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An International Regulatory Framework for Risk Governance of Carbon Capture and Storage

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An International Regulatory Framework for Risk Governance of Carbon Capture and Storage

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Abstract

This essay was prepared as part of a workshop on carbon capture and sequestration held by the International Risk Governance Council (IRGC) in Washington, DC, from March 15–16, 2007. The goal of the workshop was to bring together researchers, practitioners, and regulators from Europe, the United States, and Australia to outline the attributes that an effective regulatory regime for carbon capture and storage should possess. This essay focuses specifically on providing an overview of eight fundamental elements that we believe any effective international and national regulatory structure must address: 1) classification of carbon dioxide (CO_2); 2) oversight of CO_2 capture and storage; 3) site ownership and storage rights; 4) site operation and management; 5) long-term management and liability; 6) regulatory compliance and enforcement; 7) links to CO_2 markets and trading mechanisms; and 8) risk communication and public acceptance. This essay is one of 12 collected for the workshop, and the recommendations herein are the views of the authors and do not reflect the views of their agencies, the IRGC, or specific workshop discussions.

Key Words: carbon sequestration, geologic storage, risk, regulation

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Contents

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1. Introduction

Carbon dioxide (CO_2) capture and storage (CCS) and its possible risks have been topics of extensive study in recent years. In contrast, the legal and regulatory structures necessary to support widespread capture and long-term, secure storage have received far less attention. This essay seeks to bridge this gap by building on existing CCS risk literature and outlining some of the key components of an international risk governance framework necessary for the widespread diffusion of CCS. To cover the most common governance issues, this essay concentrates specifically on deep geologic storage *in* and *by* industrialized countries and makes preliminary recommendations on attributes that an effective regulatory regime for CCS should possess. Because geologic storage is likely to be among the earliest large-scale applications of CCS, the focus here is limited to regulation of storage in both on- and off-shore geologic formations, and there is only a cursory treatment of the regulatory issues associated with the capture process or other storage options. However, the overarching framework developed here is intended to be broadly relevant to other regulations necessary for oversight of capture and alternative storage technologies and processes.

2. General Framework

Recent studies on CCS have focused individually on regulatory problems, such as liability, operations, or monitoring. This essay attempts to bring these and other relevant issues together in a single framework. To this end, this overview section highlights eight fundamental elements that we believe any effective international and national regulatory structure must address: 1) classification of CO_2; 2) oversight of CO_2 capture and storage; 3) site ownership and

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storage rights; 4) site operation and management; 5) long-term management and liability; 6) regulatory compliance and enforcement; 7) links to CO_2 markets and trading mechanisms; and 8) risk communication and public acceptance.

These eight elements specifically are listed in order of priority for regulatory (not project) implementation; for example, classification of CO_2 is an early decision that would drive future decisions on assignment of oversight and assessment of liability.[1] Many CCS regulatory planning decisions are interrelated; however, the sections of this essay attempt to separate out and define a set of basic recommendations. The remainder of this overview section individually introduces each of the eight topics above. Sections 3–5 expand on selected issues, and Section 6 summarizes our recommendations.

2.1. Classification of CO_2

The classification of captured CO_2 is crucial, particularly in Europe, as it determines the existing regulatory frameworks under which CO_2 could be handled. Today, there are no separate international- or national-level regulations covering CCS; as a result, current projects are assessed using existing regulations for similar activities, which typically classify CO_2 as either an industrial waste or an industrial product/resource. The former triggers application of regulations established for varying degrees of hazardous substances, from low-level radioactive waste to toxic substances. Since CO_2 is not hazardous at low concentrations, this comparison is unfavorable, subjecting storage projects to more stringent regulations than might otherwise be required. Moreover, waste is often considered a substance without commercial value, but under certain circumstances, such as enhanced oil recovery (EOR) or food-grade applications, CO_2 can serve as a resource that has commercial value. In the event that captured CO_2 is classified broadly as a waste, it could limit opportunities for its use and distribution as a commercial product.

Under current regulations, the classification of CO_2 in the United States likely would occur under the oversight of the Environmental Protection Agency (EPA) as part of its Underground Injection Control Program (UIC) (Wilson et al. 2003; Keith et al. 2005).[2] Because

[1] In the case of project implementation, unlike regulatory implementation, risk communication and public acceptance are likely to be primary prerequisites.

