fuel source is "cheap and abundant," at $1 to $2 per MMBtu, and it is also found in regions outside the politically unstable Persian Gulf.[32] These facts, according to proponents, make coal a preferable candidate for meeting our future energy needs. With this premise in mind, quick deployment of CCS is seen as necessary to decrease carbon dioxide emissions to mitigate climate change. Reports written by proponents, therefore, tend to focus their arguments on supporting measures to speed deployment, whether those are subsidies or effective climate legislation. In fact, if CCS is going to play a role in climate change mitigation, both are likely to be necessary. According to MIT researchers, the price of carbon dioxide emissions will need to be around $30 per tonne in order to make CCS competitive.[33] Additionally, because no full-scale CCS coal plant is in operation, research and demonstration projects are necessary to answer key unknowns. And, as the Future of Coal states, the "government support will be needed for these demonstration projects as well as for the supporting R&D program."[34] Despite these obstacles, however, proponents see the capacity for carbon dioxide beneath the earth's surface as an indicator of the potential success of the technology. Indeed, the capacity of saline aquifers along with other geological storage formations is quite extensive, as was shown earlier. Additional information also suggests the potential success rate of CCS projects; the IPCC considers it likely that 99% or more of injected CO_2 will remain sequestered for 1,000 years.[35] Certainly the capacity and likelihood of success of CCS are helpful additions to the arguments used for supporting its widespread deployment.

Regardless of the various viewpoints, however, the federal government is currently moving forward with funding for CCS research, and formulation of CCS regulations. These key

[31] The Future of Coal, 2007, 2/8/2009 2009 <http://web.mit.edu/coal/>.
[32] Massachusetts Institute of Technology Interdisciplinary Study, ix
[33] *Ibid,.* ix.
[34] *Ibid.,* ix.
[35] Metz, et al, 197

moves indicate the potential that CCS has in the future climate strategy of the U.S. This paper will assume that the U.S. government is taking a policy approach of actively promoting CCS, and will analyze the best policy approaches from that particular lens. Evidence from current U.S. policy and statements from President Obama's administration suggest that, in fact, promotion of CCS will be the U.S. policy approach for the foreseeable future.[36]

Regulation of CCS

The United States is home to several pilot scale geological sequestration projects which are currently regulated under the Safe Drinking Water Act (SDWA) as a part of the Underground Injection Control Program (UIC). The UIC Program governs most underground injection and as of 2007, issued an experimental well category (Class V) specifically for CCS pilot projects.[37] This regulation is adequate for the current projects since total injection falls in the hundreds to thousands of tons, and the purpose is clearly experimental. However, if the federal government chooses to move forward with CCS, the regulation for commercial projects will need to be more stringent than that applied to a few small projects. Proper laws and regulations will need to be in place to ensure that commercial projects are safe and socially responsible.

Currently, the federal government is moving toward that aim. On July 25 of 2008, the Environmental Protection Agency (EPA) issued a proposed rule for geological sequestration of carbon dioxide. A proposed rule is a regulation that is published for review and public comment, and does not have the force of law. The proposed rule for CCS was given five months for public comment, and the period ended on December 24, 2008. This proposed rule, although not final, is a good representation of the choices and considerations that the federal government is going to make regarding this technology and its regulation. It covers topics from well construction standards to monitoring requirements and report filing. Although this proposed rule is within SDWA and therefore only has the jurisdiction to protect drinking water sources from the impacts of carbon dioxide injection, it is a representative look at the technology and how the government proposes to regulate it.

The publication of this proposed regulation, as well as the proposal of CCS as a climate

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[36] Young, Tom. "Obama's energy chief softens stance on coal and nuclear." BusinessGreen Jan 2009 <http://www.accountancyage.com/business-green/news/2234080/obama-energy-chief-softens>.
[37] Mark A. De Figueiredo and Massachusetts Institute of Technology. Center for Energy and Environmental Policy Research., Regulating carbon dioxide capture and storage ([Cambridge, Mass.]: MIT Center for Energy and Environmental Policy Research, 2007) 7.

mitigation strategy, rely on and assume the existence of a federal climate change mitigation policy. In fact, a federal climate change mitigation policy to reduce carbon dioxide emissions is necessary for deployment of CCS; without it CCS is economically unfeasible for private companies. There will be a brief discussion about the components of a climate mitigation strategy that would be needed to deploy CCS near the end of this paper. However, throughout the discussion of CCS, and the discussion of necessary regulations, this paper will assume the existence of a federal climate policy.

So what type of regulation is needed for commercial scale deployment, if the current Class V experimental well is only adequate for pilot projects? Before that answer can be understood, more must be explored about the technology, namely the risks involved and how those and other factors inform the type of oversight that carbon sequestration sites will require.

GEOLOGICAL RISKS ASSOCIATED WITH CCS AND A SAFE REGULATORY APPROACH

Carbon capture and storage is a novel technology, and with that comes a number of risks. The process of storing carbon dioxide underground produces risks to human safety and to the environment. This paper will first attempt to understand these risks, their probability, and the circumstances that would increase their likelihood of occurrence. Then, the necessary remediation or prevention techniques will be analyzed, particularly in the context of federal regulation.

There are three main pathways for carbon dioxide to escape from underground saline aquifers. One way is through the pore system of the caprock. This is unlikely unless very high pressures are attained; the pressure of the carbon dioxide under the caprock would need to exceed the entry pressure of the very low-permeability pore system of rocks such as shales.[38] Another pathway of carbon dioxide leakage is through cracks and fractures in the caprock. This mode of escape is much more likely, but could be prevented by careful selection of sites with intact caprocks. The third and most probable[39] type of CO_2 leakage is through anthropogenically-created channels, particularly leaking or malfunctioning wells. Wells have numerous pathways in their structure that might allow for leakage.[40] (See Figure 3) Additionally, in areas like oil and gas provinces, where there may have been thousands of wells drilled

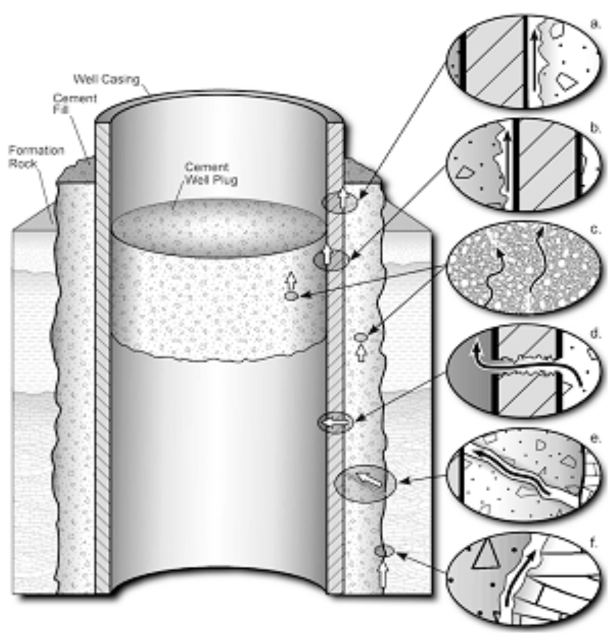

Figure 3 – Possible Leakage Pathways in an Injection Well

a) Between casing and cement; b) between cement plug and casing; c) through the cement pore space as a result of cement degradation; d) through casing as a result of corrosion; e) through fractures in cement; and f) between cement and rock

Gasda, S.E., "The potential for CO_2 leakage from storage sites in geological media: analysis of well distribution in mature sedimentary basins"

[38] Metz, et al, 242
[39] Based on experience with other forms of underground injection – See Regulatory Analogs Section
[40] S. E. Gasda, "The potential for CO_2 leakage from storage sites in geological media: analysis of well distribution in mature sedimentary basins," Environmental geology (Berlin) 46.6-7 (2004), 708-09.

within an area, the risk of this type of leakage increases dramatically.[41]

Despite the seemingly vast methods of escape, however, it is important to note that the probability of escape, given proper site selection, is actually quite low. Natural geological "lakes" of carbon dioxide exist in the subsurface, some which have been in existence for millions of years. Known oil and gas reservoirs have also remained confined under the earth's surface for over ten million years.[42] The presence of such sites indicates that long term storage in natural systems is possible and plausible. Additionally, engineered systems for storing natural gas have been used in the United States for over 25 years. Although comparatively this is a very short time span, leakage from these wells has been insignificant, even though they are subject to more rapid pressure changes (which increase the probability of leakage) than carbon sequestration sites would be.[43] The IPCC report on CCS claims that when Ïinjecting CO_2 into deep geological formations at carefully selected sites for long periods of time[,] it is considered likely that 99% or more of the injected CO_2 will be retained for 1000 years.Ó[44] Therefore, while it is important to keep in mind the risks of leakage and the hazards that they present, a perspective on the estimated probability of those events is also central to the discussion.

Risks Associated with Surface Leakage

Most risks associated with geological sequestration of carbon dioxide in saline aquifers can be grouped into three main categories: risks as a result of leakage of CO_2 at the surface, subsurface risks, and induced seismicity.

What are the risks when leakage at the surface occurs? Certainly the largest concern in the context of climate change is leakage into the atmosphere, which decreases CCS's effectiveness as a mitigation strategy. Estimates based on large amounts of storage over time claim that leakage rates need to be lower than 1%[45] to make carbon sequestration an effective

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[41] Gasda, 718

[42] Metz, et al, 244

[43] Sally M. Benson, et al, Lessons Learned from Natural and Industrial Analogues for Storage of Carbon Dioxide in Deep Geological Formations Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US), 2002) 118.; Metz, et al, 245

[44] Metz, et al, 246

[45] This is assuming that over 100 years, 600 GtC is stored. A 1% leakage rate would be 6 GtC, which is equal to our current annual global emissions. That rate of leakage would not be an effective mitigation strategy. However, this scenario is only applicable if the capacity of our storage options becomes exhausted, which currently seems unlikely.

climate mitigation strategy.[46] The quantity of stored CO_2 used in such models is quite large however; they use estimates of our current annual global emissions stored every year for 100 years. Therefore, the percentage of leakage “allowed” might be higher when based on a smaller (and more realistic) amount of stored CO_2. Regardless, this illustrates the important idea that leakage could effectively reverse the positive effects of sequestering greenhouse gases.

On a more local level, CO_2 leakage from the surface has the potential to affect the health and safety of humans. These hazards arise from accumulations of CO_2 that cause elevated concentrations of the gas. When carbon dioxide concentrations exceed 2%, human and animal respiratory functioning can be impacted, and at concentrations above 7-10%, unconsciousness or death may result.[47] Because CO_2 is denser than air and tends to sink, this could happen in low-wind situations or low topographic areas, where the gas could pool in valleys or enclosed areas like caves or buildings. According to the IPCC, however, such accumulation of CO_2 is highly “improbable,” and other than the health effects of high CO_2 concentrations, there is no other direct way that CO_2 leakage at the surface could damage human health.[48]

Leakage of CO_2 also generates hazards in offshore sites where sequestration is taking place in saline aquifers underneath the sea floor. If carbon dioxide manages to seep through the ocean floor and into the ocean, oceanic ecosystems could be at risk. Depending on the rate of leakage, as well as the pressure and temperature at the site of leakage, the CO_2 may dissolve into the surrounding waters. When CO_2 dissolves into water, it affects the water chemistry by increasing the acidity. This would likely result in negative biological impacts to ocean ecosystems and marine life; at a particular risk are organisms with calcareous skeletal structures, such as plankton and some invertebrates which form the foundation of many oceanic food systems.[49]

Terrestrial ecosystems could also be affected by surface leakage of carbon dioxide. Although CO_2 can be beneficial to plant growth in the ambient atmosphere, it can be detrimental to their health at high soil concentrations. Any carbon dioxide leakage from the surface, however, is likely to cause that problem. Usually, CO_2 concentrations in soils are below 1%,

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[46] Christian C. Azar, "Carbon Capture and Storage From Fossil Fuels and Biomass – Costs and Potential Role in Stabilizing the Atmosphere," Climatic Change 74.1-3 (2006), 59.
[47] Metz, et al, 246
[48] *Ibid.*, 246
[49] *Ibid,*, 243; See generally: Victoria Fabry, "Impacts of ocean acidification on marine fauna and ecosystem processes," ICES Journal of Marine Science 65.3 (2008).

allowing plants to absorb oxygen and nutrients directly from the soil. When soil concentrations of CO_2 surpass 5%, the plants' absorption capabilities are compromised, and above 20%, plants can "suffocate" entirely.[50] An example of where this has occurred is Mammoth Mountain, a young volcano in eastern California. In 1989, a series of small earthquakes underneath the mountain released large amounts of CO_2; the following year, vast vegetation die-offs were reported. The U.S. Geological Survey investigated the cause and found carbon dioxide leaking from the surface of the mountain at a rate of 1,300 tons per day, contaminating the soils with CO_2 concentrations between 20 and 95%.[51] Although this particular incident in California is caused by natural circumstances, it is an adequate illustration of the potential biological effects of CO_2 leakage from geological storage sites.

Subsurface Risks

It is possible that carbon dioxide sequestered in saline aquifers could leak from the intended site but never reach the surface. There are particular risks associated with this possibility, particularly the contamination of groundwater resources. This topic has garnered the most attention in terms of regulation and government concern.[52]

There are two principal ways that underground injection of carbon dioxide could affect groundwater resources that lie above the storage site.[53] One way is direct leakage of the gas through a crack or fracture in the caprock into an aquifer above the injection site. Another possible method of contamination is through brine displacement, where CO_2 forces saline brines into freshwater sources.

One danger of direct leakage of carbon dioxide into an underground drinking water source is the reaction of the gas with water: CO_2, when mixed with water, can become carbonic acid. The indirect impacts of its acidity are of particular concern, especially the mobilization of heavy metals. Modeling and experimental studies indicate that the low pH values caused by CO_2

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[50] Invisible CO2 Gas Killing Trees at Mammoth Mountain, California, U.S. Geological Survey Fact Sheet-172-96, 1/18/2009 2009 <http://quake.usgs.gov/prepare/factsheets/CO2/index.html>.; Metz, et al, 248
[51] U.S. Geological Survey Fact Sheet: Mammoth Mountain
[52] See generally: United States Government Accountability Office (Carbon Capture and Storage Report); Environmental Protection Agency. Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration (GS) Wells | Federal Register Environmental Documents | USEPA, 2008: fr25jy08-20.
[53] Although groundwater resources technically includes the saline formations into which CO_2 is being injected, for the purposes of this discussion, groundwater resources will refer solely to useable freshwater sources.

can cause release of toxic heavy metals including lead by inducing desorption and the dissolution of iron- and manganese-containing minerals with which heavy metals had been associated. The contamination of groundwater by such heavy metals has the potential to reach dangerous levels, making the water unfit for irrigation or drinking.[54] Another concern of carbon dioxide leaking into drinking water sources is the aesthetic quality of the water: dissolved iron, manganese and sulphate have the potential to cause an abnormal smell, taste, or color in the water.[55]

Another possible way for CO_2 injection to contaminate groundwater is through the displacement of brines. If enough pressure is built up in the aquifer by the injection of CO_2, displaced brines could migrate or leak out of the formation via defective wells or cracks. If the brines leak into a drinking water aquifer, they could contaminate it by increasing its salinity. This would directly affect the available uses of the water for irrigation or drinking. Additionally, if the contamination takes place in the shallow subsurface, it could have impacts on agricultural use of the land, and possibly habitat degradation. In general, however, this phenomenon is rarely found to occur with injection wells; it is not expected to occur with carbon dioxide injection because of the extremely high injection pressures that are necessary to induce such an event.[56]

Endangerment to subsurface ecosystems is another concern of carbon dioxide injection. In saline aquifers, microorganisms that range from methanogens to iron and sulphate reducers have been discovered, and some studies even suggest that the subsurface populations of microbes may exceed the mass of biota on the surface.[57] These populations may be impacted by the injection of carbon dioxide into their habitat. Because these microbes are not extensively studied, the impacts of lower pH or higher levels of CO_2 are unknown.[58] These populations require more research to anticipate the effects of carbon dioxide on their habitat, but should nevertheless be considered in the possible impacts of CO_2 on the subsurface.

[54] Y. K. Kharaka, et al, "Gas-water-rock interactions in Frio Formation following CO2 injection: Implications for the storage of greenhouse gases in sedimentary basins," Geological Society of America 34. 7 (2006) 1/18/2009.; Metz, et al, 247
[55] Metz, et al, 247
[56] *Ibid.*, 248
[57] Shelley S. A. Haveman, "Distribution of culturable microorganisms in Fennoscandian Shield groundwater," FEMS microbiology, ecology 39. 2 (2002)., 129; W. B. Whitman, "Prokaryotes: The unseen majority," Proceedings of the National Academy of Sciences of the United States of America 95.12 (1998), 6578.
[58] Metz, et al, 249; See generally: T. Onstott, Impact of CO2 injections on deep subsurface microbial ecosystems and potential ramifications for the surface biosphere, Carbon Dioxide Capture for Storage in Deep Geologic Formations - Results from the CO2 Capture Project, ed. S. M. Benson (London: Elsevier Science, 2005) 1217–1250.

