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Understanding Potential GS Risk: A Multi-Disciplinary Framework to Foster Responsible Stewardship

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Abstract

Geologic sequestration (GS) holds promise as a safe and effective approach for addressing climate change. However, concern about potential "liability" associated with GS often is cited as a significant barrier to project deployment. However, the authors contend that the term "liability" is poorly defined and conflates concerns about the uncertainty in the timing and magnitude of potential damages with the call for long-term stewardship of certified closed sites. This paper offers an analytic framework predicated on the use of risk-based probabilistic modeling to assist stakeholders in evaluating the potential environmental, human health and financial consequences of GS projects. Use of this framework will inform siting decisions for specific GS projects and provide maximum loss values and probabilistic estimates of expected loss values that can inform policy discussions addressing the "liability" issue.

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Keywords: carbon dioxide capture and storage (CCS), risk management, financial responsibility, long-term care, liability

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1. Introduction

Available scientific data suggests that CO2 capture and sequestration (CCS) likely represents a safe and effective approach by which the electric power generation industry will be able to achieve significant greenhouse gas emission reductions.[1,2] Many studies call for significant global deployment of this technology within a relatively short timeframe (i.e., within the next 10 years). Optimizing the benefits of CCS rests with the ability of utilities to successfully implement geologic sequestration (GS), which entails capturing and sequestering large volumes of CO_2 in viable subsurface reservoirs for indefinite periods of time. However, because it represents a new and relatively unproven technology, concern about potential "liability" associated with GS often is cited as a significant barrier to project deployment.

The term "liability" has been poorly defined in the context of GS projects, and often is used as a catch-all category to capture far-reaching concerns regarding deployment of GS – from adverse financial exposure under a carbon regime should the CO2 leak from the containment zone to delimited compensatory damages resulting from liability under existing statutes, common law and civil jurisdictions. Further, the 'liability' debate is clouded by a failure to clearly define the receptors and resources potentially at risk from deployment of GS on a site-specific basis; for example, risk of bodily injury, property damage, ecological / natural resource damage, endangered species issues to name a few. The authors contend that the lack of clarity arises, in part, because several applicable disciplines (e.g., financial, legal, engineering) use the terms risk, injury, damage, liability, and financial responsibility differently than each other and sometimes interchangeably. The failure of a common language conflates concerns about the uncertainty of the timing and magnitude of potential damages with the call for long-term stewardship of certified closed sites. The second section of this paper clarifies these definitions for purposes of this discussion.

Despite the lack of a clear definition, "liability" often is cited as an important issue to resolve if efforts to deploy GS on a broad scale are to be successful. [3] It is not surprising that interested stakeholders (e.g., NGOs and members of the public) have challenged that if liability protection is critical to project deployment, then perhaps GS is not 'safe enough' at this time. The authors contend that these circular arguments would benefit from a concrete assessment of the potential costs and compensatory damages that could arise from appropriately sited, constructed, operated and closed GS projects. The third section of this paper offers an analytic framework for evaluating the range of potential risks at GS sites and estimating the probable costs and compensatory damages that might arise from each stage of a GS project.

Confusion over what is meant by calls for "liability protection" or relief from "long-term liability" may be contributing to public skepticism about whether GS represents a safe, reliable and effective technology to mitigate the impacts of climate change, and thereby creating additional barriers to demonstration and deployment. Financial responsibility can be mapped to the stages of a GS project: site characterization, operation, closure and post-injection site care, and post-closure. The risk profile for each stage underpins the potential costs associated with potential mitigation, remediation and, as necessary, compensation for damages. The paper concludes by suggesting that the development of a rigorous decision framework that results in maximum loss values and probabilistic estimates of expected loss values by site will equip stakeholders and policymakers to define the array of risks, responsibilities and attendant financial obligations – informing the public dialogue of who bears responsibility for what, and for how long – necessary to explore the range of potential mitigation strategies.[i] This information will inform siting decisions and will contribute to the development of a concrete "liability" framework that integrates regulation, private sector response and public policy interests in a cost effective, economically efficient manner.