[2] In April 2007 the United States Supreme Court ruled in the case of Massachusetts v. EPA that greenhouse gases are within the Clean Air Act's definition of an air pollutant and EPA has the authority to regulate CO_2 emissions from vehicles under the act.

most EPA regulations, including the Clean Air Acts from 1970 and 1990, do not consider CO_2 to be toxic, it could conceivably retain its non-hazardous status under existing statutes.[3] However, this status alone is unlikely to provide adequate regulatory or public support for CCS projects. Under recent amendments to the London Protocol the parties have agreed that CO_2 is not a waste, as this classification would make sub-sea storage illegal. However, by avoiding this classification, these rules also fail to make clear that CO_2 leakages need to be minimized.

One example of how classification gaps in existing regulations could impact CCS projects is an EU pilot project for oxyfuel combustion. Although the project aims to test and demonstrate a particular capture process in which captured CO_2 would be emitted into the air (without storage) during the early stages of the project, to avoid classification of the CO_2 as an industrial waste, which would cause it to fall under the EU waste directive, regulations require the project to implement advanced cleaning techniques that would make the emitted CO_2 safe as food. In this case, this regulatory hurdle serves only to increase project costs unnecessarily, as it is unlikely that the captured CO_2 would contain any compounds outside those that would have been emitted under normal power plant operating conditions. EU efforts are currently under way to address this regulatory gap. The issue is especially important when considering the potential obstacles facing demonstration projects. To avoid these problems, we recommend that CO_2 from CCS projects be assigned its own classification either within existing regulations by establishing, for example, a Class VI under the EPA UIC program, or within a completely separate regulatory framework set up for this particular purpose.[4]

2.2. Oversight of CO_2 Capture and Storage

Currently, regulatory oversight of on-shore geologic CO_2 storage within a single nation (not influencing the sub-surface of neighboring nations) is subject to national and, potentially,

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[3] It is important to note that although the EPA is the only agency in the U.S. with clear regulatory authority over CCS, it does not have any current classification for CO_2. In contrast, the Federal Emergency Management Agency, the Toxic Substances Control Act, and the National Institute for Occupational Safety and Health all have existing classifications for CO_2 under which it is defined as a hazardous material under the premise that any concentrated, pressurised, or cryogenic gas can pose a danger to the public. The Department of Transportation Office of Pipeline Safety and Pipeline and Hazardous Materials Safety Administration refer to carbon dioxide pipelines as separate and distinct from hazardous liquid pipelines.

[4] Since this essay was first submitted in January 2007, the EPA has since issued guidance on using Class V experimental technology wells for pilot CCS projects (EPA 2007). The full guidance document is available online at http://www.epa.gov/safewater/uic/pdfs/guide_uic_carbonsequestration_final-03-07.pdf (accessed March 7, 2007).

regional regulation; off-shore regulation additionally could be subject to international regulation. This section outlines some of the existing regulations most relevant for CCS. Even proponents of CCS argue whether CCS is sufficiently unique to warrant its own regulatory framework or if it is better instead to amend existing rules. In either case, the development of an appropriate regulatory framework is a time-consuming process. To this end, we believe that even a new international regulatory framework needs to take into account and respond to existing regulations and statutes in its early phases; therefore, this section outlines current systems of international and national oversight to lay the groundwork for future regulatory development. Based on these existing systems, we recommend that an international regulatory framework bring together and address (to the greatest degree possible) the requirements of relevant existing standards and establish independent, minimum standards for CCS, above and beyond which states and municipalities could add their own rules for special cases and increased stringency.