Induced Seismicity Risks

Seismicity is the fracturing and movement along faults in a given area that can be synonymous with, or cause, earthquake activity. When materials (carbon dioxide or other liquids) are injected underground at a pressure higher than the formation pressure, the integrity of nearby faults can be affected, inducing earthquakes and microseismic events like brittle fault fractures.[59] This is caused by a reduction in frictional resistance at the fault. Essentially, the stress of overlying and surrounding rocks keep a fault from moving; this stress is reduced or removed by the injection of materials, which causes an increase in pore pressure, and therefore more fault mobility.[60] These effects are site specific, and will be a higher risk in low permeability and low porosity formations, where higher injection pressures will be required.

There are two particular concerns with induced seismicity. One hazard is small seismic events like brittle fracturing or resulting microseismicity (small tremors under the surface). These may cause fracturing in the storage formation, creating new pathways for stored carbon dioxide to escape. The second concern is that activated faults could cause larger earthquakes, causing local damage to human health or infrastructure. In fact, deep well injection has been shown to induce such events, like the 1967 Denver earthquakes or the earthquakes in Ohio from 1986-1987.[61]

The 1967 Denver earthquakes were researched and believed to be caused by a deep well used by a U.S. Army Arsenal for disposal of waste fluids from chemical manufacturing. Underground injection at nearly 3,700 meters began in 1962, the same time that small earthquakes began being recorded at local seismograph stations. Throughout the time of injection, many larger earthquakes occurred, at a Richter scale between 3 and 4. Eventually injection ceased in 1966 after correlation to the earthquakes was suspected, but the seismic activity continued after that point, with the largest earthquake, at a magnitude of 5, occurring the following year. All of these events took place within a few kilometers of the injection well, a region that had very little evidence of previous seismic activity.[62] The events in Denver, and

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[59] J. Sminchak, et al, "Aspects of induced seismic activity and deep-well sequestration of carbon dioxide," Environmental Geosciences 10.2, 81-89 <http://eg.geoscienceworld.org/cgi/content/full/10/2/81>., 81; J. H. Healy, "The Denver Earthquakes," Science (New York, N.Y.) 161. 3848 (1968). 1301; Metz, et al, 249
[60] Healy, 1309; Sminchak, et al, 81
[61] Metz, et al, 249
[62] Healy, 1301

those like it, provide an educational analog to carbon sequestration.[63] Because the volume of injected carbon dioxide is projected to far surpass that of hazardous waste, this particular issue must be given serious attention. Nevertheless, because so few events have been recorded in correlation to deep well injection, the risk is likely to be low and close monitoring during operation as well as careful site selection will likely be enough to avoid injection-induced seismicity.[64]

Key Unknowns and Further Research

Knowledge of the risks of carbon sequestration, as well as the mechanisms involved in trapping carbon dioxide underground, comes from the experience of the oil and gas industry over the last century, pilot scale and commercial sequestration activities conducted over the last 10-30 years, and research in the earth sciences. However, the novelty of carbon sequestration limits the extent of our knowledge about the process and the risks as well as poses technical barriers. Therefore, it is imperative to acknowledge the key gaps in knowledge that still exist and take them into consideration when evaluating how or even whether to move forward with regulation. The following is a list of key unknowns and some methods for addressing them.

- Storage Capacity – Both the estimates of storage capacity and the methodologies for measuring capacity require further research. Storage capacity estimates vary greatly with different methodologies. These assessment methodologies require more development, as well as universal agreement, to produce more accurate estimates of capacity. Additionally, there needs to be increased research to attain storage capacities in many developing areas, particularly those with the highest energy use, like China, India, Russia and the Middle East.[65] Already the U.S. Geological Survey has begun research on this topic, developing a methodology and conducting an assessment of carbon sequestration capacity in the U.S. The assessment is expected to be released in March 2009.[66]
- Leakage Rates – Leakage rates and general geological performance assessments must be

[63] The difference in material injected does not affect the relevance of the previous experience with induced seismicity because it is the rate and quantity of the injection that determines the risk of induced seismicity, not the type of fluid injected.
[64] Metz, et al, 250
[65] *Ibid.*, 264; United States Government Accountability Office (Carbon Capture and Storage Report), 46
[66] United States Government Accountability Office (Carbon Capture and Storage Report), 47

done for a variety of geological settings and formation types.[67] This would allow for quantification of potential leakage rates in a variety of sites, accurate simulation models for long term storage based on site-specific characteristics, and protocols for how to achieve desirable storage duration coupled with safety.[68]

- Leakage Detection – The ability to monitor and detect for leakage is crucial for CO_2 sequestration. Further research and information is needed on detecting and monitoring leakage on the ocean floor (to detect leakage from storage formations under its surface), cost effective surface methods for detecting leakage (particularly dispersed leaks), and fracture detection in the subsurface along with quantification of leakage potential.[69]
- Effects of Impurities – The effect of gas impurities on the subsurface is a key unknown because most research has assumed the storage of only carbon dioxide. The addition of gases like hydrogen sulfide, sulfur dioxide, nitrogen oxide, and nitrogen dioxide (which are also gases emitted from coal-fired power plants and might be stored with CO_2) may increase the toxicity of the injection stream. More research must be done on the varying purity of gas streams to assess the risks associated with the practice.[70] This issue will certainly be of importance in the regulation of carbon sequestration, given the variability of the streams produced from each power plant.
- Remediation – There has been almost no experience with remediating or mitigating leakage of carbon dioxide. Although technologies exist that might be used for this purpose, more information is needed on the logistics and cost of remediation.[71] This is perhaps one of the larger issues, and is of particular concern in the development of a regulatory framework that considers costs of remediation and leakage.

An important point must be made about remediation for CCS projects. Remediation techniques for leaks of carbon dioxide from the surface currently revolve around prevention of further leakage (i.e. plugging a well). This, however, is not true remediation. Once the previously stored carbon dioxide is released into the atmosphere, the purpose of storage – to prevent

[67] International Risk Governance Council, <u>Policy Brief: Regulation of Carbon Capture and Storage</u> (Geneva, Switzerland:, 2008) 18.
[68] Metz, et al, 264
[69] International Risk Governance Council, 18; Metz, et al, 264
[70] *Ibid*., 18; Metz, et al, 250
[71] *Ibid*, 18

greenhouse gas emissions – is negated. Unless the gas is re-captured and re-sequestered, then the measures only prevent further harm; they do not reverse the harm already done by the escaped CO_2. Remediation, in this paper, will refer to such preventative measures, as opposed to true "remediation" measures of recapturing CO_2. It should be noted, then, that only prevention of leakage can truly preserve the purpose of carbon sequestration.

These key unknowns have important implications for regulatory decisions, particularly related to the EPA's current development of regulations for a technology that has not yet been deployed at a commercial scale. With such a young technology as carbon capture and storage, it is impossible to understand all of the aspects that affect cost, risks, and environmental health. Two conclusions generally follow this understanding: one is that the immature state of the technology requires a flexible framework that allows for room to change with the latest technology and discoveries; the other viewpoint is that the deployment and regulation should not proceed for CCS until these unknowns are better understood, and risks can be better minimized. Ultimately no regulatory framework can be completely flexible nor can all of the unknowns ever be fully understood, so the reconciliation of these two viewpoints is a balancing act.

Although this paper takes a stand on neither of those positions, an important point must be made. The key unknowns of the technology form a vicious cycle with the deployment of the technology. Large scale deployment and specifically, commercial scale projects are needed for better understanding of the risks and technology. However, without a proper regulatory framework, the liability and risks to private investors are too great to undertake such large projects, and no commercial ventures will be developed.[72] Deployment relies on technical understanding of the unknowns and vice versa. Because one relies on the other for success, such binary arguments about regulation versus deployment are practically void. One cannot truly be placed against another, but regulatory agencies and initial developers should work together simultaneously if commercial deployment of CCS is favored.

RISK MITIGATION AND REGULATION

Several of the major risks associated with carbon sequestration in saline aquifers should now be clear. However, what are the next steps? If the U.S. government moves forward with

[72] See generally: International Risk Governance Council; United States Government Accountability Office (Carbon Capture and Storage Report)

CCS deployment, how can these risks be avoided or minimized through regulation? This next section examines the necessary regulatory components that must be in place to minimize the risks that have been discussed. Then, it will cover analogs that can be used for carbon sequestration regulation, and how those inform the policy choices that may be made for CCS.

Policy Components for Addressing Risks Associated with CCS: Site Selection

Most of the risks associated with carbon storage can be minimized with careful site selection. Although there is no guarantee that proper site selection would completely prevent leakage, there is a greater chance that hazards associated with surface and subsurface leakage could be avoided. To properly select a site and ensure minimized risks of leakage, several parameters must be measured: a site's tectonic setting, size and depth of the basin, geothermal and pressure gradient, geological characteristics of the caprock or sealing formation, hydrogeology and hydrodynamic regime, as well as permeability and porosity of the site.[73]

Tectonic activity, size and depth of the site, and geothermal and pressure gradient are the basic parameters for a site: they can be used to narrow down the site possibilities in the initial selection phase. Sites within regions of high tectonic activity are risky for geological storage because there is a high potential for rapid release of the carbon dioxide due to converging plates or faulting in the subsurface. For that reason, convergent geological regions like those found in Los Angeles or the Gulf of Alaska are not favorable. Instead, divergent regions, which are more stable, are preferable for sequestration sites.[74] Size and depth are rather obvious criteria for site selection: saline formations that are larger and deeper are more favorable. Size and depth, along with porosity, largely determine the capacity of the site and

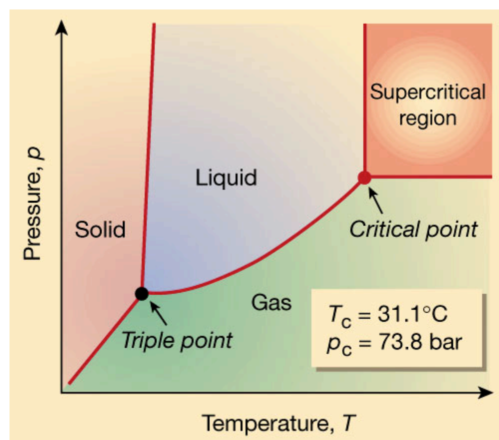

Figure 4 – Carbon Dioxide density as a function of temperature and pressure**.**
Leitner, W. "Designed to dissolve." Nature 405 (2000): 129-30.

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[73] Stefan Bachu, "Screening and ranking of sedimentary basins for sequestration of CO2 in geological media in response to climate change," Environmental Geology 44 (2003): 277; Stefan Bachu, "Sequestration of CO2 in geological media in response to climate change: road map for site selection using the transform of the geological space into the CO2 phase space," Energy Conversion and Management 43.1 (2002): 87.

[74] Stefan Bachu, "Sequestration of CO2 in geological media: criteria and approach for site selection in response to climate change," 41 (2000): 966.

therefore its suitability for various project scales. Finally, the geothermal and pressure gradients are very important because they affect the density of carbon dioxide.[75] Temperature and pressure increase with depth, increasing the density of carbon dioxide, although not uniformly. At higher densities, CO_2 is less buoyant, which increases the safety of storage because the upward force against the caprock is diminished. Additionally, increased density of carbon dioxide makes storage more efficient because more CO_2 can be stored per unit volume. As mentioned previously, carbon dioxide is most dense when it is a supercritical fluid,[76] which is achieved when it is at high temperature and pressure. It was initially thought that sequestration had to take place below 800 meters to achieve a supercritical state, but it was found that actual temperature and pressure conditions can vary.[77] (See the phase diagram in Figure 4) Colder basins are preferable because at a given pressure, CO_2 is denser at lower temperatures. The geothermal and pressure gradient is also important to ensuring that carbon dioxide does not experience a phase change in the storage formation. If CO_2 is injected into a formation where the temperature and pressure conditions are close to those conditions of CO_2 gas, the supercritical fluid might experience a transition to the gaseous phase. Because the gaseous phase experiences larger buoyancy forces, the phase change could cause a leak or a rapid release of CO_2.[78]

Another site selection criterion is the geological character of the caprock. Since the caprock is the primary sealing feature of the storage site, it is imperative that its integrity be assured. Stefan Bachu, in his article about the "road map for site selection," divides the concerns about caprock characteristics into two categories: immediate and ultimate safety.[79] Immediate safety refers to the potential for upwards migration: cracks, fissures, and fractures (natural or man-made) within the sealing rock that would allow for leakage during or soon after injection. Ultimate safety refers to the dependability of the caprock over time, as CO_2 laterally migrates along the aquifer. The sealing formation for a saline aquifer should spread over the entire region, allowing for CO_2 to travel without leaking.[80] A caprock with uniform lithology will also be preferable, meaning that the composition of the base of the rock should be even and

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[75] Bachu, Screening and Ranking: 280
[76] For subsurface conditions. Liquid carbon dioxide is denser, but harder to achieve in subsurface geological settings.
[77] Bachu, Road Map for Site Selection: 93; Metz, et al, 214
[78] Bachu, Criteria and Approach: 953-970
[79] Bachu, Road Map for Site Selection: 90
[80] *Ibid.,* 90

homogeneous.[81]Additional considerations about the caprock include thickness, strength, and potential for chemical reactions with carbon dioxide: the caprock should be both thick enough and strong enough to handle the increased pressure of the injected CO_2, and its composition must ensure that the caprock will maintain integrity despite any reactions with carbonic acid.[82]

Water pressure and flow are important factors in site selection because of the potential for water contamination, the tendency for hydrodynamic and mineral trapping, and the effects of water pressure on the injection of carbon dioxide. If the water in the storage formation is likely to flow out of the reservoir, or if it intersects another body of water, the injected carbon dioxide is more likely to cause contamination of other water bodies, and potentially drinking water sources.[83] Therefore, saline aquifers with stagnant or low water flow and long geological residence times are preferable for storage. Low flow and high residence times also increase the chances of mineral and hydrodynamic trapping, which increases the security and safety of long-term storage of CO_2.[84] The pressure regime of the formation waters is also important, especially concerning leakage and induced seismicity. High-pressure sites are more likely to cause fractures in the caprock and induce seismicity, partly due to the high injection pressures that would be necessary.[85] Sites with lower pressure regimes are therefore more preferable for injection.

In considering the permeability and porosity requirements for site selection, it is first important to define the difference between the two terms. Porosity is a measure of the void spaces available in a material; permeability, on the other hand, is the ability of a fluid to flow through that material. In the context of carbon sequestration, porosity determines the capacity of the formation and usually decreases with depth due to compaction. Permeability is the most important factor in determining injection rate; the higher the permeability, the lower the pressure needed to move the fluid into the storage formation.[86] Higher permeability formations are favorable because lower injection pressures pose fewer risks.[87]

The collection of all of this geological data for site selection essentially measures the safety and risks of the formation. Data collection, however, is not easy and requires several tests

[81] Metz, et al, 225
[82] *Ibid.*, 225
[83] Bachu, Criteria and Approach: 967
[84] Metz, et al, 215; Bachu, Criteria and Approach: 967
[85] Healy, 1301; Metz, et al, 214
[86] Bachu, Criteria and Approach: 967
[87] As previously discussed, higher injection pressures can increase likelihood of fracturing the caprock and inducing seismicity.

and measurements. Some of these methods have been used by the oil and gas industry, such as drill stem tests, but other evaluation techniques will require further research, development, and standardization before they can be widely deployed. However, since data about underground conditions is never likely to be 100% certain or complete, regulations regarding site selection need to be conservative and preventative.

Policy Components for Addressing Risks Associated with CCS: Operation

Beyond site selection, several other elements might affect site integrity and therefore, need to be regulated: injection pressure, composition of injection stream, and assessment of abandoned wells.

To inject carbon dioxide into a storage formation, the injection pressure must be greater than the pressure of the fluid within the reservoir; however, injection pressures that are too high are more likely to induce fracturing in the caprock, cause brine displacement, and stimulate microseismic events.[88] In the United States, injection pressure is monitored and regulated for all wells, and the maximum pressure cannot exceed the pressures necessary to initiate or propagate fractures. This practice is particularly necessary for carbon sequestration, which faces the additional risk of upwardly buoyant CO_2.

Impurities in the injection stream alter the behavior of the carbon dioxide, and therefore require specific regulation tailored to the chemical composition and contaminants. Depending on the process used at the coal facility, the injection stream may have small amounts of SO_2, NO_2 or other gases. These contaminants could affect properties of the carbon dioxide like compressibility, solubility, and ability to leach heavy metals from minerals within the formation. SO_2 is a particular concern because its dissolution with water creates a stronger acid than carbon dioxide; it may increase the mobilization of heavy metals or contribute to the dissolution of surrounding minerals, increasing the possibility of leakage.[89] The effects of impurities on the surrounding rock, the caprock, or other parts of the subsurface environment are largely unknown due to the fact that most risk assessment studies have been focused on the effects of CO_2 alone. Therefore, any regulation about impurities must provide for collection of new data and must

[88] R. A. Chadwick and British Geological Survey., Best practice for the storage of CO_2 in saline aquifers : observations and guidelines from the SACS and CO2STORE projects (Keyworth, Nottingham: British Geological Survey, 2008) 112; Metz, et al, 232; Healy, 1301
[89] Metz, et al, 250

account for the increased risks associated with varying purities of injected fluids.

