Environmental Bonds and the Problem of Long-Term Carbon Sequestration

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Abstract: The potential to capture carbon from industrial sources and put it in long-term storage, known as carbon capture and sequestration (CCS), is widely recognized as an important option to reduce atmospheric carbon dioxide emissions. Specifically, CCS has the potential to provide emissions cuts sufficient to stabilize greenhouse gas levels, while still allowing for the continued use of fossil fuels. In addition, CCS is both technologically-feasible and commercially viable compared with alternatives with the same emissions profile. Although the concept appears to be solid from a technical perspective, initial public perceptions of the technology are uncertain. Moreover, little attention has been paid to developing an understanding of the social and political institutional infrastructure necessary to implement CCS projects. In this paper we explore a particularly dicey issue – how to ensure adequate long-term monitoring and maintenance of the carbon sequestration sites. Bonding mechanisms have been suggested as a potential mechanism to reduce these problems (where *bonding* refers to financial instruments used to ensure regulatory or contractual commitments). Such mechanisms have been successfully applied in a number of settings (e.g., to ensure court appearances, completion of construction projects, and payment of taxes). The paper examines the use of bonding to address environmental problems and looks at its possible application to nascent CCS projects. We also present evidence on the use of bonding for other projects involving deep underground injection of materials for the purpose of long-term storage or disposal.

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1 Introduction

Carbon capture and sequestration (CCS), the capture and underground sequestration of CO_2 from power plants and other industrial sources, is a potential policy option for near-term reductions in atmospheric greenhouse gas emissions. The technologies for capturing, transporting, and injecting CO_2 from industrial facilities are generally well understood and achievable (Gale and Kaya 2003; IPCC 2005) and there are a number of on-going research efforts to improve and refine the process (National Energy Technology Laboratory 2005). Because CCS is compatible with existing fossil energy infrastructure, its deployment is likely a less expensive means to reduce greenhouse gas emissions in the coming decades compared to major additions to energy capacity of technologies such as solar energy and nuclear power (Herzog et al. 2005). Indeed, there is substantial interest in using CO_2 for enhanced oil recovery projects, and these may serve as some test cases for both technological and regulatory implementation of CCS technologies.[1]

Although CCS appears to be solid from a technical perspective, a number of important scientific and institutional uncertainties remain. With respect to the sequestered CO_2, there are concerns both about its migration underground, as well as possible leakage and escape to the surface (IPCC 2005). Surface releases would undermine efforts to stabilize atmospheric CO_2 concentrations, and could, in a worst case scenario, pose ecological and human health risks (IPCC 2005). With respect to the institutional setting, initial public perceptions of CCS are uncertain, ranging from slightly positive, to slightly negative (Itaoka et al. 2004; Palmgren et al.

[1] An enhanced oil recovery project in Texas' Permian Basin injects approximately 25 million tons of CO_2 a year (Wilson et al. 2003), and many EOR and sequestration projects are in the planning stage worldwide (IEA 2004).

2004), and there has been relatively little attention to how extant regulatory and institutional infrastructure would accommodate the technological requirements of large-scale CCS projects.[2]

A central question of both scientific and regulatory interest is how to ensure adequate long-term monitoring and maintenance of sequestration sites. Long-term storage costs are expected to be a trivial percentage of a CCS project (Herzog et al. 2005).[3] Yet, current regulations for underground injection primarily address the operational phase (when the injection takes place), rather than the long-term monitoring and risk management issues (Wilson and Gerard 2007). Specifically, as the sequestration site reaches its storage capacity,[4] there will need to be steps taken to close the site and to monitor the behavior of the injected material and verify that the injected CO_2 remains underground. Ensuring adequate institutional and regulatory mechanisms to manage long-term risks may well be a key to allaying public concerns and the effective siting and implementation of sequestration projects (Schively 2007).