2.2.1. International Institutions

Current international conventions that have implications for CCS include: the United Nations Convention on the Law of the Seas (UNCLOS), the London Convention, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the London Protocol, the UN Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol. Together, these conventions set some existing limits on how CCS might be regulated in the absence of an independent regulatory framework. The first three conventions primarily are relevant for sub-sea storage by European nations.[5] The London Protocol (being a revision of the London Convention) has a broader scope and extends to the storage of wastes in the subsoil. Regulation under this convention could be circumvented only if CO_2 were *not* classified as an industrial waste but instead as some other form of non-hazardous discharge. Similarly, the

[5] More than on-shore geologic storage, off-shore geologic storage of CO_2 (in the sub-sea bed) is affected to a greater degree by international conventions, many of which were formulated before CCS was considered a CO_2 mitigation option. These conventions include 1982 UNCLOS, the 1972 London Convention (which governs the dumping of waste and other hazardous matter at sea), the 1996 London Protocol, and the 1992 OSPAR. For example, UNCLOS might rule out sub-seabed storage if CO_2 is considered an industrial waste. Similarly, OSPAR prohibits dumping of waste and other matter into the water column and seabed; however, OSPAR allows for storage of CO_2 from land-based installations via pipelines or off-shore sources (if the CO_2 is considered a discharge—not a waste). Additionally, in some cases these regulations permit storage on a temporary basis if the intention is to eventually remove the CO_2 from the site. In November 2006, the London Protocol was amended to allow for CO_2 storage in sub-seabed formations, making it the first such regulation to explicitly account for new CCS projects. In addition OSPAR recently adopted a decision to ensure environmentally safe storage of CO_2 streams in geological formations and OSPAR Guidelines for Risk Assessment and Management of that activity.

UNFCCC and the Kyoto Protocol have implications for nearly all storage projects with links to CO_2 markets or emissions trading programs, as there will have to be international agreements on how to credit CO_2 from CCS. Section 2.7 discusses this specific requirement further.

The most important point regarding international conventions is that large-scale CCS will require some type of international oversight or, at the very least, multilateral regulations. These issues become most complex when regulations (amended or new) require approval and ratification from a specified majority of parties and then apply only to parties that have ratified any proposed changes. Given these constraints on establishing uniform standards, ensuring widespread regulatory acceptance will likely involve a combination of amending existing regulations and implementing new standards.

2.2.2. National Institutions

National regulations mainly are relevant for on-shore storage projects within the borders of a nation where the risk of CO_2 migration to other nations is negligible. Some nations also might fall under regional rules, such as EU Directives. Currently, many countries moving forward with CCS projects apply the rules and regulations of analogous activities; for example, petroleum legislation is applied to the CCS activities at the Norwegian Sleipner field. The Intergovernmental Panel on Climate Change (IPCC) Special Report on CO_2 Capture and Storage (2005) mentions several such potential models for regulation of CCS, including mining, oil/gas operations, pollution control, and waste disposal. The scale at which agencies will have jurisdiction over any specific site likely will vary by country, and, in most cases, sub-national agencies, including state-level entities, are currently vested with primary regulatory authority.

There is also the potential for overlap and redundancy of federal, state, and local oversight of CO_2 storage. For example, in United States, Texas recently passed legislation accepting long-term responsibility for new CCS projects as part of the state's bid for the proposed FutureGen zero-emissions power plant. In Canada, the primary authority is at the provincial level, and some provinces have existing regulations that by and large would cover most activities related to CCS, except for the monitoring of injected CO_2 through post-abandonment stages. The International Energy Agency (IEA) has summarized the national legal and regulatory frameworks in the United States, the United Kingdom, Japan, Canada, and Australia (IEA 2005). Generally, there are gaps in all of these existing national legal and regulatory frameworks that need to be addressed before CCS can be applied extensively. These gaps primarily are associated with long-term storage and the inclusion of CCS in climate policies. Most countries so far appear to prefer the amendment of existing policies instead of the adoption of new, CCS-specific regulations.

2.3. Site Ownership and Storage Rights

Because of the anticipated scale of geologic storage projects and formations, a variety of land, mineral, sub-sea and reservoir rights could be required in some areas. Depending on the location of any particular site, ownership, easement, and right-of-way access are subject to specific state and local rules. In Europe and on federal and state lands in the United States, natural resources are typically owned by a state and extraction by private interests requires a formal permit or license. In contrast, outside of federal and states lands in the United States, these same rights are usually held by private interests on private lands (Wilson and de Figueiredo 2006). Furthermore, extraction gives rise to a resource rent, which is commonly taxed by the state.