Leaking wells, abandoned or operational, within the area of sequestration pose the largest risk for CO_2 to escape out of the storage formation and potentially into the atmosphere.[90] Of particular concern are those wells penetrating the storage formation. For this reason, a thorough assessment of active or abandoned wells in the area above the injection zone and the larger storage site is a crucial component of the operation of any CCS project.[91] This area of inspection will likely be very large due to the long term nature of the storage and the migration of CO_2 within the formation during that time. Regulation should specify that, within that area, all wells must have reliable sealing capacity, and if any do not, they must be repaired. Reliable sealing capacity usually involves a cement plug as well as bonding with the penetrated rocks; such techniques have been extensively used in the oil and gas industry.[92] The identification and repair of leaking wells will greatly reduce the chances of leakage.

In addition to locating and restoring old wells, certain procedures must be established for construction and abandonment of injection wells to ensure their safety before and after site closure. Firstly, construction materials and techniques must be made to last the duration of the storage project, which is easily upwards of 100 years. The construction materials must also be able to maintain their integrity in acidic conditions, as carbon dioxide is corrosive and in solution with water might break down the cement or metal casing of a well.[93] Sealing plugs and cement that are resistant to the effects of CO_2 have been developed for the oil and gas industry as well as the geothermal industry, and are available for use for sequestration. Well abandonment regulations are also necessary, to ensure that a well is properly plugged post-closure. To prevent long term corrosion by CO_2 one suggestion is to remove the metal casing and liner after abandonment to prevent the deterioration of the metal, and replace it with a cement plug.[94] To ensure the integrity of the seals, the well may require some amount of monitoring after closure. These and other abandonment procedures must be in place to ensure the safety of injection wells after closure.

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[90] Jonathan Pearce, et al, The objectives and design of generic monitoring protocols for CO2 storage (Trondheim, Norway 2006), 3.

[91] See generally: Sarah S. E. Gasda, "Spatial characterization of the location of potentially leaky wells penetrating a deep saline aquifer in a mature sedimentary basin," Environmental geology 46.6-7 (2004).

[92] Metz, et al, 231

[93] *Ibid.*, 228

[94] *Ibid.,* 231

Policy Components for Addressing Risks Associated with CCS: Monitoring

Monitoring is a very important element of regulation pertaining to carbon sequestration, especially given the time span of the projects. Monitoring should take place before and during injection as well as during and after closure, with the primary goals to ensure that there is no leakage and that the integrity of the storage formation is maintained.

Baseline monitoring will include the collection of site-specific data during initial site selection. Not only will this data inform the project design, but it can be used for the duration of the project as a comparison tool. Monitoring will need to continue throughout injection, and should focus on migration of carbon dioxide within the reservoir and detection of any leakage out of the reservoir.[95] The types of tests and monitoring that will yield this information include microseismicity monitoring, annular well pressure conditions, soil gas CO_2 concentrations, reservoir pressure and temperature, injection pressure, and atmospheric CO_2 monitoring. Combined, these techniques give a well-rounded view of the status of the carbon dioxide in the subsurface, as well as provide information on well functioning and any necessary remediation.[96]

Monitoring during and after site closure is a controversial topic, with varying opinions on how to handle liability and measure performance of the project. Because the carbon dioxide is meant to be stored for thousands to millions of years and no carbon sequestration project has reached the site closure stage, the necessary monitoring to ensure continued safety of the site is still unclear.[97] Minimum requirements for such monitoring, however, can be examined. The monitoring that takes place during site closure will need to demonstrate that performance is in line with the simulation models for the project and that effective well closure techniques were used. This can be done through seismic surveys that show migration, pressure and water quality measurements above the storage formation, wellhead pressure monitoring, and well abandonment standards.[98] Post-closure assessments should continue to monitor for leaks and predicted migration, but will vary depending on the liable party and geological events that occur over the span of the project. There must also be mechanisms in place to ensure the continued public knowledge of the CCS storage site to prevent compromising the site in the future.

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[95] Pearce, et al, 3

[96] *Ibid.*, 3; S. M. Benson, et al, Monitoring protocols and life-cycle costs for geologic storage of carbon dioxide: Elsevier, 2005), 3.

[97] Pearce, et al, 4

[98] Benson, et al. Monitoring Protocols: 3.

REGULATORY ANALOGS TO CARBON SEQUESTRATION

The risks involved with geological storage of carbon dioxide have now been enumerated, as have their potential regulatory responses. Another resource for understanding how CCS will be regulated is to look at similar regulations already in place for geological sequestration. Existing policies have been dealing with many risks comparable to those of CCS for several years. Firstly, underground storage of hazardous waste has taken place for the last 60 years in the United States, with over 9 billion gallons stored in saline formations as of 2006.[99] This type of injection has been regulated since 1974 by the Underground Injection Control Program (UIC) of the Safe Drinking Water Act. The UIC is a good analog for looking at site selection and operation as well as long term monitoring and verification of CCS projects. In addition, natural gas storage provides a very similar analogy to storing CO_2 underground, particularly because of the gas's properties. Natural gas storage uses similar leak detection devices and methods, and can inform the economic criteria of sequestration sites. Finally, the disposal and storage of nuclear waste provides another useful regulatory analog, and presents some additional criteria to consider when developing the regulatory framework for carbon sequestration. The use of long-term warning mechanisms as well as the available technology for site selection is especially pertinent to CCS regulations.

Underground Injection Control – Deep Well Injection of Hazardous Waste

Deep underground injection wells for hazardous waste are classified as Class 1 Injection Wells under the Underground Injection Control Program (UIC), which is part C of the Safe Drinking Water Act (SDWA).[100] The UIC Program's purpose is to protect underground drinking water supplies from contamination from materials injected into the subsurface. Many similarities between the injection of hazardous waste and carbon dioxide should be considered. Hazardous waste must be injected below the lowermost underground source of drinking water (USDW);[101] similarly, carbon dioxide will likely need to be injected below the lowermost USDW to meet the temperature and pressure criteria of the supercritical fluid phase. Additionally, the UIC Program for hazardous waste requires that the waste must be contained for 10,000 years or become non-

[99] Metz, et al, 212
[100] Environmental Protection Agency. Electronic Code of Federal Regulations: Underground Injection Control Program Regulations (1983). 40 CFR Part 144
[101] *Ibid.* Pt. 144.80

hazardous during that time. This is analogous to the long time spans that carbon dioxide must remain underground for CCS. Their difference, however, lies primarily in their composition. Hazardous waste is usually denser than water and is therefore at a lower risk for leakage; unlike carbon dioxide, it does not "float" along the top of the reservoir.

Looking at the regulations for hazardous waste injection gives useful information about the type of policies that will need to be in place for CCS. The particularly pertinent policies are divided into several categories: site selection, well construction, monitoring and reporting, and well closure.

The regulations regarding site selection for deep injection of hazardous waste have several criteria. The proposed site must be beneath the furthermost underground source of drinking water, and in an area deemed "geologically suitable." Geologically suitable refers to structural and stratigraphic geology, hydrogeology, and seismicity that allows for confidence in determining a predictable path and fate of the injected fluids.[102] The site must have more than one confining layer, and be free of cracks or fractures that might allow for the migration of fluids. The site must also have an injection zone with appropriate permeability, porosity, volume, and thickness to prevent migration of fluids into underground sources of drinking water (USDW). Additionally, in order to have a permit approved, the operator must determine an Area of Review (AoR), or area around the injection well, that will be subject to analysis. An AoR can be determined three ways: using lateral distance from the well, using an area in which the pressure of the well might cause migration of fluids, or using an aquifer properties test (Theis equation).[103] Within this area, data must be collected to determine the safety and properties of the site, including data regarding all of the wells within the area (dry and producing), maps of all USDW's within the AoR, and maps of geological faults. A plan for repairing any improperly plugged wells within AoR must be drafted as well, to ensure that there are no leaking wells within the area at the time that injection begins.

Well construction is also regulated to ensure safety and prevent leakage. The wells must be constructed using materials expected to last the duration of the project, including post-closure; for hazardous waste this can be up to 10,000 years, although for CCS it might be considerably longer. Several factors must be determined and considered in the construction of the well to

[102] Environmental Protection Agency, UIC Regulations: 40 CFR Part 144; Benson, et al, Industrial Analogues: 84
[103] Environmental Protection Agency, UIC Regulations: 40 CFR Part 144, 146.06

ensure its long-term safety, namely injection pressure, internal pressure, and corrosiveness of injected fluid. The metal casing and cement must be able to withstand the pressure and the toxicity of the injected chemicals for the life-time of the well. Additionally, there must be an automatic alarm and shut-off system that engages in case any parameters (i.e. flow rate, injection pressure) exceed a certain value.[104] This allows for a rapid response to any potential well failure or leakage.

Monitoring and reporting take place throughout the project to ensure its operational safety; they focus on three main areas of operation: well integrity, injection and injection fluid, and ambient monitoring.[105] Monitoring of the well involves assessing the construction materials for corrosion, inspecting the casing for deterioration, monitoring the pressure in the well, and demonstrating the mechanical integrity of the well every five years.[106] Other types of monitoring ensure that an appropriate injection pressure is maintained, which is imperative for the continued integrity of the caprock as well as preventing induced seismicity; the pressure must be low enough to not cause new fractures or cracks in the caprock (this amount is likely to be site specific), and must be monitored continuously to ensure compliance. The injection stream also requires monitoring to ensure that the amount and composition are congruent with the project design. To do this, flow rate, volume, temperature of fluids, composition, and physical characteristics of waste stream must be regularly assessed and recorded. Ambient monitoring is also required and meant to observe conditions in the injection zone, confining zone, and adjacent USDW's, including pressure and composition changes in any drinking water source overlying the confining zone. Ambient monitoring is required to different degrees depending on the project and site conditions; additional monitoring to ensure that there is no movement between USDW's may be required as well.[107] All of this information must be submitted to the EPA quarterly to summarize the operation of the project. In addition, operators are also required to submit detailed descriptions of any events that trigger the well's shutdown or alarm devices or exceed the operating requirements for annulus and injection pressure.[108]

Site closure regulations are in place to ensure that the hazardous waste well is closed down in a way that minimizes risks of leakage and groundwater contamination. Prior to closure,

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[104] *Ibid.*; Benson, et al, Industrial Analogues: 87
[105] Benson, et al, Industrial Analogues: 87
[106] Environmental Protection Agency, UIC Regulations: 40 CFR Part 144.28
[107] *Ibid.*; Benson, et al, Industrial Analogues: 88
[108] *Ibid.;* Benson, et al, Industrial Analogues: 89

the operator must demonstrate the integrity of the well and flush it with a buffer liquid to make sure that any hazardous materials are contained below the lowest USDW. Then, the well must be properly plugged according to a judgment made by the EPA regarding the necessary materials and location of each well-plug at that particular site. It must prevent movement between any USDW and be tested for a seal stability.[109] In addition to sealing the well, a post-closure plan must be submitted to the EPA, detailing the current and anticipated future pressures of the storage formation. As pressures decrease, the likelihood of leakage and contamination decreases, which is why this information is pertinent.[110] Groundwater monitoring must then take place until the cone of increased pressure from the injection no longer intersects the base of a USDW.[111] At this point, it is considered at a lower risk for contamination because the injected waste can be predicted to remain immobile for long periods of time. Finally, in order to ensure that information about the hazardous waste storage site will be available for future generations (given the long time span of the storage), operators must submit notification that state and local officials have been made aware of the hazardous waste injection. This allows local officials to impose conditions on subsequent drilling activities in the area. Along these same lines, notation must be placed on the deed of the property providing information about the type and volume of hazardous waste injected, the intervals of injection, and the duration of the project.[112]

The Underground Injection Control Program provides many thorough and preventive regulations that can be applied to CCS; however, certain elements of the regulatory framework require additional caution for carbon sequestration. For instance, the UIC does not require any ambient monitoring above the confining layers of the storage formation to check for contamination of aquifers; it can only be mandated if additional wells are previously installed in the area. For hazardous waste, which is denser than water, leakage out of the top of the formation is a particularly low risk, but for carbon sequestration this would be a necessary requirement to ensure that leakage is not occurring.[113] The UIC similarly does not require monitoring to detect for contamination further from the injection site, which is also a very low risk with dense

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[109] *Ibid.;* Benson, et al, Industrial Analogues: 94
[110] Metz, et al, 232
[111] Environmental Protection Agency, UIC Regulations: 40 CFR Part 144
[112] *Ibid.*
[113] The drilling of multiple monitoring wells was ruled out for hazardous waste because of the lower risks and the high expense. Likewise, drilling multiple wells for CCS will also be costly. Benson, et al, Monitoring Protocols: 89

hazardous waste. The buoyancy of carbon dioxide, however, suggests that CCS projects would benefit from that additional monitoring as well. An element of the regulation for hazardous waste that is unlikely to be cited for carbon dioxide is the multiple confining layers. Although the failure of more than one confining caprock is significantly less likely than the failure of just one, this would inhibit available sites and might be considered prohibitively cautious. Overall, the UIC regulations for injection of hazardous waste have been effective in preventing leakage and contamination.[114] Since the current regulations have been in place (1988), no events of contamination have been reported. On the other hand, failure and malfunction of well components has occurred, but only in one instance was flow outside of the well casing.[115] This attests to the necessity of protective barriers along the outside of the well, but also illustrates the overall effective nature of UIC regulations.

Underground Storage of Natural Gas

The many similarities that natural gas storage has to carbon sequestration make it a useful analogy for regulation pertaining to geological risks. The most significant similarity between natural gas and carbon dioxide is their density; both are less dense than water and therefore face the same challenges of containment when sequestered underground. The technologies for detecting leaks are therefore also similar, which is directly useful for CCS projects. Additionally, injection techniques and pressures are directly analogous between the two types of storage, as are many accompanying risks.[116] The regulation of the two gases, however, is inherently different. Natural gas is stored temporarily in depleted oil and gas reservoirs or aquifers to help meet the seasonal demand for gas. Operators have a direct economic incentive to prevent leaks; they want gas to be readily available in times of shifting demand, and leakage could lead to financial loss. It is reasonable, then, to assume that this particular type of injection may require less oversight or regulation. Therefore, while the geological constraints prove a constructive analogy, the regulation itself may not be entirely comparable.

The Underground Injection Control regulations do not include wells used for the

[114] Benson, et al, Industrial Analogues: 92
[115] *Ibid.,* 92
[116] "CO2 Capture Project." About CCS: Storage, Monitoring and Verification. 2008. CO2 Capture Project. <http://www.co2captureproject.org/faq_storage.html>.

temporary storage of natural gas;[117] regulation, instead, falls to the states. Although this section focuses on unique aspects of natural gas storage regulations that are not covered by the UIC Program, it is worth mentioning the similarities in the monitoring and operation requirements of the two industries. Like UIC regulations, site selection involves an analysis of site geology, properties of the caprock, and characteristics of the injection zone.[118] Wells for natural gas storage must be constructed to avoid leakage, their reliability must be monitored throughout injection, and abandoned or plugged wells in the surrounding area must be inspected for integrity.[119] Additionally, the injection pressure, formation integrity, and emergency responses must be recorded and reported to the state agencies, although the frequency of reporting varies with each state.[120] Well abandonment policies are also similar to those of hazardous waste and require proof of proper plugging; however, no states require long term monitoring after the site is closed.[121]

Several methods used by the natural gas industry for leakage detection can be useful when determining regulation for CCS projects. Some methods include monitoring water chemistry levels in water sources above the caprock, installing gas detectors at the surface and near well installations, and surveying vegetation at the surface overlying the storage formation.[122] Also, to monitor and track the migration of gas, natural or man-made tracers may be used. Employing these assessments throughout the project can prevent leakage in its early stages and speed remediation efforts. For natural gas storage operators, quick remediation can prevent economic losses and ensure the safety of the project; this is imperative because of the extreme flammability and human health impacts of natural gas. Although leakage detection for CCS might not have the same impact in terms of protecting human health, immediate remediation would still prevent the addition of greenhouse gases to the atmosphere.