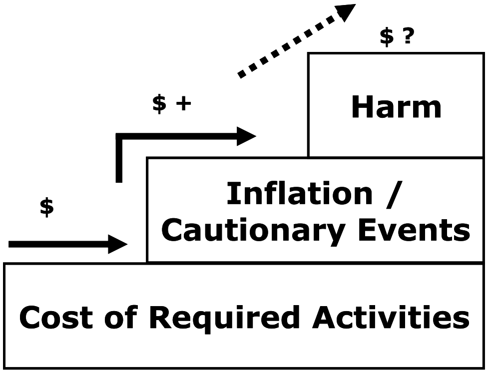
2. Understanding Financial Responsibility for GS Projects

This paper uses the framework of "Financial Responsibility" to organize activities and events that must be funded in the context of projects like GS. For purposes of discussion, "financial responsibility" is defined as the obligation to pay for the cost of required activities as prescribed by regulation, as well as the responsibility, in the event of harm or injury, to pay for compensatory damages that could include but are not necessarily limited to payment for mitigation, remediation, or reclamation. This paper intentionally avoids the question of who should pay these costs. Instead, the authors attempt to more clearly delineate the components of these 'cost' categories.

The various stages in the lifecycle of a GS project give rise to discrete risks, many of which are typical of large industrial projects:

- **Site Selection and Characterization** – Activities during this stage involve passive and active data collection and assessment. Passive data collection involves reviewing existing records. Active data collection may include contracting with service providers for seismic surveys, drilling exploratory wells, taking physical samples and measurements and other related site evaluation work.
- **Site Construction and Operation** – Activities during this stage include well drilling and completion, permitting, injection, monitoring and related activities. This stage also may include closure and/or development of individual wells at large facilities.
- **Site Closure and Post-Injection Site Monitoring** – Once injection ceases, all wells are plugged and abandoned; and unnecessary site facilities may be removed. The exceptions are those wells used for monitoring. At this time, a project begins post-injection monitoring to determine when the injected CO2 has stabilized and no longer poses a threat to underground sources of drinking water (USDWs).
- **Post-Closure** – Once it has been demonstrated that the injected CO2 does not threaten USDWs, any remaining wells used for monitoring are plugged and abandoned, the site is restored, and the project is certified as closed. At this time, a public interest remains to proactively manage the closed site to ensure access to records; to possibly conduct routine maintenance at aging closed wells or monitor the site if concerns arise; and, if harm or injury arises, then mitigation, remediation and compensation may be necessary.

Within each of these project stages, there are at least three areas of financial responsibility, each of which gives rise to different financial risks, as illustrated in Figure 1. The three areas of financial responsibility include: (1) the obligation to pay for required activities prescribed by regulation; (2) the obligation to pay for increased costs for required activities including, for example, changes in regulatory requirements or cautionary events associated with unexpected project performance; and finally, (3) the obligation to redress harm or injury that arise during the project lifecycle.



The first tier of Figure 1 indicates the routine costs for conducting a project. In the case of GS, these include the costs associated with site characterization, construction of wells and site facilities, operation (including monitoring and reporting), plugging and abandoning wells, and site closure. A project developer can estimate these costs at the start of a project based on the cost of materials and requirements (e.g., closure, post-closure care) prescribed by regulation. Financial risks related to these costs centers around the fact that, in the case of GS, these are large costs that will be incurred over a period that could easily range up to eighty years. In general, these costs tend to be readily quantified.