Across countries, legal rights governing geological formations potentially viable for storing CO_2 are unclear, but storage rights are likely to belong to the state with jurisdiction over the storage site in Europe, while pore space ownership in the United States is more complicated and could involve multiple surface and subsurface property owners (Wilson and de Figueiredo 2006). For some large sites, the geological formation may be under the jurisdiction of many states. In all case, storage of CO_2 by private companies is likely to require a license from one or more states. A possible alternative to the extensive permitting required under existing systems is the establishment of a single, state-owned company responsible for storage. Since storage should at a minimum last for many hundreds to several thousand years, the state sooner or later must take responsibility for the storage site. We recommend that initial structures to vest or transfer ownership to the state as necessary be formed, as part of the early stages of CCS regulatory planning and implementation.

2.4. Site Operation and Management

Responsibility for effective site operation lies with the private or state-owned company licensed to store CO_2. As discussed in the previous sections, licensing could be handled by a variety of international, national, or sub-national agencies; however, once assigned, it is likely that operation permits would govern only the short-term responsibility for injection operations of CO_2. International rules on injection operations could be established within existing frameworks, such as the UNFCCC and/or through governing bodies like the European Union. Furthermore regulations should be consistent with IPCC recommendations and guidelines. The regulations could also contain conditions for maintenance of the site and its technical facilities; instructions for handling of irregular events, such as unexpected leakages in the operational phase; and requirements for contingency plans and for actions if irregular situations should occur. All of these items are discussed in greater detail in Section 4.

2.5. Long-Term Management and Liability

In standard cases, storage sites will need to be covered by extended insurance for the long-term liability and potential risks posed by leakage, seepage, trespass (migration into other areas), and possible contamination. Based on existing literature, liability issues related to CCS can be considered from three perspectives: 1) operational liability associated with the technical CCS system; 2) climate liability associated with climate impacts of leakages; and 3) in situ liability related to health and environmental risks in case of sudden leakages (Stenhouse et al. 2004; de Figueiredo et al. 2005). Because all geologic storage of CO_2 implies some non-zero probability of leakage (i.e. escape of a fraction of stored gas through the injection points, overburden, or fracture over the very long-term), assignment of liability is a key regulatory issue.

There is little known about leakage risk, except that geological history shows that oil and gas reservoirs have been able to securely store oil and gas over millions of years. Much less is known about the leakage risk associated with aquifers, where the largest CO_2 storage potential is found. The IPCC (2005) states it is likely that less than 1% of the stored CO_2 will escape over 1,000 years. Most models of CCS suggest that leakage and seepage will occur at the fastest rates in the first 50-100 years of a project's lifetime, before significant permeability, solubility, and mineralogical trapping occur (Oldenburg and Unger 2003). Other models of CO_2 escape from underground reservoirs show that if non-marginal leakage takes place, little happens in the first 1,000- year period and most effects occur over the following 3,000 to 5,000 years (Lindenberg 2006; Torvanger 2006). In both cases, across several thousand years, there are possible climate consequences of the escaped CO_2. Corrective measures and strategies to anticipate the timing and locations of potential failures must be developed to reduce these effects.

On the other hand, long-term injection of CO_2 on a global scale implies that lower-quality sites are eventually made use of (Hepple and Benson 2002). Handling this leakage-related climate risk requires a certain quality level in terms of minimum retention time for the stored CO_2 (Ha Duong and Keith 2003; Benson 2006). Such a standard gives important guidance for governance, site selection, and operation and for repair activities as necessary. We recommend that the types of climate models described above also be used to develop the preliminary assessments necessary for calculating insurance premiums for CCS projects and leakage-related risks. Until robust systems for assigning liability and insuring projects are also in place, good site selection, management, and repair strategies can reduce leakage risks and their potential impacts.

2.6. Regulatory Compliance and Enforcement

If existing conventions are the primary source of CCS regulation, implementation and enforcement will require a reevaluation of how these existing laws and statutes governing land, mineral, water, sub-sea geological formations, and other rights are applied specifically to CCS. For example, mineral rights are inadequate for CCS projects since many such statutes govern only extraction, not injection, processes.