Beyond just detection, how does the natural gas industry remediate leaks? Generally leakage from natural gas reservoirs is related to well failure, and can be remediated by repairing

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[117] Environmental Protection Agency, UIC Regulations: 40 CFR Part 144.1

[118] California State Law was used as an example here, but similarities can be found across most state regulation of natural gas storage.
Benson, et al, Industrial Analogues: 115; California Department of Conservation. Gas Storage Projects 2007: Section 1724.9; California Department of Conservation. Approval of Underground Injection and Disposal Projects 2007: Section 1724.6

[119] Metz, et al, 211

[120] Benson, et al, Industrial Analogues: 115

[121] *Ibid.*, 111

[122] *Ibid.*, 111

faulty well components.[123] Other leaks can be caused by over-pressurization, operating at injection pressures that exceed the original assessment. Such leakage can be remediated by reducing injection pressure or relieving pressure within formation by extracting some gas. Herein lies the largest difference between natural gas storage and carbon sequestration: natural gas storage is meant to be temporary. For natural gas storage, removal of the gas is expected at some point; therefore, extracting natural gas to relieve pressure in the formation is accomplished relatively easily.[124] The remediation techniques for natural gas reservoirs could theoretically be used for carbon sequestration; however, because carbon dioxide is not stored for short-term purposes, removal of the gas to remediate a leak is not desirable, though it may in some cases be the only option. Nonetheless, very few incidents of leakage are known to occur with natural gas storage. Those that do occur are usually due to faulty well construction and the improper sealing of old, abandoned wells, which are both easily prevented.

What can the storage and regulation of natural gas add to the conversation about CCS regulation? One key element is the importance, again, of site selection and operation, particularly the sealing ability of the caprock and monitoring the injection pressure. Another relevant issue for both industries is economic practicality: any storage formation used for natural gas or carbon sequestration must have the capacity for enough gas to offset the cost of monitoring, injection, and infrastructure construction. This element of site selection will be imperative for the success of any private CCS venture. Certain elements of natural gas storage make it an imperfect comparison to CCS, primarily remediation tactics. Natural gas operations have the capacity to efficiently remove the gas from the reservoir in case of leakage. Any leakage or removal of carbon dioxide, however, detracts from the original purpose of the project – decreasing atmospheric emissions of CO_2 – and is therefore not desirable.

The fact that natural gas storage is regulated by the states provides a useful analogy for potentially decentralized CCS regulation. Decentralized authority allows states to tailor regulations to address local issues overlooked at the federal level. For example, Pennsylvania has many coal resources, and as a result monitors natural gas injection wells with a particular attention to potential invasion of neighboring coal seams. Decentralized regulation, however,

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[123] *Ibid.*, 111; Metz, et al, 211
[124] M. J. Lippmann and S. M. Benson, "Relevance of Underground Natural Gas Storage to Geological Sequestration of Carbon Dioxide," Department of Energy's Information Bridge (2003), 4.

may prove to be impractical for carbon sequestration. Saline aquifers are large and can often span multiple states. Therefore, it could become unrealistic for an operator to receive permission from all states for a CCS project in a single reservoir. States might also have different regulations, tempting operators to pick a state with the most lax policies. An important case for centralized regulation derives from the reality that leaks from a storage site are more likely to have global versus local impacts; therefore, it seems favorable to create a framework for CCS regulation that is uniform across the country.

Nuclear Waste Storage and Disposal

Nuclear waste storage and carbon sequestration have obvious differences that need to be considered before sorting out any similarities between their regulations. First of all, there is a drastic difference in toxicity. Carbon dioxide is only directly hazardous to human health in abnormally high doses. Radioactive waste is harmful in any dosage, whether cumulative small doses or lifetime exposure. In terms of site selection, the criteria and level of selectivity needed for each will vary. Carbon sequestration sites are likely to be more numerous and unlikely to go through the same level of scrutiny and detailed analysis necessary for a radioactive waste site. Finally, nuclear waste disposal requires an additional layer of engineered protection: waste is usually stored in canisters which are then placed inside of sealing materials. Carbon sequestration will not have, nor does it necessarily need, this additional protection.

Currently, there are two existing nuclear repositories in the world: the Waste Isolation Pilot Project (WIPP) in New Mexico, which opened in 1999; and the Finnish Nuclear Waste Program in Finland, which will not be analyzed for these purposes. WIPP was the first geological repository for nuclear waste in the U.S. and located in a salt cavern 40 kilometers outside of Carlsbad, New Mexico.[125] It is regulated by the EPA under the Waste Isolation Pilot Plant Land Withdrawal Act, which specifies the criteria used for building and maintaining the nuclear waste site.[126]

The systematic approach to site selection has been consistent in all of the regulatory

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[125] The fact that WIPP is located in a salt cavern makes some of the regulations irrelevant for geological storage in saline aquifers.

[126] Environmental Protection Agency. Waste Isolation Pilot Plant Land Withdrawal Act - Federal Regulations. http://www.wipp.energy.gov/Documents_Federal_Reg.htm ed. Vol. 40 CFR Part 191 and 40 CFR Part 194., 1996. 1/31/2009.

This is not the same regulation that covers the Yucca Mountain Repository, which will not be covered in this paper.

analogs discussed, and nuclear waste storage is no exception. The geology, hydrology, hydrogeology, and geochemistry of the site were all investigated to determine its safety. In this case, many of these parameters were also used to create computational modeling systems that are able to predict the performance of a site. These models were developed specifically for nuclear waste disposal, but simulate complex physical-chemical-mechanical processes that are directly relevant to carbon dioxide storage.[127]

A specific and well-designed monitoring program is in place for WIPP. Continued monitoring to ensure that there is no leakage includes: groundwater surveillance above the site (water levels, flow direction, chemical composition); geomechanical and seismic monitoring; and measurements of nearby ecosystems for signs of contamination, all conducted annually.[128] These measurements provide information as to whether the site is functioning as designed.

WIPP was built for a performance near 10,000 years, but monitoring is meant only for 50 to 150 years.[129] It is reasonable to design the repository so that long-term monitoring is not necessary, but there must be a system to ensure that future generations are aware of the hazardous waste stored at that site. For this purpose, a program of Passive Institutional Controls (PIC) has been implemented. According to the EPA, the purpose of the PICs is to "indicate the location of the repository and the dangers associated with radioactive and hazardous materials contact, thus reducing the likelihood of inadvertent human intrusion into the repository."[130] PICs can and will include permanent markers, long term records, and "awareness triggers," which include symbols on maps, a website, and other markings to increase public awareness.[131] These controls can also be useful for carbon dioxide storage to inform future generations and governments of the storage site locations, specifically to caution against drilling in the area.

Admittedly, there is very limited data and experience with nuclear waste storage; one pilot project is hardly enough to use as a precedent. However, even the limited experience of geologically storing nuclear waste has contributed to the pool of knowledge that is useful for storage of carbon dioxide. The computational modeling of natural and human-induced processes

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[127] Benson, et al, Industrial Analogues: 134
[128] WIPP Regulations: 40 CFR Part 191 and 40 CFR Part 194
[129] WIPP Regulations: 40 CFR Part 191 and 40 CFR Part 194; Benson, et al, Industrial Analogues: 132
[130] U.S. Department of Energy, Passive Institutional Controls Implementation Plan: Waste Isolation Pilot Plant (Carlsbad Field Office: 2004).
[131] *Ibid.*

for predicting the long-term performance of a site is particularly important for carbon sequestration.[132] The monitoring used for nuclear waste storage is also relevant, particularly the required testing of groundwater above the storage facility, and periodic inspections of surrounding ecosystems to check for impacts. The use of long-term institutional controls to alert future generations of the hazards of the storage site is also imperative for carbon sequestration, although the implications of installing PIC's for one site versus several might become problematic. Because both projects are designed for long lifetimes, having ways to inform unknowing populations about the site is crucial to maintaining its integrity as well as protecting environmental and human health.

The experience of hazardous waste injection, natural gas storage, and nuclear waste storage all provide useful regulatory analogs for carbon sequestration. Stringent regulations for these operations have largely prevented leakage and minimized risks. However, it is also imperative to note the short time scales of these engineered sequestration projects, which have only been in existence for a few decades. The security of CCS storage sites will need to maintained for centuries, a time scale for which there are no comparable existing projects. Although it is important to keep this difference in mind, these existing regulations can still inform aspects of CCS regulation.

UIC regulations for hazardous wastes are most helpful for informing potential site selection for CCS, particularly the stringent criteria for geological suitability and the delineation of an Area of Review for evaluating abandoned wells. This analog also illuminates the need for well construction and abandonment standards, since this is the most probable pathway for leakage. Additionally, UIC regulations demonstrate the need to monitor for contamination further from the site and in nearby groundwater sources, an unnecessary precaution for hazardous waste, but relevant for carbon dioxide. Natural gas storage was a useful analog for the economic factors involved in site selection, namely that the capacity must be worth the costs endured for the infrastructure and injection of the carbon dioxide. It provided a helpful background in using leakage detection technologies, which will be critical for CCS sites. It was also a useful illustration of state versus federal regulation, although the benefits of state-specific rules are not necessarily advantageous for carbon sequestration. Finally, nuclear waste storage

[132] Benson, et al, Industrial Analogues: 134

provides useful computational models for simulating long-term storage as well as a framework for alerting future generations to the presence of the site and its accompanying hazards. These analogies for carbon sequestration will inform the upcoming discussion about the regulations proposed by the EPA for geological carbon sequestration.

Table 1: Summary of Regulatory Analogs for Geological Risk

Regulatory Analog	Injection Similarities	Injection Differences	Lessons to Apply to CCS	Additional Regulations Needed for CCS
UIC – Deep Well Injection of Hazardous Waste	• Requires deep injection to protect underground sources of drinking water • Requires storage for long periods of time – 10,000 years or until non-hazardous	• Hazardous waste is denser than water, unlike CO_2	• Stringent site selection criteria: site must be "geological suitability," caprock must be intact, operator must delineate Area of Review, abandoned wells in AoR must be plugged • Well construction standards: requires automatic shut-offs and durable construction materials • Well integrity is monitored during project • Migration of fluids is monitored • Must maintain a low injection pressure to prevent fractures • Closure procedures: must ensure well integrity, inject buffer fluid into well, properly plug well, and monitor groundwater post-injection • Operator must notify state authorities of closure for long-term knowledge	• UIC doesn't require ambient monitoring - either above confining layer to check for groundwater contamination or further from site
Underground Natural Gas Injection	• Density of liquids: gas and CO_2 are less dense than water • Technologies for detecting leaks can be used for both	• Natural gas is stored only temporarily – it is meant for removal • Economic incentives exist to keep gas contained • Natural gas storage is regulated by states • Natural gas is flammable and poses larger human safety implications	• Stringent site selection – similar to UIC • Well construction standards – similar to UIC • Must monitor injection pressure • Closure procedures require proof of proper well plugging • Leakage detection methods used: monitoring of water chemistry levels above caprock, gas detectors near surface, tracers in gas	• Removal of CO_2 is not a preferable remediation option, so other methods are needed • Decentralization may be a poor regulatory choice for CCS due to conflicting or ambiguous regulations
Nuclear Waste Storage	• Long-term (indefinite) storage	• Nuclear waste is cumulative and toxic • Carbon sequestration sites will be more numerous • Additional engineered protection is used for nuclear waste in the form of canisters or sealing materials	• Site selection: includes geology, hydrogeology, hydrology, and geochemistry • Computational modeling systems of physical-chemical-mechanical processes used to predict site performance • Baseline measurements used for later performance evaluation • Monitoring: groundwater surveillance, seismic monitoring, measurements of nearby ecosystems • Passive Institutional Controls used to indicate location and dangers of site for the long-term	• Nuclear waste storage requires more stringent regulations than those that will be needed for CCS

EPA PROPOSED RULE FOR CARBON SEQUESTRATION

The Environmental Protection Agency released a proposed rule on the regulation of carbon sequestration in June 2008. It is a proposed rule and is therefore not yet in effect, but reflects the initial thinking of the federal agencies about how to regulate CCS.[133] The Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geological Sequestration Wells Proposed Rule covers the requirements under the Safe Drinking Water Act that would be applied to carbon sequestration. It proposes a new Class VI well[134] and minimum criteria for "geological site characterization, fluid movement, Area of Review and corrective action, well construction, operation, mechanical integrity testing, monitoring, well plugging, post-injection site care, and site closure for the purposes of protecting underground sources of drinking water."[135] It must be emphasized that this regulation is predominantly "*for the purposes of protecting underground sources of drinking water*." Because the UIC is a part of the Safe Drinking Water Act (SDWA), its mandate is to protect water sources, not anything beyond that. Therefore, as it will become clear, the proposed rule is limited in how it can regulate carbon sequestration, and additional regulations may be necessary.

How does the EPA choose to regulate carbon sequestration in this proposed rule, and how is it similar or dissimilar to the analogs discussed previously? By looking at the EPA's requirements of CCS projects, this section will evaluate whether all necessary components are present in the rule in order to minimize the risks to the environment and human health.[136]

Site selection is the first element of EPA's proposed rule. These requirements are similar to the UIC requirements for hazardous waste injection and, although they are tailored slightly to fit carbon sequestration projects, they will only be covered briefly. Before it can be characterized further, a site's region must be evaluated for seismic activity, including the seismic history and the potential for injection induced seismicity. According to the EPA, a storage site must also

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[133] The public comment period for the proposed rule ended on December 24, 2008 and the rule is now being reviewed by the EPA for changes according to the public comments.
[134] As a reminder, hazardous waste injection wells are Class I and CCS pilot projects are Class V. The new class designated for these commercial scale CCS projects is Class VI.
[135] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43492
[136] Because the proposed rule is a part of the Underground Injection Control Program, it builds off of the existing framework, much of which was discussed in the section on hazardous waste. The regulations that are redundant will be touched upon, but not elaborated upon in detail.

have a suitable geologic system,[137] be located below the lowermost underground source of drinking water (USDW), and include a confining zone free of faults or fractures. Additionally, the storage formation must be sufficiently porous to receive the total volume of anticipated injected CO_2, a measurement that can be used by the operator to estimate the economic viability of the site as well. The site must also be large enough to allow fluid movement within the injection zone without displacing brines. To demonstrate the existence of all of these characteristics, operators would need to submit data about the following: lateral extent, thickness, and strength of the caprock; site capacity and porosity; local seismicity; and permeability of the subsurface. An element that was not covered in the hazardous waste injection regulation was geochemistry; for carbon sequestration projects, geochemical data must be submitted on the injection zone, confining zone, and any nearby USDW's to identify potential chemical or mineralogical reactions that could compromise the formation's integrity.[138] This data will also serve as a useful baseline measurement for monitoring geochemical changes as a result of CO_2 storage over time.

Beyond classifying the underground aspects of the site, site selection will include an Area of Review: the vertical and horizontal extent of the area that might be affected or influenced by injection and storage activities.[139] Within this area, all penetrations into the injection or confining zone must be identified and their mechanical integrity evaluated. Any wells or penetrations that pose a leakage potential must then be plugged or repaired.[140] The proposed rule does not specify the type of corrective action necessary, or the construction materials that must be used for plugging abandoned wells, but rather assumes that the industry standards will be the latest available technology. The Area of Review (AoR), unlike Class I wells for hazardous waste, will be determined by computational fluid flow models completed by the operator, which are based on site characteristics and injection regime.[141] The AoR will also require periodic review during operation to ensure that the carbon dioxide in the subsurface is behaving as predicted and that the delineated area is still an accurate prediction of CO_2 movement.

[137] As defined during the discussion on the UIC hazardous injection well, Geologically suitable refers to structural and stratigraphic geology, hydrogeology, and seismicity that allows for confidence in determining a predictable path and fate of the injected fluids

[138] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43505

[139] *Ibid.*, 43499

[140] Repairing the wells can take place before or after injection begins, depending on their distance to the well and the projected course of the carbon dioxide in the subsurface.

[141] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43506

Construction and operation standards are also set by the EPA's proposed rule, although again, many are similar to UIC controls for hazardous waste. For well construction, materials must be used that meet or exceed industry standards; any materials must also be compatible with carbon dioxide (i.e. corrosion-resistant cement) and meant to last for the life span of the well. The operator must be able to verify the integrity of the cement using logs or other testing devices to ensure that corrosion is not taking place. Wells must also be fitted with automatic shut off valves, down-hole and at the surface. A down-hole automatic shut-off device would isolate the injectate below the lowest USDW instead of at the surface, in case of well failure. Injection pressure limits set for the pumping of the CO_2 will also protect the integrity of the well and the storage formation. During operation, injection pressure must not exceed 90% of the fracture pressure, the amount of pressure needed to initiate or propagate fractures in the injection or confining zone.[142] The EPA does not, however, set a minimum injection depth, which means that legally, carbon dioxide could be stored as a gas. If CO_2 is injected as a supercritical fluid and it changes to a gas, the phase change would result in drastic temperature changes in the vicinity of the well that could compromise its structural integrity. There is potential that the CO_2 could freeze or even contribute to well blow-outs, although this issue requires more research.[143] Regardless, this regulation choice may create extra risks of leakage or well failure.