The second tier of Figure 1 captures the potential for projects costs to increase over time due to inflationary pressure or changes in supply and demand for key raw materials. This tier also captures adverse financial risks arising for cautionary events, or events which require an intervention or change in project plan. In the case of GS, these risks may include changes in regulatory requirements over time; developments in the performance of a project that require action such as well stimulation and maintenance to ensure project integrity or to improve performance; or business interruption. Similar to Tier 1, the financial risks related to these costs tend to be quantifiable, tend to manifest during the operational stage of the facility's lifecycle, and first-party assurances are available to manage these risks. [4]

The third tier addresses harm or injury, and attendant compensatory damages that may result despite best practices or due to project negligence. These are costs that are typically included under the umbrella category of "liability." For example, damages could result from worker or industrial accidents, inappropriate procedures, leakage of injected CO2 or from other causes. [1,4] The materiality of financial consequences under this tier is wholly influenced by the probability of an event occurring, the cost of mitigation or remediation, and the financial implications of torte compensation. These consequences are further compounded by the up-front uncertainty of project duration. This financial responsibility spans the obligation to pay for costs associated with mitigation, remediation or reclamation – cost of mitigation to prevent harm from occurring, and cost of remediation plus compensatory damages in the event harm has occurred. Notable risk pathways with the potential for financial and economic consequences include, but are not necessarily limited to: (1) induced seismic activity; (2) surface/subsurface trespass; (3) USDW/ground water contamination; (4) property damage resulting from leakage or ground heave; (5) asset infringement, where the value of an existing surface owner's oil, gas, or storage rights is diminished; or (6) under a CO2 management regime, compliance failure if a GS project that leaks has been used to meet carbon constraint standards. Claims may result from private actors along the carbon sequestration chain, as well as from affected public stakeholders.

3. A Probabilistic Framework for Answering the Question: What's at Risk and How Much Will It Cost?

In the previous section, we define 'financial responsibility' as the obligation to pay for costs associated with activities prescribed by regulation, as well as the responsibility to compensate affected parties in the event of harm or injury. In the absence of information about the potential timing and magnitude of these costs, the idea of bearing blanket financial responsibility is understandably chilling to both project developers/financiers and the public. However, the authors contend that the process for deriving maximum potential loss values and probabilistic estimates of expected loss values is very similar to the process used in developing a risk assessment, and there is significant practical and analogous experience suggesting how it might be done for GS projects. Further, there is an array of GS projects that have advanced the process of developing site-specific risk assessments. The data from these (and other) studies could be used to underpin a risk-based probabilistic modeling tool. In addition to estimated loss values, the analytic outputs from this tool could include identification of site characteristics that have the most significant impact on the magnitude of financial consequences at a candidate site and identification of key data (e.g., analytic, regulatory or other uncertainties) that may significantly impact the range in loss estimates.

Notably, the FutureGen Alliance aimed to build and operate a a large IGCC power plant and related sequestration project as part of a larger research and development effort in the U.S. The FutureGen Alliance engaged in a rigorous RFP-based site selection process that resulted in the detailed vetting of four final candidate locations. A risk assessment was developed for each location, including a set of conceptual site models, toxicity data, a pre-injection risk assessment that estimates the potential impact on various human and ecosystem receptors, a post-injection risk assessment, and a performance assessment.[5] This report not only rates each project but also provides a comparative assessment across projects.

The approach used in the FutureGen risk assessment is not unlike the approach proposed by the authors to estimate the magnitude of potential, event-based costs arising from a specific GS site. The following technical approach reflects a preliminary, high-level framework for evaluating the range of risks and potential financial consequences related to GS. This framework underpins a probabilistic risk-based modeling tool, the analytic outputs of which include: (1) probabilistic estimates of the maximum potential loss expected at a candidate site; and (2) probabilistic estimates of the expected value of losses at a candidate site. The process for generating the information necessary to run the tool is very similar to that used in developing an EIS or conducting a risk assessment; however, the focus is on estimating the costs and financial consequences associated with potential risk factors. Specifically, the suggested approach integrates factors that may increase (or decrease) risk potentials, characterizes the range of possible response scenarios, and offers a gauge of the magnitude of damages that could result from various risk pathways. More importantly, the below-referenced decision framework could be applied to an individual (or model) site or to a group of projects to assess the range and materiality of potential financial consequences on a site-level, project-level and/or regional level. With these results, private and public stakeholders can enter into an informed dialogue of what is at risk, how much will it cost, and related policy options.