Our objective is to examine the possible application of financial assurance mechanisms, generically referred to as *bonding*, to address long-term risk management issues for CCS storage and disposal sites.[5] Bonding is widely used to enforce contractual and regulatory provisions. Typically, an agent (or a third-party) posts a bond as a promise of compliance, and the bond is released when the promise is satisfied. In the context of mining, for example, regulations often

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[2] Exceptions include(Tsang et al. 2002; Wilson et al. 2003; Bliss 2005; Keith et al. 2005), and (de Figueiredo et al. 2003)

[3] In terms of costs of electricity generation, capture costs are the greatest component – 1.8 to 3.4 ¢/kWh for pulverized coal plants; 0.9 to 2.2 ¢/kWh for integrated gasification combined cycle coal plants; 1.2 – 2.4 ¢/kWh for natural gas combined cycle power plants. Transport and sequestration costs range from -1 to 1 ¢/kWh (the negative values are possible if captured CO_2 is sold for use in enhanced oil recovery or enhanced coal-bed methane production. These transport costs would be considerably higher if sequestration sites are not located within a reasonable distance from the plant (Herzog et al. 2005).

[4] When the injection well pressure needed to inject nears the lithostatic pressure safety margin, a well is considered "full" and injection ceases.

[5] Bonding includes the use of surety bonds, performance bonds, letters of credit, cash, treasury bonds, certificates of deposit, or other forms of liquid assets.

require post-mining site reclamation.[6] A bond is posted to ensure this is satisfied, if compliance is incomplete or insufficient, the firm forfeits the bond and the proceeds are used to finance reclamation.

Despite the promise of bonding mechanisms for environmental issues (Costanza and Perrings 1990), financial assurance mechanisms entail tradeoffs that limit their scope and effectiveness (Shogren et al. 1993).[7] In practice, the application of bonding to environmental projects has been narrow and the success mixed (Boyd 2002). Therefore, investigating the potential effectiveness of bonding within the context of regulating CCS projects is of immediate interest to public policy. In its efforts to develop the first integrated sequestration power plant, for example, the Department of Energy is exploring potential liability associated with the CO_2, including statutory liability caps, state insurance programs, and bonding programs "similar to that used for the installation of an underground gas storage field or well storage subject to the UIC program or mine reclamation" (p. 44, (FutureGen Industrial Alliance Inc. 2006).

We describe the technical and institutional context for the closure of carbon sequestration sites and examine the possible application of bonding within this context. To do this, we provide an overview of the technology and current regulations governing the underground injection and disposal of materials under U.S. law. Because no empirical evidence is available on closure of carbon sequestration sites, we examine bonding rules for underground injection and oil and gas wells in Texas, California, and Illinois. Finally we offer possible avenues for empirical research to test the effectiveness of bonding for long-term sequestration projects.

[6] Bonding is compulsory for coal mining projects under the Surface Mining Control and Reclamation Act of 1977. It is also often required for hardrock mining projects on federal lands under Department of Interior (Bureau of Land Management) or Department of Agriculture (Forest Service) regulations. In most cases, states have primacy in regulating hardrock mining activities, and state agencies require some form of environmental assurance, typically a reclamation bond (McElfish et al. 1996).

[7] Other analyses of actual or potential applications of bonding include Macauley (1992), Cornwell and Costanza (1994), Weersink and Livernois (1996), and Mooney and Gerard (2003) (Macauley 1992; Cornwell and Costanza 1994; Weersink and Livernois 1996; Mooney and Gerard 2003).

2 Technology, Site Closure, and Regulation

The basic technical requirements of a CCS project are to first capture CO_2 from power plants or industrial sources and transport it to the sequestration site. The CO_2 is then injected underground into deep geological formations (roughly deeper than 1 km), such as depleted oil and gas reservoirs, saline aquifers, and unminable coal seams. To the first order, injecting CO_2 into an injection well is essentially the reverse of pumping oil or water from a confined aquifer. The injection pressure must exceed the formation pressure, and the CO_2 fills the permeable pore space within the sedimentary rocks, essentially trapped by less permeable rock layers which impede fluid migration. CO_2 will be sequestered either as a gas, a dense supercritical gas,[8] or a liquid. Depending on reservoir temperature and pressure injected, in almost all circumstances, except deep ocean subsurface sequestration, CO_2 will be less dense than the brine present in the reservoir. Because injected CO_2 will initially be more buoyant than the receiving waters, upwards and lateral migration within the subsurface is an important consideration for modeling and managing subsurface behavior. Importantly, storage integrity will become more secure over time as CO_2 is trapped in rock capillaries, geochemical reactions dissolve CO_2 in formation waters (centuries), and eventually convert it to minerals like calcium carbonate (millennia) (Pruess et al. 2004). Thus an effective geologic sequestration site will keep large volumes of a buoyant fluid underground for centuries to millennia.