When filing for a permit from the EPA for a carbon sequestration project, operators must submit a complete testing and monitoring plan designed to detect changes in groundwater quality, as well as track the migration of the CO_2 plume and area of elevated pressures.[144] This plan details the tests that will be executed throughout the operation of the project and post-closure. Operators must continually monitor injection pressure, rate of injection, volume of total injectate, and annular pressure, reporting these semiannually to the EPA. These parameters indicate the overall performance of the site. Additionally, mechanical integrity tests must be performed for the interior and exterior of the well to demonstrate that there is no corrosion on the inside of the well and no flow along the outside of the casing. These assessments must be reported to the EPA semiannually as well. In order to monitor the movement of the plume, operators would be required to track the extent of pressure changes (using gauges in the zone

[142] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43510
[143] Environmental Protection Agency, Meeting Notes of EPA Workshop on Well Construction and MIT. "EPA Technical Workshop on Geosequestration: Well Construction and Mechanical Integrity Testing" 2007.
[144] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43514

overlying the caprock), as well as groundwater quality and geochemical changes in aquifers above the caprock.[145] At the EPA Regional Administrator's discretion, other tests can be required, such as geochemical monitoring for heavy metal contaminants, surface air monitoring, or soil gas monitoring. These additional monitoring technologies, however, are not blanket requirements for all projects.

For site closure, a number of requirements are in place to ensure that the project is performing as designed. In the process of plugging a well, it must first be flushed with a buffer fluid. Then, its mechanical integrity must be tested before plugging the well to prevent any movement of fluid that might endanger an USDW. After closure, more monitoring is required to ensure the safety of the site; to determine the length of post-closure care, the EPA is utilizing a performance and time based approach. In other words, operators are responsible for monitoring the site for 50 years after injection ceases, but the Regional Administrator has the discretion to extend or shorten that length of time depending on the performance of the site. During this time, the operator must submit periodic reports on the monitoring results for the project until a demonstration of "non-endangerment" can be made.[146] A site can demonstrate non-endangerment by providing evidence that the movement of the CO_2 is consistent with the predicted models, or that the pressure within the storage formation is not likely to endanger any USDW's.[147] The tests that will be required to demonstrate this will differ with each project and will be decided when submitting the post-closure plan.

One element of the proposed rule that might pose a danger to the integrity of the site is aquifer exemption. In the proposed rule, the EPA suggests that the regional administrator would have the discretion to exempt aquifers, which means that they would no longer be protected under the SDWA. This would be pertinent if a CCS storage site was proposed above an existing source of drinking water. That source of drinking water could be exempted from the SDWA if there was "no reasonable expectation that the exempted aquifer will be used as a drinking water supply."[148] One concern with this exemption would be the long-term ramifications of placing a CCS storage site above an aquifer that might be used in the future. Using that aquifer within the several thousands to millions of years following the CCS project could endanger the storage of

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[145] *Ibid.*, 43515

[146] The proposed rule specifies only the "periodic" reporting required after site closure and asks for public comment on this detail.

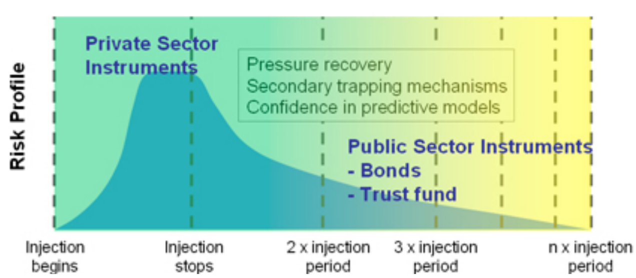
[147] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43520

[148] *Ibid.*, 43512

CO_2 by providing pathways for leakage via wells drilled into the drinking water supply. Although this would be an exemption that would need to be sought for each individual project, this may pose a concern if over-utilized or misused.

How does the proposed EPA rule address the geological concerns and risks of carbon sequestration, and does it incorporate (or not incorporate) the regulatory analogs previously discussed? Given the current level of knowledge about this technology, the proposed regulations seem to address many geological risks thoroughly. The level of safety demonstrated by most UIC Class 1 Wells shows that the stringent regulations imposed on hazardous waste injection are effective at minimizing leakage, and many of these regulations are used for Class VI wells for carbon sequestration.[149] The thorough site selection criteria and abandoned well procedures are likely to prevent leakage from the storage reservoir, as are the injection pressure standards. Additionally, setting a maximum injection pressure reduces the risks of induced seismicity. The proposed rule also contains elements from natural gas storage and even nuclear waste that are not included in the regulations for hazardous waste wells, including groundwater monitoring above the confining zone. This regulation will be helpful to detect any leakage early, and speed any necessary remediation. Geochemical monitoring will also provide a better illustration of what is happening in the subsurface. By taking a baseline measurement of geochemical parameters in the injection and confining zone, as well as any USDW's, changes induced by the carbon dioxide can be tracked. Other safety measures required by the EPA that will minimize risks are the down-hole automatic shut-off valves that must be installed in wells. Should well failure occur, these would isolate the carbon dioxide below the lowest source of drinking water, reducing the chances of contamination.

Figure 5 – Conceptual Risk Profile for Carbon Sequestration
Benson, S.M., "Conceptual Risk Profile for Sequestration."
< http://www.wri.org/chart/conceptual-risk-profile-sequestration>.



Post-closure monitoring also seems preventative and appropriate, but could use some additional definition. If the 50 year post-closure care time span had been based only on the

[149] Again, the time frame of experience for UIC wells is limited, and should be considered in the discussion; however, with existing knowledge and background, it is a sufficient demonstration of initial success.

length of time, it might have been impractical to assume that all storage sites would be deemed "safe" by then. The inclusion of a performance-based standard to measure the declining pressure and predict the behavior accounts for variability of different projects and ensures that a certain level of safety is attained before the operator can stop monitoring the site. However, a firm definition for what is considered "adequate and safe performance" is necessary. A performance-based standard that is not adequately defined could change unreasonably with political tides. Assuming the performance standard is strictly defined and is used as the ultimate decision maker, then the post-closure monitoring plan would likely minimize risks. Most estimates of risk suggest that when the site is twice as old as the injection period, the risks are low enough that monitoring can cease or be turned over to the government.[150] (See Figure 5) In summary, many of the regulations proposed by the EPA take into account the special circumstances and risks of carbon sequestration and provide a preventative framework for construction and operation of projects.

On the other hand, certain elements of the proposed rule could be more preventative, and a number of elements have not been included at all. One example is allowing CO_2 to be injected as a gas. The phase changes that would take place when the injected supercritical fluid became a gas could affect the integrity of the well by exposing it to extremely cold temperatures. The proposed rule cites its own workshop findings which suggest that "these phase changes are potentially a greater mechanical integrity concern than corrosivity."[151] It seems then, that preventative measures should be taken by prohibiting the injection of carbon dioxide at depths where phase changes are possible. One risk that is not addressed in the proposed rule is the contamination of the injection stream, and standards for purity. If the injection stream is contaminated with a compound like SO_2, then the standards for pure carbon dioxide may not be effective, especially when it comes to well construction and corrosivity. This particular oversight reflects lack of knowledge, and might require additional research before an adequate policy can address its risks. Remediation standards are also missing any thorough mention throughout the proposed rule. This is likely due to the lack of knowledge about remediation techniques for leakage of CO_2. Certainly, before any projects are deployed, some knowledge of potential remediation methods must be attained through research or performed through pilot project

[150] Elizabeth Wilson, et al, "Liability and Financial Responsibility Frameworks for Carbon Capture and Sequestration," World Resources Institute Issue Brief Carbon Capture and Sequestration. 1 (2007) .
[151] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43512

simulations; mention must be made of such available technologies in the regulatory framework. Finally, institutional controls as seen with nuclear storage are not addressed in the proposed rule, yet the necessity to inform future generations of storage sites is imperative.

It is worth noting that this proposed rule came out before a federal climate mitigation strategy and, therefore, probably well in advance of the first CCS permit. It is understandable then that key missing pieces from research are also missing from the proposed rule (i.e. injection stream purity and remediation techniques). One feature that is included in the rule that addresses these oversights and exclusions is flexibility. The Rule accounts for advances made by new research by not specifying the materials necessary for well construction but rather deferring to up-to-date industry standards. These allowances are also made in giving the EPA Regional Administrator discretion to require more or less monitoring tests for any sequestration project. Admittedly, once the regulations reach the implementation stage, flexibility within the framework can simply become ambiguity that is difficult to enforce. Only if EPA maintains an active role in updating the regulations will the "flexibility" mechanisms be a constructive element of the framework.

A separate question arises of whether it is safe and preventative to allow the construction of carbon sequestration projects when key unknowns are not yet included in the regulatory framework. To be truly preventative, the EPA should acquire certain answers (particularly those regarding remediation, leakage detection, and injection stream impurities) before allowing industry to move forward with projects. However, many answers cannot be attained before at least one commercial scale project is in operation.[152] Assuming that the government is moving forward with deploying CCS, then at least a few commercial scale projects must be constructed to get important answers necessary for wide-scale deployment. However, there will inevitably be a delay between the technical findings of the project and when they are translated into policy, and this time period may potentially allow for the construction of plants that are insufficiently regulated. This is a risk that must be evaluated given the necessity of commercial projects for determining proper regulation.

It can be argued that the EPA Proposed Rule adequately addresses geological risks, but additional regulatory components are necessary for CCS projects: namely components of liability and financial responsibility. These are aspects of carbon sequestration projects that

[152] International Risk Governance Council, 19.

might be considered social responsibility: the mechanisms that can be used by private parties and even the government to hold industry responsible if a project malfunctions. The liability and financial components must be investigated to determine how they can minimize risk and maximize human and environmental safety with carbon sequestration.

SOCIAL RESPONSIBILITY OF CARBON SEQUESTRATION REGULATIONS: LIABILITY AND FINANCIAL MECHANISMS

Ideally, proper regulation would minimize risks from CCS, but it is always a possibility that unforeseeable accidents could affect human health, the environment, drinking water supplies, or climate change. Under these circumstances it is important to understand who would be responsible for the accident, and where the funds for remediation would come from. These two concerns are essentially those of liability and financial mechanisms.

There are two major categories of liability and financial mechanism concerns: who is responsible during the operation of the project, and who is responsible after site closure. The former can be addressed using legal tools governed at a state level (although federal level regulation is possible and will be covered). However, post-closure liability and financial responsibility has been the source of much debate, and requires a more detailed analysis of the duration and extent of both liability and financial responsibility.

Liability during Operation

Although legal and financial liability during the operation of a CCS project is not extensively debated, it is worth addressing how operators can be held accountable for malfunctions or accidents. Liability during injection can be over a number of hazards already discussed: groundwater contamination, carbon dioxide leakage into the atmosphere, human health effects of carbon dioxide, or damage incurred by induced seismicity.[153] Established legal structures would likely hold the operator accountable for any of these accidents that occur during injection. These legal tools are outside the regulatory framework and are available for private claims, meaning that individuals negatively affected by the long-term storage of carbon dioxide can pursue damages from the company to compensate their loss or inconvenience.

Nuisance is a legal tool used frequently in environmental law and is based on the idea that any one person or entity cannot "unreasonably interfere with public rights or a private

[153] Elizabeth Wilson, et al, Liability and Financial Responsibility: 3
Other liability concerns for companies would involve siting and geophysical surface or subsurface trespassing; however, those are not going to be addressed here, as they have nearly identical analogs to the natural gas and oil operations, which use unitization to address that issue. These will be addressed later in the paper.

party's interest in land."[154] It has commonly been used to make commercial or industrial operations cease or pay for causing air, water, or soil pollution.[155] It is predominantly used when the infringement on public and personal use of land is intentional and unreasonable, or unintentional and reckless. In the context of carbon sequestration, leakage that resulted in harm to human health, groundwater, soil, surface water, mineral resources or property could be cause for an injunction requiring remediation and monetary damages. This could occur even if the facility had complied with all of the regulations imposed by the EPA.

Another legal tool that can be used by private parties affected by carbon sequestration is strict liability. Strict liability is unique because it requires no declaration of fault. Instead, it is based on the principle that when someone engages in an activity for profit that causes harm, they are liable because they are in the best position to bear the loss. This is particularly effective for public health and environment cases where the defendant has engaged in a "non-natural," "abnormal," or "abnormally dangerous" use of the land.[156] The courts will ultimately determine whether CCS is subject to strict liability, but the ruling can differ in different regions. For example, in Texas where carbon dioxide injection is used commonly for enhanced oil recovery, geological carbon storage may not be seen as an "abnormal" use of the land; its widespread use essentially makes it "normal."[157] In addition to local decisions of strict liability, however, the federal government has the ability to impose strict liability in its regulatory framework. Certainly, if CCS projects were subject to strict liability, it would be a powerful incentive for operators to err on the side of caution and minimize the potential for risks and accidents.

Negligence is another legal theory that could be used for damage caused by carbon storage or leakage. Negligence, the failure of a person to exercise reasonable care, is used in most modern accident law. Firms conducting carbon storage activities must "exercise the skill and knowledge normally possessed by members of the profession; otherwise they may be found

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[154] Alexandra B. Klass and Elizabeth Wilson, "Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long-Term Storage of Carbon Dioxide," Emory Law Journal 58 (2008): 21.
[155] Klass and Wilson, 21
[156] *Ibid.*, 23
These definitions for when strict liability apply can be found in the case *Rylands vs. Fletcher* or in the Restatement (Second) of Torts.
[157] Klass and Wilson, 24

negligent."[158] Negligence can be harder to prove and requires evidence of a breach in "reasonable care" that directly caused harm to the claimant; however, if overall industry standards are low then this legal tool is relatively ineffective.

All of these methods for addressing liability during the operation of a CCS project are legal frameworks that already exist and are largely unrelated to policy. They have the potential to apply to CCS projects as long as there is no federal legislation barring such claims under the CCS regulatory framework. However, including these liability rules within the regulatory framework may provide additional benefits. These benefits, including easier enforcement of liability, will be discussed later in this section.

Liability and Financial Responsibility Post-Closure

A geological sequestration site is meant to store carbon dioxide away from the atmosphere permanently or at least on a scale of thousands to millions of years. However, a post-closure site care period of 50 years (plus performance standards) was discussed in the previous section. There is an enormous gap between the amount of time that the operator is directly responsible for monitoring the site and the lifespan of the project, during which time some monitoring or even remediation may need to take place. Who is responsible for the site at that time? And who pays for the remediation or necessary monitoring? Post-closure liability is the largest concern for CCS, and the most controversial. Unlike accidents that occur during operation, it is harder to assign liability post-closure. Additionally, because the life of the project is so long, the initial operator may not be around, in which case the government must be able to address the leak or malfunction. In fact, it is widely acknowledged that the government must take over the responsibility of carbon sequestration projects at some point, as they are the only body likely to "live" long enough to ensure continual and quality monitoring.[159] Therefore, there needs to be: 1) a defined point where the government assumes liability, and 2) a method for ensuring adequate financial coverage of the costs of monitoring and potentially remediating. This discussion will focus on methods of addressing these issues of post-closure liability and financial mechanisms.

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[158] Mark A. De Figueiredo, "Framing the Long-Term In Situ Liability Issue for Geologic Carbon Storage in the United States," Mitigation and Adaptation Strategies for Global Change 10. 4 (2005), 3; Wilson, et al, Liability and Financial Responsibility: 12
This definition can be found in the Restatement (Second) of Torts.
[159] Hiranya, et al, 24.

What should the liability and the financial structures look like within the regulation for carbon sequestration? First of all, liability, from this point on, is nearly inseparable from financial responsibility; this is because post-closure responsibility for a site, in most cases, means financial accountability for the costs incurred in monitoring, remediation, or lawsuits. Several minimum requirements for liability and financial responsibility have been proposed by scholars and think tanks, most of which build on two fundamental principles: appropriate incentives to ensure proper long-term design and construction of a project, and a method for collecting the necessary funds for monitoring and (potentially) remediating post-closure. Some basic building blocks for the regulation include:

- A defined point at which federal institutions take over active care of CCS sites. The timeline for existence of a project far exceeds the reasonably expected life of a private enterprise.[160]
- The ability of private parties to take legal action, pursuing monetary relief or punitive action from companies that operate CCS; this ability for non-federal parties to pursue relief complements federal or state government action, and provides added incentive for operators to ensure safety. In the past, private parties have been "critical to ensuring enforcement to environmental laws."[161]
- Financial liability that comes from within the industry; this ensures that taxpayers are not responsible for the expensive remediation in the case that an operator failed to properly manage a project.[162]
- A financial responsibility framework that ensures that funds are adequate and accessible, if and when they are needed.[163]
- Minimum standards for financial institutions that are insuring the funds and continuity of financial responsibility in case of site ownership transfer.[164]

If the federal government chooses to actively promote the use of carbon capture and storage, additional criteria can be added to the list to ensure that the liability and financial responsibility requirements do not hinder deployment. The costs and benefits of these

[160] Klass and Wilson, 34
[161] *Ibid.*, 14
[162] International Risk Governance Council, 23
[163] Wilson, et al, Liability and Financial Responsibility: 8
[164] Wilson, et al, Liability and Financial Responsibility: 8

approaches will be evaluated later, but they primarily revolve around indefinite liability, which is liability for the entire life of the project. Several arguments are in favor of limited liability: operators should be liable for a certain amount of time after site closure to ensure the safety of their project, but not an indefinite time period, which would be a burden on deployment of the technology.[165] If active promotion of the technology were pursued, then indefinite liability for a project should be called into question. However, if a "free market" approach is taken for CCS, and government does not *actively* promote the deployment of CCS, then this is not a concern.