In order to minimize redundancy and streamline the regulatory process, we recommend that siting and monitoring be delegated to a single authority at the national level, where governance and oversight are likely to be sufficient. The long time horizon for effective storage means that data on the storage site and the injected CO_2 must be recorded in a robust format so that it is available for a number of generations into the future. A national agency could contract monitoring and verification to independent, third-party assessors and consolidate the data collection necessary for such long-term assessments and global emissions management.

2.7. Links to CO_2 Markets and Trading Mechanisms

For the purpose of linking geological CO_2 storage to emissions trading, we recommend that a standard unit for CCS be created; for example, a “Geological Storage Unit” (GSU) equivalent to 1-ton of CO_2 stored in a geological formation in compliance with international rules and standards on site approval, injection, reporting, monitoring, and crediting.[6] This unit would be comparable to the Kyoto Protocol’s Certified Emission Reduction (CER) units for the Clean Development Mechanism, Emission Reduction Unit (ERU) for Joint Implementation, Assigned Amount Unit (AAU) for emissions trading, and Removal Units (RMU) for land use, land use change, and forestry based CO_2 sequestration in industrialized countries. A GSU also would be comparable to European Union Allowances (EUA) under the EU Emissions Trading Scheme (ETS).

[6] A similar terminology (Geologic Sequestration Unit) was developed and proposed by the Plains CO_2 Reduction (PCOR) Partnership (2005). In this report, however, this term is used to collectively describe all target sequestration sites in the PCOR region and not a market-relevant metric.

Specifying a standard unit is simpler than assigning credit for every CCS case. A GSU would most likely be generated *in* the country where storage takes place provided that capture, transportation, and storage are in accordance with international guidelines. The capture of CO_2 by one country and storage by another implies some joint acceptance of the costs and benefits of the eventual emissions reduction. This suggests that one ton of CO_2 emitted in national accounts and reports is entered as emissions until capture, transportation, and storage take place.[7] As soon as a GSU has been approved, the responsible state (or company) may use the resulting GSU or sell it. Thus, trading can take place between companies in a country, companies in different countries, or entire states.

2.8. Risk Communication and Public Acceptance

Based on recent studies of public perceptions, such as the EU ACCSEPT project, awareness of CCS is typically low among the general public.[8] Studies on public perceptions of CCS reveal mixed results, but all emphasize public outreach as a prerequisite of successful technology adoption (Palmgren et al. 2003; de Coninck et al. 2006). To this end, we believe that early risk communication and involvement of stakeholders is crucial for both acceptance of CCS projects and associated regulatory rulings. Public concerns about CCS are similar to concerns about many large facilities, including fear of leakages, health risks, environmental effects, and loss of property value.[9] Just as the term "NIMBY" (not-in-my-backyard) has grown to characterize public response to a variety of projects, CCS regulators need to develop positive public perceptions to avoid the emergence of a NUMBY (not-under-my-backyard) movement.

We recommend a policy of broad and early information dissemination by assigned regulatory agencies to educate potential neighbors of storage sites about CCS technologies and injection/storage processes. This level of outreach is particularly important as most other stakeholders likely will be engaged in project decision making without the need for special

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[7] Under the Kyoto Protocol rules for mitigation are much simpler than for storage, and depending on other decisions on the classification of CCS projects and how such projects are included in emissions markets, a GSU could be generated based on CO_2 captured *by* a country instead of CO_2 stored *in* a country. The IPCC guidelines (IPCC 2006) propose that CCS reporting should be the responsibility of the country where capture takes place. However, reporting based on storage of CO_2 simplifies monitoring of CCS activities.

[8] See the Acceptance of CO_2 Capture and Storage, Economics, Policy and Technology (ACCSEPT) project (http://www.accsept.org/question.htm), Palmgren et al. (2004), and de Coninck et al. (2006) for examples.

[9] Although environment and climate NGOs typically are supportive of CCS technologies, concerns at the NGO level could include arguments that CCS takes away resources from alternative options.

provisions to ensure their inclusion in the planning process. Because the success of early projects and the dissemination of positive results will be essential for establishing a positive perception of CCS, we also recommend that early, prototype storage projects should, wherever possible, focus on the most suitable and secure sites with less ecologically sensitive ecosystems.