3.1. 1. Identify Receptors/Resources at Risk

a) Confirm boundaries of the project site.

b) Map the location of groundwater, mineable resources, oil / gas reserves, and other subsurface resources of potential value within an area that could be affected by the project.

c) Create a linked database with known information about subsurface resource quantity and quality.

d) Map surface land use directly above the site and extending to areas that could be affected by the project. Data to be obtained include, but are not limited to, the size and location of:

  i) Residential, industrial/commercial, and agricultural assets;

  ii) Undeveloped areas, including an indication of habitat type (e.g., wetland, upland, forest, waterbodies, etc.) and areas of special concern (e.g., critical habitat for endangered species, national/state parks, etc.); and

  iii) Lands owned by private entities, tribal authorities, and public lands (owned by federal, state, county or local governments).

e) Obtain additional data needed to assess key drivers of damages, for example:

  i) Residential population density and workforce density;

  ii) The approximate value of residential development and industrial/commercial development; and

  iii) Recreational use of natural resources (e.g., types of recreation, number of annual trips, etc.).

3.2. 2. Identify Site-Specific Unit Costs for Damages Calculations

a) Groundwater: Unit costs based on a combination of treatment costs, added costs for users to obtain water from an alternate source, and the cost of replacing "lost" water.

b) Other Subsurface Resources: Unit costs based on a combination of added costs to extract the resource, added costs to restore the quality of extracted material, and the lost profit for any resources that can no longer be extracted.

c) Human Health: For mortality, unit costs based on publicly available data from settlements or awards from private litigation, as well as primary and secondary literature reviews. For sub-lethal effects, unit costs based on a combination of the expected costs of treatment, future medical monitoring, lost wages and potentially other measures of opportunity costs and lost productivity. Also identify the potential for relatively inexpensive actions that could reduce the likelihood of human health impacts (e.g., project-sponsored installation of exhaust fans in basements).

d) Climate Impacts: Estimate unit costs based on the assumption that advance offsets may need to be purchased to hedge the risk that carbon dioxide may escape the containment zone; e.g., offsets could be purchased from the global market.

e) Habitat Impacts: Unit costs based on a combination of treatment costs to return affected habitat/biota to baseline condition, and the cost of restoration (remediation) projects to compensate for the degraded quantity/quality of habitat/biota prior to their return to baseline condition.

f) Recreational Impacts: Unit costs based on lost fees (or profits) to the resource owner/manager and per-trip estimates of lost consumer surplus, transferred from studies of similar recreational opportunities in the technical literature.

g) Agricultural Impacts: Unit costs based on estimates of lost profits from reduced product quality, quantity and/or increased costs.

h) Diminution of Residential Property Value: Identify a reasonable range of percentage reductions in property values expected to arise in the event of a surface release of CO2.

i) Property Damage: Unit costs based on a reasonable range of costs to repair/replace property damaged by subsidence or other physical surface disturbances.

j) Tribal Loss: Unit costs based on costs of projects to provide uses similar in type, quality and quantity to those affected.

3.3. 3. Probabilistic Risk-Based Analysis

a) Refine model based on aforementioned in order to:
    i) Generate present value estimates and expected value estimates of financial consequences based on the information identified above and user-defined incident timing, receptor impacts and probabilities.
    ii) Develop a range of plausible release (probabilistic) scenarios and associated estimates of financial consequences.
    iii) Identify key damages categories and sources of (sensitivity) uncertainty, and evaluate the need for further research to refine model inputs.

3.4. Analytic Outputs

a) Probabilistic estimates of the maximum potential loss expected at the site.

b) Probabilistic estimates of the expected value of losses at the site to provide other measures of the central tendency of loss estimates.

c) Identification of site characteristics that have the most significant impact on the magnitude of potential damages at the site.

d) Identification of key data (e.g., analytic, regulatory or other uncertainties) that substantially impact the range in loss estimates.

e) Identification of analytic approaches and likely costs for reducing uncertainty ranges.