Because this particular issue is so contentious, even these basic foundations of the liability and financial responsibility regime can be called into question. For that reason, it is helpful to again turn to regulatory analogs that address this issue, and analyze the approaches that have or have not worked for similar technologies.

REGULATORY ANALOGS FOR LIABILITY AND FINANCIAL MECHANISMS

As was shown in the previous section, regulations already in existence are similar to the type of regulation that will be necessary for CCS. Some analogs, like long-term storage of hazardous and nuclear waste, consider liability and financial mechanisms within their framework. Looking more closely at these analogies may provide useful examples for how to address the issue of liability within the carbon sequestration regulatory framework.

The Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act (RCRA) was passed in 1976 as a way for the EPA to regulate the improper disposal of hazardous wastes. It is meant to be a "cradle to grave" regulatory system for "generation, transportation, treatment, storage, and disposal of hazardous waste."[166] RCRA implements the regulation of all hazardous waste disposal except injection, which is regulated by the Underground Injection Control Program. The RCRA financial mechanisms serve as the model for those used by the UIC Program.

RCRA is significant in this discussion because it contains some of the most comprehensive requirements for financial liability that exist in federal regulation.[167] The purpose

[165] United States Government Accountability Office (Carbon Capture and Storage Report), 39; Hiranya, et al, 24
[166] Environmental Protection Agency. RCRA | Laws, Regulations, Guidance & Dockets | US EPA 1976. 42 U.S.C. §6901 et seq.
[167] Wilson, et al, Liability and Financial Responsibility: 6

of the RCRA financial mechanism is to ensure funds for closure and post-closure care in case of company dissolution, bankruptcy or site abandonment. It protects both the government and the public from having to incur potential remediation costs because financial responsibility must be demonstrated at the time of permit issuance and through post-closure site care. These funds must be provided by one or more financial mechanisms;[168] companies subject to RCRA can use mechanisms from two categories: third party instruments or self insurance instruments.[169]

Third party instruments can be trust funds, surety bonds, letters of credit, or insurance.[170] The first three forms of financial mechanisms are essentially bonds and require the agreed-upon amount to be posted up-front. Although bonds effectively place the burden of proof onto the operator, they are also limiting; because of the lag time between posting the bond and the potential harm, it is harder to guarantee that the firm will still be responsible for the bond. Surety providers may not be willing to underwrite bonds with that level of uncertainty.[171] Additionally, the cost of the bond can also be contentious. The RCRA financial responsibility framework assumes that all costs are estimable, whether on-going or a one-time payment.[172] However, because of the present uncertainty in remediation methods and costs for CCS, this information is currently unavailable for CO_2 sequestration projects. Insurance is another third party instrument used by RCRA. Environmental impairment liability, the type of insurance used for RCRA, has had experience with most of the hazards associated with CCS (except for the climate-related risks) and is evaluated on a site-by-site basis for risk potential. Therefore, it might make a flexible and adequate choice for ensuring financial responsibility for CCS; however, it may not be reasonable to expect insurance to cover the site for its anticipated lifetime.[173] Self-insurance instruments are usually corporate financial tests or corporate guarantees. These mechanisms are not guaranteed by any third party, but are based on the firm's financial competence. The long lifetime for CCS projects makes these financial mechanisms impractical.

As discussed earlier, the ability of private parties to seek injunction or monetary relief from an industry or corporation in case of harm could be a powerful incentive to minimize risks

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[168] Theodore L. Garrett and American Bar Association Section of Environment, Energy, and Resources, The RCRA Practice Manual American Bar Association, 2004., 509.
[169] Wilson, et al, Liability and Financial Responsibility: 6
[170] Garrett and American Bar Association Section of Environment, Energy, and Resources, 509
[171] Klass and Wilson, 36
[172] Environmental Protection Agency, RCRA: 42 U.S.C. §6901
[173] Klass and Wilson, 40

beyond the federal regulatory framework. RCRA is unique in that it does allow non-federal parties to take action without the involvement of the government. Specifically, Section 7002 under RCRA allows private parties, if they can prove that there is a reasonable prospect of potentially serious harm, to pursue injunctive relief to compel remediation of a hazardous waste that presents endangerment to human health or the environment.[174] This framework has allowed parties to seek damages even if the "harm" took place decades after the initial disposal; under RCRA, liability remains with the operating party indefinitely.[175] It is the present nature of harm that is important in this case, not the recent nature of the operation. This model could prove especially useful for CCS projects where humans or the environment could suffer damages years after injection ceased.[176]

Although RCRA is acclaimed as having one of the most thorough financial assurance mechanisms, not all elements of the framework are directly relevant to CCS, and not all of them have been shown to work as planned. As mentioned, RCRA assumes that the risks and costs necessary to determine financial responsibility are estimable and manageable. It is necessary then, that remediation and monitoring costs are more clearly established for carbon sequestration before a detailed framework and estimate of the costs can be generated. Additionally, under RCRA, companies must only demonstrate financial responsibility within the time period of post-closure care. After that point, if remediation or monitoring is necessary, there is no assurance of funds; the company is still liable indefinitely, but it no longer has to prove the ability to pay. Rather, the EPA depends on the fact that the firm still exists and is able to pay. This time limit on financial responsibility would pose a problem for CCS projects that encounter remediation or monitoring needs after the 50 year post-closure period. For that reason, the regulation of geological sequestration must provide for the availability of funds even after the post-closure period.

Lately, RCRA has also faced scrutiny from government agencies for certain inadequacies of the regulation. Firstly, RCRA has been criticized for its inflexibility in rapidly changing markets. For example, the regulations do not account for advances in accounting and reporting

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[174] Environmental Protection Agency, RCRA: 42 U.S.C. §6901
[175] *Ibid.*
[176] Klass and Wilson, 18

standards, which have evolved substantially since RCRA's initial development.[177] Secondly, a recent United States General Accounting Office report noted concerns over the inadequate resources available to the EPA should a firm declare bankruptcy or abandon a site.[178] In response, the EPA acknowledged that there is "insufficient assurance that funds will be available [when needed]," and admitted that the risk associated with financial assurance may be higher than initially estimated.[179] Therefore, while these financial mechanisms are an adequate baseline to use for forming CCS regulation, the importance of flexibility and collecting adequate funds must be stressed to ensure the operability of the framework.

Underground Injection Control

Because the financial responsibility framework of the Underground Injection Control Program is so similar to RCRA, this discussion will focus on its liability framework. As previously discussed, once a UIC site is closed, the operator is responsible for monitoring until the safety and performance of the well is demonstrated. Yet even after a performance evaluation when the well is deemed to pose no hazard to nearby USDW's, operators are still liable. In fact, operators of injected hazardous waste wells are indefinitely liable in case the hazardous waste contaminates an underground source of drinking water. Operators are, therefore, susceptible to litigation, fines, and possible bankruptcy in perpetuity if their site does not perform as planned.[180] Once the performance criteria have been reached, however, operators are no longer responsible for demonstrating financial responsibility for accident remediation.

The financial mechanisms of the UIC mimic the RCRA framework, and, therefore, pose the same issues. The UIC's financial responsibility framework, however, is more ambiguous than RCRA. It does not provide as much detail about the types of financial mechanisms available, and is thereby slightly less effective. The GAO report noted that the UIC is particularly likely to lack adequate funds in case a firm ceases or abandons operations.

The EPA's proposed rule for carbon sequestration relies heavily on the Underground

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[177] Wilson, et al, Liability and Financial Responsibility: 6

[178] The GAO Report was specifically targeting UIC regulations for financial assurance. The UIC financial responsibility framework is less specific about the mechanisms that can be used and therefore less effective. The specificity of financial mechanisms, therefore, contributes to RCRA's marginally better success.

[179] Environmental Protection Agency, RCRA Financial Assurance for Closure and Post-Closure, 2003., ii.; United States Government Accountability Office, ENVIRONMENTAL LIABILITIES: EPA Should Do More to Ensure That Liable Parties Meet Their Cleanup Obligations (Washington, DC:.)

[180] Environmental Protection Agency, UIC Regulations: 40 CFR Part 144

Injection Control Program's liability and financial mechanisms, and therefore, as will become evident, has many similar shortcomings.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA, better known as Superfund, was created in 1980 to provide a cost-recovery vehicle for the federal government to address problems related to improperly disposed hazardous waste. It imposes taxes on the chemical and petroleum industries, the revenues of which are diverted to a Superfund Trust Fund for cleaning up abandoned or uncontrolled hazardous waste sites. Congress provided that the fund could be tapped when the original polluters of sites could not be identified, had gone into bankruptcy, or refused to pay for cleanup.[181] When current owners or responsible parties are identified (and still in existence), CERCLA holds them financially responsible for the clean-up of the site. In these cases where operators are held liable, they must demonstrate evidence of financial responsibility for the clean-up and remediation of the site.[182] Additionally, CERCLA has the ability to mandate advance proof of financial responsibility from certain operators of hazardous waste facilities; however, this element of the regulation has never been promulgated.[183] In 1995, the chemical and petroleum industry taxes that funded Superfund were not renewed, and in 2003 the trust fund ran out of money.[184] Although this section will look at Superfund before the tax cuts, this current situation illustrates the importance of changing political motives, and how they might affect the financial stability of CCS remediation. This should be considered when choosing a financial mechanism.

For this discussion, CERCLA has two pertinent financial elements: the financial responsibility requirements for existing hazardous waste facilities and the retroactive fund to pay for hazardous waste clean-ups. Both will be analyzed for their usefulness to CCS projects.

CERCLA includes a provision in which companies that handle[185] hazardous materials

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[181] Environmental Protection Agency. United States Code: Comprehensive Environmental Response, Compensation, And Liability., Title 42, Chapter 103: (1980).
[182] Environmental Protection Agency. CERCLA - Sec. 9608. Financial Responsibility | Superfund 1980 Sec. 9608
[183] United States Government Accountability Office (Environmental Liabilities), 33
[184] U.S. Superfund Program Pioneers Hazardous Waste Remediation, Bureau of International Information Programs, U.S. Department of State, 2/3/2009 2009 <http://www.america.gov/st/washfile-english/2006/April/20060421162126lcnirellep0.6585766.html>.
[185] A company can be subject to CERCLA if they manufacture, transport, dispose of, treat, or store hazardous waste. Environmental Protection Agency, CERCLA Sec. 9608

must demonstrate financial responsibility to the EPA for potential waste clean-up; this section of the regulation has never been implemented, which limits its usefulness for this discussion. However, should this section be promulgated in the future, the regulation allows companies to demonstrate financial responsibility in a number of ways. Unlike RCRA, CERCLA has built-in flexibility:[186] it allows for hybrid financial instruments – third party coupled with self-insurance instruments.[187] For example, operators could use insurance and a corporate financial guarantee to demonstrate their financial responsibility. CERCLA's flexibility led to the evolution of cost-cap insurance, which provides coverage for costs above the expected price of remediation.[188] The model for these financial mechanisms is useful but because it has never been utilized, it is hard to judge the success of this flexibility and how it could be directly useful for CCS.[189]

The signature element of Superfund is the retroactive fund established to clean up abandoned hazardous waste sites. By imposing taxes on the chemical and petroleum industry, the cost of the remediation does not burden taxpayers. This idea could be transferred to CCS projects by taxing carbon sequestration operators. Similar to many Superfund sites, there will be a time when the operators of carbon sequestration projects are no longer in business or in existence. Having the available resources to fund remediation in the future would be favorable, especially if it does not require the government to withdraw funds out of general revenues. Potentially, this financial resource could last longer than the financial responsibility demonstrated by individual companies. However, as Superfund's current status illustrates, the success of this fund would be dependent on political support in order to maintain the taxes that generate its revenue.

CERCLA's liability regime covers both industries and private parties. CERCLA has a limited liability framework that allows private parties to seek recovery for investigation and remediation of hazardous waste, although not lost wages, personal injury, or punitive damages.[190] Some state statutes supplement CERCLA with more stringent liability requirements, but not all of them. The liability statutes, however, that are used by the EPA to charge the responsible parties of hazardous waste clean-up sites are incredibly stringent in order to "cast as wide a net as possible."[191] This is because most of the contaminations took place at a time when regulation

[186] Wilson, et al, Liability and Financial Responsibility:12
[187] Environmental Protection Agency, CERCLA Sec. 9608
[188] Wilson, et al, Liability and Financial Responsibility: 12
[189] United States Government Accountability Office (Environmental Liabilities), 33
[190] Environmental Protection Agency: CERCLA Title 42, Chapter 103
[191] Klass and Wilson, 15

allowed such disposal of wastes, yet defendants must still be held responsible for clean-up. For this reason, CERCLA liability is strict, joint and several. Strict liability, as was discussed previously, holds the defendant responsible regardless of whether he is at fault. Joint and several liability refers to the ability of the EPA to sue multiple parties, each for the full amount of the clean-up; it is then the responsibility of the parties to figure out the percentage each of them will pay towards the full amount.[192] The ability of the EPA to utilize this stringent liability framework allows for them to recuperate costs of site clean-up more effectively, and would be a useful element of CCS regulation, given the similarly long time period that sequestration sites will be in existence.

Although admittedly the nature of remediation for hazardous waste is significantly different than that of carbon sequestration, many elements of the regulatory framework are analogous to one another. The flexibility of CERCLA's financial mechanisms is a helpful lesson for CCS regulations. Combining their flexibility with the more stringent regulatory measures found in RCRA might increase the potential for success. Additionally, the signature elements of CERCLA are very important to CCS. The creation of a national fund to pay for remediation measures in the future should be considered, given the time frame of CCS projects. Again, however, the ability to change the revenues of the fund based on differing political agendas represents a limitation. The strict, joint and several liability provisions, if applied to CCS, would also benefit private parties and government in collecting the funds necessary for any remediation or monitoring.[193]

One important difference between CERCLA and CCS that must be noted is the retroactive nature of CERCLA. It was a regulation meant to address the "past haphazard disposal of chemical wastes," the costs for which were well known due to experience with remediation and clean-up.[194] Unlike CERCLA, a fund for CCS may not have the advantage of knowing definite costs beforehand. This lack of knowledge might prove to be a barrier for setting up this type of fund for CCS; however, it is important to acknowledge the potential savings on the part of the U.S. government if such a fund is set up to be fully funded by industry.

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[192] Environmental Protection Agency: CERCLA Title 42, Chapter 103
[193] Klass and Wilson, 16
[194] Stafford, Senator Robert T.. "Why Superfund Was Needed | EPA History | US EPA." EPA Journal 1981. June 1981 <http://www.epa.gov/history/topics/cercla/04.htm>.

Price Anderson Industries Indemnity Act

The Price-Anderson Act is a federal indemnity, or insurance, program. The purpose of such a program is to pool risks between entities likely to reap a shared benefit. In this case, the Price Anderson Act exempts the nuclear industry from full liability in case of nuclear accidents. When it was enacted in 1957, the act was intended to promote economic development in the industry at a time when the risks were unknown; critics, on the other hand, still see it as a subsidy for the nuclear industry.[195]

The Price Anderson Act mandates that individual plants obtain private insurance up to a certain amount: $300 million for each reactor over 10 megawatts. In case of an accident, companies have a cap, or maximum amount, that they are responsible for paying. This cap is about $95 million dollars; after an accident, companies are required to pay an annual amount of $15 million until the cost of the damages is met or the maximum cap is reached.[196] The federal government must provide funds from the general treasury to address the remaining balance once the caps have been reached.[197] In short, the Price Anderson act sets a maximum amount for which any nuclear power plant can be held liable, even in the case of an accident. For the expansion of industry, this was helpful because it decreased the risk that private investors faced, but the continuation of the Price Anderson Act prevents nuclear plants from being fully responsible for any damages that they may cause. Although a benefit of the Act is that it requires operators to hold a higher amount of insurance than might otherwise be necessary, it is hard to determine whether the Price Anderson Act would be cost effective for the government and industry in the situation of a large-scale accident, since one has not yet occurred.[198]

An indemnity program like the Price Anderson Act only works when there is a low probability of occurrence for an accident. For example, the National Flood Insurance Program uses the same framework, and the estimated U.S. Treasury losses after Hurricanes Katrina and Rita was $30 billion, compared to the $2 billion in premium payments collected by the program during the year before.[199] If not used properly, such insurance programs can shift the burden from

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[195] Klass and Wilson, 41; Wilson, et al, Liability and Financial Responsibility: 12

[196] US CODE: Title 42,2210. Indemnification and limitation of liability (Price Anderson Act), , 2/4/2009 2009 <http://www4.law.cornell.edu/uscode/uscode42/usc_sec_42_00002210----000-.html>.