3. Details on Storage Site Assessment and Selection

CCS projects currently are predominantly based on EOR methods, where the potential short-term commercial returns are greatest. However, the largest long-term global storage potential is in aquifers and there are few formal standards for assessing site adequacy over the very long term. Examples of assessment methods that could serve as models for CCS regulatory standards include reservoir imaging methods/standards at the Sleipner site (at the Norwegian Continental Shelf) and related techniques mandated by the EPA UIC program. This section expands on the discussion in Section 2.3 on establishing storage and site adequacy with regards to permanency for climate change mitigation and health and environmental standards.

Worldwide, there are a vast number of geological formations that may be suitable for CO_2 storage.[10] The challenge is to identify formations that are best suited to the purpose of long-term storage. To this end, we recommend that selection be based at a minimum on the following criteria, with other criteria added as necessary:

1. The pore volume's capacity to accept injected CO_2
2. The site's ability to trap the injected CO_2 over time (i.e., low risk of leakage)
3. The total storage capacity of the geologic formation
4. Distance to major CO_2 sources and transport infrastructure
5. Transferability of knowledge from operation of the site to other formations
6. Measures of security, including geological stability (risk of earthquakes), leakage risk profiles, political stability, etc.

Candidate sites for storage can be mapped using seismic shooting and other methods to assess criteria 1–3, where drivers of site selection are primarily geographic/ topographical,

[10] Bradshaw and Dance (2004) present a set of maps of global CO_2 storage potential showing the "prospectivity" of sites worldwide. Selected maps are also included in the IPCC special report on CCS (2005).

technical, and economic considerations. In contrast, criteria 4–6 vary based on decisions specific to a given managing entity. For example, the decision to transport CO_2 from a source to storage sites by either ship or pipeline would be driven by the total volumes of CO_2 and the geographic relationships between planned facilities. In cases with larger volumes of CO_2, shorter distances, and longer operation times, pipeline transport is likely to be more competitive than shipping due to the sunk costs associated with large capital investments in pipeline infrastructure. Additionally, there can be foreign policy constraints if pipelines cross national borders (and bring into question the political stability of neighboring countries- criteria 6) or issues of public concern if a pipeline has to depart from the shortest route (e.g., close to a city) because of safety concerns related to small, but non-zero, risks of CO_2 leakage.

We broadly recommend the development of a general system for both site and transport assessment to ensure that the highest quality sites are identified and used early on as the technology and monitoring processes mature. As highlighted above, successful demonstrations are critical for building public acceptance and long-term support of CCS. Possible assessment systems could weight a set of criteria, like those listed above, and assign scores based on each criterion, giving each storage site a total score and ranking on adequacy and suitability. Siting and market decisions can then drive selection of specific sites from different scoring categories and potentially trigger different levels of required monitoring and review. As with any such system, in some cases weighting and comparison across criteria and sites is straightforward, such as the cost per ton of injected CO_2 at one site compared to another. In other cases, direct comparison is difficult; for example, if the risk profile with regard to leakage varies across sites.

4. More on Site Operation Requirements

Although there are a range of established standards for underground injection of a variety of industrial wastes, including nuclear waste, the injection of CO_2 poses several new problems both in terms of its potential mobility (trespass to other areas underground and leakage above ground) and the long time span for which it has to remain securely stored.[11] As a result, assigning responsibility and liability for a site and its stored carbon requires clear systems for monitoring and reporting both during the operating phase and the long-term storage phase. Once injection operations have begun, the focus of regulations should be on monitoring the effectiveness of site managers at following the project's operational plan and on enforcing the requirements and rules for CO_2 injection established through international agreements and national laws and regulations.

Regulation of both the process of properly storing CO_2 and the eventual maintenance of the CO_2 underground requires appropriate, site-specific monitoring and assessment of possible leaks (underground and surface) with a focus on possible or actual effects, including contamination of soils and water (surface and ground); ground heave or displacement; negative human, animal, and plant health effects; and, in the longer-term, potential climate impact.