4. Conclusions

Geologic sequestration holds great promise as an approach for preventing CO2 emissions from entering the atmosphere. The success of GS depends on the ability of a site to safely confine CO2 in injection reservoirs, preventing it from migrating to the surface and causing harm or injury to public health or ecosystems. There is extensive experience with injection of super critical fluids that suggests that long-term containment of CO2 can be achieved in sites that are appropriately sited, constructed, operated and closed. Notably, per the Intergovernmental Panel on Climate Change (IPCC), "Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years. …Similar fractions retained are likely for even longer periods of time, as the risk of leakage is expected to decrease over time as other mechanisms provide additional trapping."[1] Despite this affirmation, there remains a non-zero probability that injected CO2 will migrate, resulting in the need for mitigation, possible remediation and compensatory damages should harm or injury arise. The current public dialogue regarding 'long-term liability' fails to appropriately define the compensatory damages likely to be incurred and estimate the expected value of expenses. This uncertainty and lack of clarity exacerbates concerns that these costs may present decades to centuries after CO2 injection has ceased. However, the real question, that has yet to be answered, is whether these costs are financially material – it's not a matter of if they present, but rather when they do will they be material.

Interested private and public-sector stakeholders fear that the financial consequences arising from GS over the long-term will be significant, and thereby projects are likely to be either cost-prohibitive or leave the public with no financial accountability if something unexpected were to occur after the site is closed and the project developer ceases to exist. Efforts to develop risk assessments as part of the site characterization phase will generate much of the information necessary to determine the array of potential costs. Further, analogs exist to evaluate and monetize financial consequences arising from harm and injury to receptors and resources at risk from CCS. Using a risk-based probabilistic modeling tool interested stakeholders, be they private or public, can derive a reasonable estimate of the expected value of long-term care expenses, as well as value the potential for compensatory damages. Armed with these data, policy makers and stakeholders can more effectively and productively consider the questions of: Who bears responsibility for what, and for how long? The analytic outputs from the above described decision framework also could be used to inform discussions of how to structure financial assurance programs to ensure that the incentives for appropriate site selection, construction, operation and closure are well aligned to protect those who have the largest potential impact, while also ensuring that there is proactive management of certified closed sites over the long-term. Collectively, this information will be crucial for developing a concrete "liability" framework that integrates regulation, private sector response and public policy.

References

[1] Intergovernmental Panel on Climate Change (IPCC). 2005. Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B.,O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[2] World Resources Institute. 2008. *Guidelines for CO2 Capture, Transport and Storage*. Washington DC. In review

[3] R. Specker. July 10, 2008. *Written Testimony: Hearing of the Subcommittee on Energy and Air Quality, Committee on Energy and Commerce United States House of Representatives*. Washington, D.C. Found online at: http://energycommerce.house.gov/cmte_mtgs/110-eaq-hrg.071008.Specker-testimony.pdf

[4]C. Trabucchi and L. Patton. 2008. *Storing Carbon: Options for Liability Risk Management, Financial Responsibility*. The Bureau of National Affairs, Inc., Daily Environment, Vol. 2008, No. 170, 09/03/2008.

[5] U.S. Department of Energy.December 22, 2006; (Revision 1 April 2007); (Revision 2 October 2007). *Final Risk Assessment Report for the FutureGen Project Environmental Impact Statement;* Contract No. DE-AT26-06NT42921. Found online at: http://www.netl.doe.gov/technologies/coalpower/futuregen/EIS/FG%20Risk%20Assessment%20110807.pdf

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[i] Expected value should incorporate the probability of adverse events occurring. Expected financial consequences in a given year are calculated as the product of potential financial consequences multiplied by the annual probability of occurrence. Results for each year are summed over the relevant time period and discounted to generate an expected value of financial consequences.[4]