[197] *Ibid.*

[198] Klass and Wilson, 41

[199] Wilson, et al, Liability and Financial Responsibility: 12

the private onto the public. Also, such frameworks require knowledge of the approximate costs for remediation in order to set a cap; arbitrary caps may result in an inadequate collection of funds.[200]

None of the discussed regulations are adequate for addressing the needs of carbon sequestration alone. Instead, the financial responsibility and liability requirements for CCS should take into account the variety of approaches, and use the best elements of each when producing a framework. It is important to note, however, that for any of these frameworks to function, there must increased data and knowledge about the cost of remediation and well closure. Remediation, in particular, is an unknown in regards to CCS, and would need to be researched further before those standards could be set.

RCRA's up-front financial responsibility requirement for remediation and well closure is very important. However, if this is going to be in place, there needs to be a way to ensure that the funds collected are adequate in case of site abandonment, operator bankruptcy, or dissolution. This problem could likely be solved by having more stringent requirements for financial responsibility, coupled with flexibility in combining financial mechanisms. In other words, such mechanisms as cost-cap insurance and hybrid financial mechanisms are encouraged, but the EPA must take more action to ensure that adequate funds are available. In particular, the EPA has been admonished by the Government Accountability Office for allowing companies to choose their own mode of financial assurance. This allows industry to choose the methods of the lowest cost, but that prove the highest risk to the government, such as corporate financial guarantees.[201] The EPA should set stringent rules that dictate the type of financial mechanisms that may be allowed for each company based on its financial risk profile. This will better ensure that adequate funds are available when remediation is necessary.

In addition to demonstrating financial responsibility that extends through the post-closure period, there should be an ongoing fund to cover costs if a liable party can no longer pay. This would likely require up-front payments into a lasting fund. The Superfund is a useful example for this element. The fund can be supplied by taxes that come from within the industry, either paid by a general tax or a tax per ton of carbon sequestered. Everyone with a CCS project pays;

[200] *Ibid.*, 12
[201] United States Government Accountability Office (Environmental Liabilities), 40

theoretically, therefore, the liable party would have contributed to the remediation costs. Before such a fund could be established, however, estimates of remediation costs would be necessary. Also, a downside to this mechanism is that it is vulnerable to change under differing political agendas. There could be a safety net that allows for a shifting political agenda that could take the form of an indemnity program without a cap. For example, each CCS operator would be responsible for holding insurance; in case of an accident, each operator would pay out until the claim is met. Both options that provide for this fund would likely be unpopular with industry leaders who would be responsible for paying additional taxes and/or holding extra insurance. Arguments could even be made that this would limit deployment by introducing barriers to business. However, these options do ensure the public will not be left with the burden of paying for remediation.

The liability standards from CERCLA also provide an example of a potential framework for CCS. Given the long term nature of CCS projects, and potentially high costs for remediation, it would benefit the government to allow retroactive lawsuits. Strict, joint, and several liability would additionally ensure that the EPA is able to collect costs from liable companies. Although this liability framework was very specific to CERCLA and cleaning up abandoned sites, it could be applied to CCS with very positive effects. Not only would it be easier for the government to hold companies responsible for paying remediation or monitoring costs in the event that they abandoned a site, but it would also be additional incentive for companies to minimize risk during the operation phase of the project.

Table 2: Summary of Regulatory Analogs for Liability and Financial Mechanisms

Regulatory Analog	Purpose of Regulation	Elements Useful for CCS	Evaluation of Regulation	Additional Concerns for CCS
RCRA – Resource Conservation and Recovery Act	• "Cradle to grave" regulatory framework for hazardous waste • Implements regulation of waste aboveground • Meant to ensure availability of funds for closure and post-closure care in case of company dissolution	• Delineates specific financial mechanisms that must be used: trust funds, surety bonds, letters of credit, insurance, corporate financial tests, or corporate guarantees • Allows private parties to seek damages in case of harm from waste	• It has been shown that RCRA does effectively ensure that adequate funds would be available	• The risks and costs associated with CCS must first be determined before financial responsibility can be measured • Additional funds must be available in case needed after post-closure site care • CCS regulation should mandate certain financial mechanisms based on the financial integrity of the company, instead of allowing the company to decide, to ensure adequate funds are available
Underground Injection Control	• Regulation of hazardous waste injected underground • Financial mechanisms modeled from RCRA	• Operators of hazardous waste injection wells are indefinitely liable for damages	• Financial mechanisms for UIC are more ambiguous than RCRA and therefore less effective	• The indefinite liability of a company is only sufficient if the company is in existence; CCS needs an additional mechanism to cover damages for the long-term existence of the site
CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act	• Addresses problems related to improperly disposed hazardous waste • Established financial mechanisms for current hazardous waste facilities to pay for waste clean-up • Establishes a trust fund funded by taxes on the chemical and petroleum industry to pay for hazardous waste clean-up if the responsible party is no longer able to pay	• Allows for hybrid financial instruments to be used by current companies • Trust fund is funded by the industry and does not pose a burden on taxpayers • Imposes strict, several, and joint liability on companies that can be used by government or private parties	• Funding for the Superfund was eliminated because Congress did not renew the taxes • The financial mechanisms were never promulgated, and therefore their effectiveness cannot be determined	• CCS would need a mechanisms for retroactive clean-up as well as financial responsibility demonstrations during project operation • Any fund established for CCS that was susceptible to political changes could endanger the availability of funds for remediation
Price Anderson Industries Indemnity Act	• Insurance program meant to pool risks of nuclear power plants in case of an accident	• Encourages deployment by limiting the liability of private parties • Requires parties to hold more insurance than they otherwise might	• Such a program works only when there is a low probability of an accident occurring • Potentially shifts the burden of paying for remediation to the public	• An indemnity program would require approximate costs for remediation, which are not yet known for CCS

EPA PROPOSED RULE: How It Addresses Financial Responsibility and Liability

The EPA's proposed rule has laid out a basic framework for the liability and financial mechanisms for CCS. It will become clear that the proposed regulations are heavily based on those of the Underground Injection Control, and therefore tend to face similar critiques.

For liability, the EPA has proposed the 50 year post-injection site care period, with proof of non-endangerment necessary for site closure. At the end of this post-injection site care period, operators must submit a site closure report that contains a non-endangerment demonstration, showing that conditions in the subsurface indicate "no additional monitoring is necessary to assure that there is no endangerment associated with USDW's associated with the injection."[202] Despite this proof of non-endangerment, however, operators are indefinitely liable for any harm to underground sources of drinking water. This liability, however, does not explicitly extend to claims by private parties, nor does it cover risks beyond those to sources of drinking water.

The financial responsibility framework for this proposed rule is purposefully incomplete. Although the rule specifies that "the EPA plans to develop guidance that is similar to UIC financial responsibility guidance," it also acknowledges the criticism from the Government Accountability Office and request comments for improving the financial responsibility mechanisms.[203] Should the guidance take the shape of the established UIC financial assurance framework, operators would be required to demonstrate financial responsibility for well plugging and post-closure site care at the time of the permit allocation.[204] Operators would be allowed to demonstrate financial responsibility through third party or self-insurance instruments. This assurance will need to be maintained through the 50 year post-closure site care period, but not beyond it. Throughout the project, this financial responsibility demonstration would require periodic updates of cost estimates for corrective action, and a re-demonstration of the ability to meet the new financial needs.[205] Despite these proposed regulations, the EPA actively asks for comments on the financial mechanisms. The rule voices concern over the GAO recommendations, and refers to an evaluation of RCRA's financial mechanisms that will be used for providing additional guidance.

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[202] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43517

[203] *Ibid.*, 43521

[204] The agency was also considering allowing separate financial demonstrations to be submitted forwell plugging and post-closure site care. It is seeking comment on allowing the post-closure site care financial assurance to take place at a later time, such as within 180 days of notification of well closure. *Ibid.*, 43522

[205] *Ibid.*, 43497

So how does the EPA's proposed rule of the financial responsibility and liability framework measure up to the analogs and minimum requirements that were discussed? As already mentioned, the rule does not provide a thorough assessment of financial mechanisms because of the Agency's desire to seek guidance on this topic. However, some omissions suggest that the proposed rule is not taking into account all possible methods to ensure the social responsibility of the carbon sequestration industry.

The Rule's indefinite liability clause is unavoidable, due to the fact that the EPA does not have the authority to transfer liability from one entity to another.[206] This may provide additional incentive for companies to minimize risks, since they can be held liable for damages or leakage in perpetuity. Unfortunately, beyond drinking water, the rule does not adequately cover liability of damages to human health and the environment (e.g. health effects of concentrated CO_2, ecosystem damage, climate change impact, property damage), which is also due to the jurisdictional limitations of the SDWA. This suggests a need for other regulations that can cover such topics. Additionally, there is no mention of strict, joint, or several liability, yet this may be necessary for the EPA to recover any potential remediation or monitoring costs in the future for abandoned sites.

There are strong arguments from CCS proponents that indefinite liability will hinder deployment. However, Class 1 Wells under the UIC face the same liability framework and function because injection is more economical than other disposal options. Therefore, it is reasonable to assume that if CCS becomes economically favorable (through a government subsidy or a price on carbon emissions), then it too will overcome the disincentive posed by indefinite liability.

The Proposed Rule overlooks certain issues that should be included in the regulations. One particular issue is that the UIC financial mechanism would not extend financial responsibility "for activities unrelated to protection of USDW's (e.g., coverage of risks to air, ecosystems, or public health unrelated to USDW endangerment)."[207] This is inherently a concern since the risks to these entities are comparable to those of drinking water sources. Again, this inability on the behalf of the SDWA to cover these risks demonstrates a need for additional

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[206] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43495
[207] *Ibid.,* 43520

regulation that can protect the health of humans and the larger environment. Additionally, operators would no longer need to demonstrate financial assurance after post-injection site care. How then, will the federal government pay for remediation after that period? They propose that indefinite liability is enough to hold owners financially responsible after the site care period ends; if the company is still in existence, this might be true, but what if they are not? The proposed rule should account for that possibility by having an available fund (like Superfund or an indemnity program). Such a fund was discussed earlier and provides an additional safety net on which the government can rely. It ensures that remediation funds are coming from within the industry and prevents the general public from assuming the costs imposed by industrial activities.

Financial responsibility and liability frameworks are very important components of any regulation pertaining to carbon sequestration. Companies must be held responsible for the operation of their site, both during and after injection. Additionally, companies that invest in carbon sequestration should expect to shoulder the costs pertaining to remediation and monitoring. Industrial analogs demonstrate that such an expectation is reasonable and legally feasible. EPA's proposed rule attempts to address these issues, but falls short in several areas. Many shortcomings are due to the limited authority of the Safe Drinking Water Act, and demonstrate the importance for additional regulations. Other omissions in the proposed rule, however, could and should be covered by the SDWA. Operators should be held responsible for human or environmental damage resulting from a malfunction of their site, whether it takes place during injection or several years after site closure. The financial responsibility portion of the rule must ensure that companies demonstrate their ability to pay for well closure and post-injection site care. Additionally, however, it should include a provision for collecting funds for future remediation and monitoring when the parent companies are no longer around to assume financial responsibility.

FURTHER CONCERNS REGARDING THE REGULATION OF GEOLOGICAL CARBON SEQUESTRATION

It has already been shown that the framework of the Safe Drinking Water Act is not sufficient to address all the necessary components of a liability and financial responsibility regulation, yet there are still more issues that must be addressed in a carbon sequestration policy framework. Some issues that must still be addressed include property rights, public education, governmental incentives, and research and development. These components are beyond the scope of the SDWA, but may still be integral parts of a comprehensive policy for CCS.

Although there are several additional concerns beyond geological risks or social responsibility that relate to the regulation of carbon sequestration, one important topic supersedes the rest – a national climate policy. The existence and design of such a national policy is the very backbone of carbon sequestration, and must be analyzed for possible components that might favor or hinder CCS technology.

Role of Carbon Sequestration in National Climate Policy

An assumption throughout this paper has been the existence of a national climate policy. Without a comprehensive climate mitigation plan, and an appropriate "price" for carbon emissions, the incentives for a carbon capture and storage project are very low, and the technology is unlikely to get off the ground. However, public and governmental motivations toward a greener economy and renewable energy suggest that a climate policy is approaching. Not just any climate policy would be enough to deploy carbon sequestration, however. If the government were to pursue CCS (and, again, the assumption is that they will), what would the climate policy choices need to look like, and what would be included?

The most general policy requirement for a climate strategy incorporating carbon sequestration is an incentive to reduce CO_2. This can come in the form of a carbon tax or a cap-and-trade program. The cost of CO_2 emissions must exceed or equal the cost of CCS construction and operation to make it economically viable; estimates from multiple sources suggest that carbon dioxide will need to be priced between \$30 and \$60 per ton for this criterion to be met.[208] A safety valve, a price cap on carbon, is a possible component of a climate mitigation policy that would prevent CO_2 from getting too expensive. This component, however, could hinder deployment if it is set lower than the price that makes CCS economically viable.[209]

Other policy design factors can also have a significant impact, including the cost of other technologies that reduce emissions, as well as the program for accounting for CCS emission reductions. Are emissions "reduced" by carbon sequestration given the same weight as those reduced through efficiency or zero-carbon energy? If CCS is to be promoted, versus simply allowed, then such reductions should receive the same credit as other options, although this does not necessarily have to be the case. Also, the policy must account for leakage of CO_2 into the atmosphere. In situations where the amount of escaped CO_2 is hard to quantify, what will be the penalty to operators? How these questions are answered with a climate mitigation strategy will greatly depend on the priorities that the government sets, and which technologies or methods will be incentivized over others.

The design and implementation of a national climate policy will greatly impact the deployment of carbon capture and storage. The lack of a national policy to address climate change will probably prevent it altogether. If the government chooses to favor the deployment of CCS, several parameters would be necessary in the climate policy: an adequate price for carbon dioxide, no safety valve (or a safety valve above that minimum price), and an accounting system that calculates emission reductions by CCS as equal or comparable to those reduced by other methods. This measure alone – the passing of a national climate policy – could affect the entire future of carbon sequestration as a climate change mitigation option.

A national climate policy is absolutely necessary for the deployment of CCS, but under the assumption that a climate policy will exist, there are still other issues beyond geological risks and social responsibility that account for a thorough and comprehensive policy framework for carbon sequestration. These issues merit a brief discussion to analyze the approaches that could be taken for their inclusion in the regulatory framework.

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[208] Hiranya, et al, 17
Referring to studies done by MIT, McKinsey and Company, and J. Dooley
[209] For example, if \$40 per ton of CO_2 is the break-even price for a CCS project, then a safety valve at \$35 per ton would mean that CCS never becomes economically sensible.
Ibid., 18

Property Rights

Characterizing a site and injecting carbon dioxide underground has the potential to interfere with two types of property rights: surface trespassing, and geological subsurface trespassing. Surface trespassing could take place if the operator needed to conduct monitoring, seismic tests, or other operations on land owned by someone else. Subsurface trespassing is more likely to be a concern, and would occur if the injected carbon dioxide migrated to an area where property rights had not been acquired by the operator. Either form of trespassing could take place on federal or non-federal land, with complex property rights issues accompanying both.

In the United States, surface and subsurface property rights may be owned separately.[210] In order to attain rights, pore space can be rented or bought. Using natural gas storage as an example, public utilities have a right to use eminent domain to acquire the necessary property for storage. In other words, when private property owners do not voluntarily agree to lease their land, the government can confiscate it (with just compensation) for public use. [211] In this case, buffer zones are usually included, since the escape of the gas beyond the property rights is still trespass. For oil and gas mining, unitization is used to attain property rights. Unitization joins individual tracts of land together, and usually does not require more than a certain percentage (50-85%) of the private property owners to agree before it can occur.[212] For hazardous waste wells, there is no purchase of property. Unless the private property owner had reason to use the pore space for other purposes, they relinquish their rights to the subsurface, and the well owner has the right to use it.[213] Water storage property rights are handled differently because water is considered a public resource; “servitude” is imposed on pore space used for temporary water storage, so it doesn’t require any payment or lease of land. [214] This is the most lax of the analogs mentioned.

Methods for determining property rights issues must be included in a comprehensive regulatory framework for CCS and it will be crucial to determine how those regulations will work. Using the oil and gas industry method of unitization may not work because carbon sequestration will take place over such large areas that acquiring permission of the necessary 50 to 85 percent of land owners will likely be prohibitively time consuming and expensive. On the

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[210] Jerry R. Fish, Carbon Sequestration Property and Regulatory Issues, 2008., 14; Metz, et al, 256
[211] Fish, 17-18; Wilson, et al, Liability and Financial Responsibility: 12
[212] Wilson, et al, Liability and Financial Responsibility: 12
[213] Fish, 19
[214] *Ibid.*, 21

other hand, using lax regulations such as those for water injection seems unreasonable given the larger risk of sequestering carbon dioxide. A key question is whether the emphasis of property rights will placed on the private owners' right to the subsurface, or finding an economical and feasible way for operators to obtain permission to utilize the land and subsurface (if the site is reasonably safe). All of these issues need to be further explored to determine the proper course of action for carbon sequestration regulation. Because the EPA does not have the authority to regulate this issue, it will likely fall under the general jurisdiction of the Department of the Interior or the Department of Transportation.[215] The decentralization of this particular issue from others of site characterization and operation might pose problems.