In the operational phase, monitoring and reporting is likely a task for the company or state assigned responsibility under established conventions. Rules for monitoring and reporting formats and frequency also must be established through international agreements (e.g., under the UNFCCC) or through separate national laws and regulations. If the operational phase lasts longer than two or three decades, we recommend that post-closure responsibility be transferred to a relevant state, as discussed above, after an agreed period (e.g., 30 years). Most importantly, site operations should remain under continuous monitoring for irregularities. Taking reporting of greenhouse gas emissions under the UNFCCC as a model, we recommend a similar system of annual reporting and review, with more in-depth verification every 10 years. All the data related to site operation, monitoring, and verification must be collected and stored in a robust format. For the purpose of securing long-term and safe accessibility of site-specific storage information, a new international database management and/or archival institution, possibly under the United Nations, may also be required.

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[11] The analogy of nuclear waste is a good, but complicated one, when discussing CCS regulation. The catastrophic outcomes of a nuclear accident are ill-suited to describing potential CO_2 leakage effects, and from a regulatory perspective CCS is theoretically "less risky" over time, as CO_2 is permanently dissolved or trapped in the surrounding pore space, while it can be argued that any facilities for nuclear waste storage are likely to become less secure over time. However, regulatory structures, such as the Price-Anderson Act, establishing an insurance pool across all participating nuclear operators provide a valuable example of the types of insurance pools that could be required for long-term CO_2 management. On the other hand, nuclear waste disposal/storage is a very politically complex issue and comparisons of CO_2 storage to nuclear waste could lead to a public backlash or opposition by association, even though the comparison is useful from a regulatory perspective.

5. Additional Notes on Long-Term Management and Liability

Ensuring safe and secure storage of CO_2 is important to avoid counteracting the primary aims of CCS and to minimize any environmental and health risks. Slow, diffuse CO_2 leaks can cause substantial CO_2 releases if large-scale storage has been undertaken. These types of leaks could have gradual, marginal effects on the climate, whereas sudden large leaks are likely to have greater immediate effects on surrounding ecosystems and populations (Ekström et al. 2004, IPCC 2005).

In either case, monitoring of CO_2 storage sites is necessary for both types of leaks. Remote sensing—already used in some industries for CO_2 detection—could be a widespread option for standard monitoring if the technique is adapted to detect small leaks and discern escaped CO_2 from that naturally present in the air. From a climate point of view, several hundred years may be needed for post-injection and post-closure monitoring, until significant dissolution occurs, whereas from an environmental point of view, far less time is likely to be sufficient.

How liability will be assigned will likely vary from country to country, between national stakeholders, and possibly even at different sub-national levels. As a result, our recommendation at this stage is that cooperation between countries and also governments and industry is needed to make decisions on viable monitoring strategies that will achieve widespread acceptability.

6. Summary and Recommendations

This essay only scratches the surface of the regulatory issues facing new storage projects, and given the scale and complexity of CCS issues, it raises as many questions as it seeks to answer. As a result, the recommendations summarized here reflect the preliminary stage of decision-making on CCS regulation, and are simply intended to serve as a starting point for further research and policy discussion.

Recommendation 1: Neither the categories of hazardous waste or non-hazardous waste adequately represent CO_2 stored as part of CCS projects. We recommend that CO_2 be assigned its own classification (e.g., Class VI well under the U.S. EPA's UIC program).

Recommendation 2: All conventions and regulations currently being applied to active CCS projects should be evaluated and harmonized to establish minimum international standards or thresholds for health, safety, and climate risks, above which states can mandate greater stringency.

Recommendation 3: Initial structures to vest or transfer ownership to nations or states should be established as part of the early stages of CCS regulatory planning and implementation.

Recommendation 4: Geological and climate models have been used to estimate leakage, and we recommend that similar models be used to develop the preliminary assessments necessary for calculating insurance premiums for CCS projects and leakage-related risks.

Recommendation 5: A national-level CCS siting and monitoring authority should be established in countries with large storage potential to streamline regulatory processes.

Recommendation 6: A standard “Geological Storage Unit” (GSU) equivalent to 1 ton of CO_2 stored should be created in compliance with international standards and carbon markets.

Recommendation 7: States should establish early information programs on CCS to educate the general public, especially ‘neighbors’ of anticipated early storage sites.

Recommendation 8: Wherever possible, early prototype CCS projects should select highly secure possible sites, such as those in less sensitive ecosystems, to minimize potential effects and to allow the technologies to mature and public acceptance to grow.