Public Education and Outreach

The National Academy of Sciences, in a recent report to the Department of Energy and the Environmental Protection Agency, emphasized the importance of public education in carbon capture programs. They noted that a carbon sequestration program will not succeed if "a significant fraction of the public views it as dangerous or unacceptable."[216] Public education and involvement could be an important element of a carbon sequestration program, but by no means must be included in the regulation. Arguments in favor of education cite the public's ability to hinder CCS deployment if it is viewed as unsafe or unfavorable. This was a lesson learned from nuclear waste storage, of which WIPP is a positive example. By involving the scientific community, local communities, and local politicians in advisory and decision-making roles, the credibility of the WIPP project increased. Few negative public reactions were dealt with, particularly in comparison to other projects abroad that involved little public engagement and failed partially due to that lack of engagement.[217]

If a public education campaign were included in a CCS policy, what would it look like? The campaign should require that the public be informed about the technology, with an emphasis on both its risks and benefits. Importantly, the information must be presented in a way that was understandable to the public, without scientific or regulatory jargon. It could take the form of education outreach to the general public, or seeking invested stakeholders for positions on

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[215] United States Government Accountability Office (Carbon Capture and Storage Report), 42

[216] National Research Council, National Academy of Sciences, Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two) (Washington, DC:, 2007). See United States Government Accountability Office (Carbon Capture and Storage Report), 49

[217] Benson, et al, Industrial Analogues: 134

advisory committees. Either private industry or the government could initiate this component, although there is much to be said about the potentially biased perspective that industry might present if they had an economic stake in a CCS project. The topic of public outreach and education is outside the realm of the EPA's proposed rule, and would need to be initiated separately.

Financial Incentives for Initial Development of Carbon Sequestration

If the U.S. government does decide to promote carbon sequestration, there is ample discussion about necessary incentives to jumpstart initial deployment. Although often financial incentives for CCS are viewed as another industry subsidy, there are arguments that support government assistance for rapid deployment in order to reduce emissions from coal as fast as possible. The novelty of the technology is a large barrier to the deployment of the technology, and certain incentives could quicken the pace with which industry tackled these obstacles. If the government were to proceed with financial incentives, it is important to weigh their impact on the technology's deployment as well as government spending.

Not all financial incentives are equal for all actors, and many would hold different value for operators of CCS projects. Assuming incentives were to be utilized for rapid deployment of CCS, there are several options for how to do it:

- Federal loan guarantees are the most useful for independent or unregulated producers, which usually have lower credit ratings and can take advantage of the low-interest loans. This type of incentive is largely off-budget for the government, making it more affordable, although it still has impacts on federal spending.[218]
- Cost-sharing is very common for newly developing technologies; under this type of arrangement the federal government would contribute a percentage of the capital costs of a project. Applicants could be required to pay back the government contribution, but have rarely had to in the past. This type of incentive is beneficial to any project operator, because it is a direct decrease in cost; however, 100% of the costs are on-budget for the government, and it is therefore an expensive undertaking. [219]
- Investment tax credits, under the Internal Revenue Code, provide credits against a regular

[218] State Clean Energy and Environmental Technical Forum, Integrated Gasification Combined Cycle (IGCC) and CO2 Capture and Storage (CCS) - Federal and State Incentives for Early Commercial Deployment, 2006., 3
[219] *Ibid.*, 4

income tax. These incentives can only be utilized by commercial projects and profit-making companies, who are not tax-exempt.[220] These credits effectively reduce the upfront capital costs for the company, but are expensive for government because the full amount counts on-budget.[221]

- A production subsidy is a direct payment given to the facility from the government, based on the amount of electricity produced. For example, the 2005 Energy Policy Act allotted a 1.8-cent production subsidy per kilowatt-hour for "certain advanced power system technologies."[222] In this case, an operator can only benefit if facility is producing electricity, so there is still a risk to the company if technology fails. It is less of a risk for the government who only pays if the technology works; however, it too is counted on the governmental budget, so it is still expensive.[223]
- Another form of subsidy could be to allot additional allowances to CCS plants through a cap and trade program, with the intention of allowing operators to sell the allowances at a profit. Sell additional allowances as revenue would effectively subsidize the capital costs of the technology. The direct costs to the government or benefit to the operator would greatly depend on the mechanisms of the cap and trade program, and the price per allowance.
- A type of subsidy that has been previously discussed in detail is a liability limitation. Following a structure similar to the Price Anderson Act or another indemnity program, CCS plants could have a cap on their maximum liability. This would decrease risk for the investors, possibly acting as a subsidy to the industry. The costs of this particular subsidy are two-fold: there is a direct cost to the government to pay any remediation beyond the maximum cap in case of an accident, but there is also an indirect cost in the form of increased risk. If companies have reduced liability, there may be reduced incentive for optimum performance and risk management during operation.

The incentives listed are not limited in their flexibility; they can be combined together, or

[220] Electric Power Research Institute, Financial Incentives for the Deployment of IGCC: A CoalFleet Working Paper, 2005., 6
[221] State Clean Energy and Environmental Technical Forum, 4
[222] Electric Power Research Institute, 6; American Public Power Association, Programs Authorized by the Energy Policy Act of 2005 (EPAct05) of Interest to Public Power, 2007, <www.APPAnet.org>.
[223] State Clean Energy and Environmental Technical Forum, 4

funded in different ways. For example, the incentive mechanisms do not necessarily need to be funded by the government's general revenues. One proposal for funding such subsidies is to designate revenues from auctions of CO_2 emissions to subsidize CCS capital expenditures.[224] This method keeps the funding somewhat more contained within the industry, since corporations needing emission credits will be funding the construction of CCS operations. Not all incentives need to be positive either. Senator John Kerry, for the 2007 Clean Coal Act, proposed setting a performance standard for coal plants that can only be met by CCS.[225] For that scenario, coal plants would pay for not sequestering their CO_2 emissions, which could also make CCS economically viable. Essentially, there are multiple ways to contribute to the deployment of carbon sequestration and many methods for making the technology more economically practical. Additionally, it is reasonable to have no incentive structure, and allow market forces to dictate the presence or absence of this climate mitigation strategy.

So which approach should be taken – incentives or no incentives? Each argument has its justification, and often they boil down to the same core components used for arguing for or against CCS in general. For CCS to be deployed rapidly, it must be the strategy for reducing emissions that comes with the least cost.[226] Additionally, the novelty of the technology makes investment very risky, and government involvement would decrease that risk.[227] On the other hand, a thorough climate policy could price carbon dioxide such that the market could dictate the emergence of certain technologies without government assistance. There are also arguments that the allocation of federal money toward CCS would decrease available funding for renewables and other clean technology.[228]

Regardless of the approach that is taken toward CCS – positive incentive, negative incentive, or no incentive – it will not be the jurisdiction of the EPA. Incentive structures for rapid deployment are a part of the mandate of the Department of Energy. In fact, the DOE's 2005 Energy Policy Act provides a few such incentives, such as the 1.8-cent production subsidy already mentioned. There are also several state policies that provide incentives for carbon sequestration or other greenhouse gas minimizing technologies. Because these are already in

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[224] Hiranya, et al, 19
[225] *Ibid.*, 20
[226] *Ibid.*, 32
[227] Massachusetts Institute of Technology Interdisciplinary Study, xiii
[228] See generally: Emily Rochon, "False Hope: Why Carbon Capture and Storage Won't Save the Climate," Greenpeace International (2008).

existence, their integration into a national strategy for climate policy as well as regulation for carbon sequestration should be considered.

Research and Development for Carbon Sequestration

Several unknowns about this technology have already been shown to be a barrier to deployment: the unknown cost of remediation, the effects of the CO_2 stream purity, the performance of sequestration in a variety of geological locations, and the limits of monitoring and detection. These unknowns prevent the certainty of liability, knowledge about the extent of geological risks, and even a reasonable estimate of the financial responsibility that companies should expect. The lack of any commercial scale CCS plant prevents many of these questions from being answered. However, the cost of setting up a full-scale demonstration project can be prohibitively expensive for private investors. One way to attempt to answer many of the research questions still remaining for this technology is through government sponsored research and development.

The Department of Energy has already invested in research and development for advanced coal technologies. Upwards of $500 million dollars have been spent since 1997, the majority of which has been spent on developing integrated gasification combined cycle (IGCC).[229] The emphasis on IGCC, however, has not helped the advancement of CCS technology because, although the two technologies could potentially work together, no pilot project has been done to couple IGCC with sequestration.[230] The existing R&D budget for advanced coal technologies also focuses heavily on the construction of new coal plants, whereas the majority of existing emissions are coming from older coal-fired power plants that have a lifetime of 30-50 years. The IPCC and the National Coal Council both stress the significance of installing post-combustion capture systems on existing power plants because of their large contribution to greenhouse gas emissions.[231] Historically, however, the research and development funding that has been dedicated to retrofitting older plants totals to the 10s of millions of dollars, not the $500 million seen for new technologies.[232] As a result, retrofitting an existing coal-fired power plant with new CCS technology would be prohibitively expensive,

[229] United States Government Accountability Office (Carbon Capture and Storage Report), 32
[230] *Ibid.*, 33
[231] The National Coal Council, The Urgency of Sustainable Coal (Washington D.C., 2008).; See: United States Government Accountability Office (Carbon Capture and Storage Report), 37.
[232] United States Government Accountability Office (Carbon Capture and Storage Report), 33

even compared to the cost of constructing an entirely new CCS plant.

Since a carbon sequestration program began in 2002, there has been about $50 million in funding dedicated to this technology and recently the DOE has increased focus on retrofitting existing plants.[233] This shift is significant, although many proponents of federally funded R&D argue that it is nowhere near enough.[234] The International Energy Agency proposes that at least ten major CCS demonstrations are necessary in order to "advance technological understanding, increase efficiency, and drive down costs."[235] These projects are likely to be cost-intensive and have unknown risks, increasing the role that government could play to speed their deployment. Some reports suggest that in order to meet this goal and to deploy CCS in time to start meeting emission reduction goals, a DOE research and development budget of about $5 billion is necessary.[236] This funding should go beyond government projects to also allow for grants for private R&D endeavors.

The decision to pursue federally funded R&D brings up the same arguments as those for and against a federally funded incentive program. It comes down to the key choice of whether of not the federal government will choose to promote this technology over others to reduce greenhouse gases. A key point, however, is that the money spent on research and development would affect the regulation of carbon sequestration, especially as new technical knowledge was developed. The need for the two policy choices – a research and development program and the regulatory decisions about carbon sequestration – to inform each other, therefore, is very apparent and must be considered in the development of both policies.

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[233] United States Government Accountability Office (Carbon Capture and Storage Report), 33

[234] Massachusetts Institute of Technology Interdisciplinary Study, 54

[235] International Energy Agency, Energy Technology Perspectives: Scenarios and Strategies to 2050 (Paris: OECD/IEA, 2006).; See: Hiranya, et al, 20

[236] Massachusetts Institute of Technology Interdisciplinary Study, 54

CONCLUSION

The Environmental Protection Agency's Proposed Rule is a good start to addressing the essential regulations for carbon capture and sequestration. However, it is not the comprehensive policy framework that will be necessary.

The Proposed Rule, using the Underground Injection Control Program's regulations for hazardous waste as a foundation, is strongest at addressing the geological risks of CO_2 sequestration. The processes for site selection, delineating an Area of Review, plugging abandoned wells, and setting a maximum injection pressure all reduce risks for CCS projects. The performance standard for post-closure care can also serve to increase the safety of projects if an appropriately strict definition of performance is determined. Where the proposed rule requires more oversight is predominantly in areas that require more research: injection stream composition and remediation techniques. Two points regarding geological risks should be further considered, however, in their allowance of additional and unnecessary risks: aquifer exemption and allowing storage of CO_2 as a gas. Aquifer exemption unreasonably endangers sequestration sites if certain drinking water aquifers are utilized in the future. Most worrisome is the lack of regulation surrounding phase changes and storage of CO_2 as a gas. Phase changes around the well could compromise its mechanical integrity, and the increased buoyancy of gas increases the risk of leakage and even induced seismicity.

The liability and financial components of the proposed rule were not covered as thoroughly, partially because of the limited jurisdiction of the SDWA; nevertheless, certain minimum liability and financial instruments must be included in a CCS regulatory framework. An up-front financial responsibility requirement for remediation and site closure, like RCRA, is a preventative tool to include in the regulations, and was mentioned in the proposed rule. It must assure, however, that adequate funds would be available; the EPA must designate which financial mechanisms can be used based on the financial integrity of the company. It should also include flexibility to allow for more options of financial assurance. Indefinite liability, as already established by the Rule, is also useful component in incentivizing risk minimization. This component, however, does not preclude the use of an ongoing fund to cover costs after companies are no longer around. Such a fund can be similar to Superfund and taxed within the industry, or could even take the form of a cap-less indemnity program. Finally, joint, several, and strict liability should be federally placed on all CCS operators to ensure: 1) that private parties can seek monetary or injunctive relief and 2) the U.S. government can hold parties accountable in order to recover costs from remediation or monitoring.

Overall questions remain. What is the balance between finding answers to key unknowns and allowing deployment of commercial-scale projects to answer them? If the government chooses to promote CCS, which policy components are favorable? For example, is there a need for an educational outreach program? How necessary are incentives or government-sponsored research and development? It is clear that the issue of carbon sequestration covers a lot of ground and is a topic that can be approached from a number of directions. Although many of these questions were answered, this was only a narrow discussion of the necessary policy and regulations for ensuring the safety and social responsibility of the industry, related primarily to geological sequestration in saline aquifers. It did not include the wide array of geological sequestration sites like salt caverns, coal seams, or depleted oil reserves, nor did it cover the regulations necessary for the capture and transport elements of CCS. Although this paper attempted to cover the necessary elements of CCS related to sequestration, for a well-rounded policy approach, much more needs to be analyzed and these additional issues, in particular, need to be addressed. However, there are broad conclusions that can be drawn from the information contained within the scope of this paper regarding the EPA proposed rule and the regulation of CCS in general.

In covering the necessary components of a regulation related to geological risks, social responsibility, and other concerns, it becomes obvious how all-encompassing and multi-disciplinary carbon sequestration really is. The Safe Drinking Water Act under the EPA has the jurisdiction to cover safety issues concerning drinking water sources, which inherently covers other leakage risks as well. However, the SDWA does not have the authority to cover liability associated with other forms of leakage – either into the atmosphere or that which affects human health. While the EPA could be given the authority to set up a fund for CCS, it cannot do so through the Underground Injection Control Program and would need to set up a separate framework outside of the UIC Class VI Well. Additionally, the EPA does not have the authority to transfer liability from one party to another, and would need still another framework to cover a transfer of liability to the government, if that was the long-term solution for CCS projects.[237]

[237] Environmental Protection Agency, Carbon Sequestration Proposed Rule: 43495

Other governmental departments will also have to get involved in the comprehensive regulation of carbon sequestration: the Department of Energy would need to authorize incentives and research and development funding and the Department of the Interior or Department of Transportation would regulate property rights. With all of these components and actors regulating one industry, how will it be monitored by a coherent or unified set of policies? It is likely that with this much overlap, departments and regulations would be redundant, overlapping, and might go so far as to undermine each other. With that said, a logical conclusion – that would lead to a more dependable and consistent set of policies – would be to have all of the elements of carbon sequestration regulated under one interdepartmental division of government.

The Government Accountability Office suggests that the Executive Office of the President should establish an inter-agency task force that could proactively work to align the agendas and strategies of multiple departments on this particular issue.[238] Currently, the Department of Energy has a similar task force focused on the technological issues of carbon sequestration, the Climate Change Technology Program. This agency has been somewhat unsuccessful at reaching out to all agencies, and therefore the maximum involvement and participation has not been reached. These issues would need to be anticipated and prevented ahead of time by carefully appointing the involved parties and departments. It is essential that this solution or another similar solution is reached for the regulation of carbon sequestration, which otherwise has the potential to be disjointed.

Carbon sequestration is one of many technologies available to reduce domestic emissions from carbon dioxide. If the federal government chooses to pursue this option, most of the technology is there, as is a baseline from which to initiate policy choices. Care must be taken, however, that environmental and human safety is fully considered in the regulation of carbon sequestration, whether that involves injection depth or monitoring criteria. And, if human health and safety is to be considered in all elements of the regulation, then elements of social responsibility that hold industry accountable for malfunctions, damages, and leakage are also crucial. Taxpayers and the government need to be protected with adequate liability and financial responsibility mechanisms. However, this is still short-sighted considering the vast regulations necessary for carbon capture and storage technology. To present a unified, and therefore optimally effective policy, government agencies should work together in the formulation and

[238] United States Government Accountability Office (Carbon Capture and Storage Report), 52

implementation of a well-rounded, congruent CCS regulatory framework.

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