Recommendation 9: Develop an international set of criteria (minimum standards) for assessing the suitability of large-scale CCS sites in terms of capture, transportation, and storage.

Recommendation 10: Development of immediate country–to–country and government–industry partnerships to build consensus on CCS regulatory requirements and implementation strategies.

References

Benson, S.M., 2006. Monitoring Carbon Dioxide Sequestration in Deep Geological Formations for Inventory Verification and Carbon Credits. SPE 102833. Society of Petroleum Engineers Annual Technical Conference and Exhibition: San Antonio, TX.

Bradshaw, J., and T. Dance, 2004. Mapping Geological Storage Prospectivity of CO_2 for the World's Sedimentary Basins and Regional Source to Sink Matching. Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies, Vancouver, BC, CA, September 5-9, 2004.

Coninck, H.C. de, et al., 2006. Acceptability of CO_2 Capture and Storage. A Review of Legal, Regulatory, Economic and Social Aspects of CO_2 Capture and Storage. ECN-C--06-026.

de Figueiredo, M. D. Reiner, et al., 2005. Framing the Long-Term In-Situ Liability Issue for Geologic Carbon Storage in the United States. *Mitigation and Adaptation Strategies for Global Change*. **10**: 647-657.

Ekström C., A. Andersson, et al., 2004. *CO_2-lagring i Sverige*, Elforsk report no 04:27.

EPA. 2007a. Using the Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects—UIC Program Guidance (UICPG # 83). Washington, D.C.

Ha-Duong, M., and D.W. Keith, 2003. Carbon Storage: The Economic Efficiency of Storing CO_2 in Leaky Reservoirs. *Clean Technologies and Environmental Policy*. **5** (3/4): 181-189.

Hepple, R.P. and S.M. Benson, 2002. Implications of Surface Seepage on the Effectiveness of Geologic Storage of Carbon Dioxide as a Climate Change Mitigation Strategy. Lawrence Berkeley National Laboratory: LBNL-51267.

IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 1, General Guidance and Reporting.* http://www.ipccnggip.iges.or.jp/public/2006gl/vol1.htm

IPCC, 2005. Carbon Dioxide Capture and Storage: Summary for Policymakers and Technical Summary. Intergovernmental Panel on Climate Change, ISBN 92-9169-119-4.

Keith, D.W., et al., 2005. Regulating the Underground Injection of CO_2. *Environmental Science & Technology*. **39** (24): 499A-505A.

Lindeberg, E., 2006. The Quality of a CO_2 Repository: What Is the Sufficient Retention Time of CO_2 Stored Underground? SINTEF Petroleum Research Report: Trondheim, Norway.

OECD/IEA, 2005. Legal Aspects of Storing CO_2. International Energy Agency: Paris, France.

Oldenburg C.M., and A.J Unger, 2003. On Leakage and Seepage from Geologic Carbon Sequestration Sites: Unsaturated Zone Attenuation. *Vadose Zone Journal*. **2**: 287-196.

Palmgren, C.R., et al., 2004. Initial Public Perceptions of Deep Geological and Oceanic Disposal of Carbon Dioxide. *Environmental Science & Technology* **38** (24): 6441-6450.

Plains CO_2 Reduction (PCOR) Partnership, 2005. Geologic Sequestration Potential of the PCOR Partners Region. PCOR Topical Report: Grand Forks, ND.

Stenhouse M., M. Wilson, et al., 2005. *Overview of Long Term Framework for CO_2 Capture and Storage*. IEA GHG Programme, Report No. PH4/35.

Torvanger, A., 2006. Climate Impacts of Leakage from Geological CO_2 Storage. Presentation at the UNFCCC SB24 Meeting, May 20, 2006: Bonn, Germany.

Wilson, E.J., T.L. Johnson, et al., 2003. Regulating the Ultimate Sink: Managing the Risk of Geologic CO_2 Storage. *Environmental Science & Technology* **37** (16): 3476-3483.

Wilson, E.J., and M. A. de Figueiredo, 2006. Geologic Carbon Dioxide Sequestration: An Analysis of Subsurface Property Law. *The Environmental Law Reporter ELR News & Analysis* **28** (11): 10631-10652.