The IPCC report on CCS (2005) stresses that in excess of 99% of injected CO_2 is very likely (probability between 90 to 99%) to remain in appropriately selected geological reservoirs for over 100 years. While the probability for leakage to the surface appears low, identifying

8 CO_2 is considered a supercritical fluid at temperatures greater than 31.1°C and 7.38 MPa (critical point). CRC Handbook of Chemistry and Physics, CRC Press, 60th edition, Table II, F-89 (1979) (CRC 1979).

potential risks for CCS and developing mitigation strategies will help to ensure that the technology is able to adequately address any potential problems. With respect to global climate change, the biggest concern is that there will be surface leaks, allowing CO_2 releases to the atmosphere and negating any climate benefit from sequestration. Persistent leakage could result in diminishing benefits in carbon emissions reductions associated with a CCS program.

There are a number of other risks associated with CCS associated both with the sheer volume of injected material, as well as the specific properties of $CO_{2,}$ and these risks vary for given stage of a CCS project, local and regional geology, and will likely decrease with time(IPCC 2005). Large surface releases could also pose direct health risks to humans, both in the form of immediate death from asphyxiation or effects from prolonged exposure of high concentrations of CO_2. Slow CO_2 seepage into the near subsurface could also harm flora and fauna, and potentially disrupt local ecology or agriculture. There are also a number of potential risks associated with injected CO_2 even if it remains underground, including displacement of saline groundwater into potable aquifers, incitement of ground heave, and even inducement of seismic events. While the probability of these risks is very low, managing CCS injection for ensuring human and environmental safety is an important component of future program success. An example of a project life-cycle is shown in Figure 1.

The project life-cycle encompasses the development and use of injection wells, including site selection and construction, operation and injection, and closure, plugging and abandonment. Of interest here is the closure, plugging and abandonment period. As the operation and injection phase ends, the well is plugged with concrete and abandoned, to ensure that injected or *in situ* fluids will not migrate and contaminate underground sources of drinking water or escape to the surface.

3 Policy Objectives and Policy Alternatives

The principal objective of carbon sequestration is to stabilize or reduce atmospheric CO_2 emissions, but in doing so, the on-the-ground application of this objective potentially poses local and regional risks. The objective of local policies is to take appropriate measures to mitigate health and environmental risk.

In the U.S., the common law liability system serves as the default option for addressing these risks. In the current context, for example, if we assume that the injection and storage of carbon is handled by a private party, then any outside party that suffers damages associated with the sequestration can petition the courts for relief (monetary compensation, injunctive relief, or both). There are, however, a number of well-known limitations of the common law in promoting deterrence, including the probability of detecting the harm, the assignment of blame, the latency period between cause and effect, and the potential judgment-proof nature of the firms (Shavell 1984; Shavell 1986).

Certainly, handling the risks associated with CO_2 sequestration will not be left solely to the domain of the private liability system, but instead liability will be augmented by some regulatory structure (Wilson and Gerard 2007). The underground injection of waste, for instance, is regulated at both the state and federal level and regulatory stringency depends on both the what is being injected and where injection occurs. However, a review of the limitations of liability in handling risks is instructive for the development of an understanding of the usefulness of bonding mechanisms.

The first concern is the ability to detect and assign blame for the harms generated. If there are problems with the storage facility, such as a surface leak in a remote area, then the damage could be difficult to detect, making it unlikely that any party would bring suit for damages. For example, if there are several possible sources an environmental or safety harm, it is often difficult for a plaintiff to demonstrate the source of the problem. These issues are not likely to present major challenges for current regulatory setting. Technical solutions, well-tailored site monitoring for the post-closure period, are being developed to address the detection issue (Benson et al. 2004). In addition, the assignment of blame is likely to be uncontroversial if a single operator is responsible for ensuring the integrity of the storage facility.

A second challenge to liability is that firms responsible for injection and storage could lack the necessary funds to address any problems that result. In such cases, the firm's assets are the upper bound on liability and the deterrent effect of liability will be insufficient. In this case the firm is said to be "judgment-proof," and *ex post* damage awards will not provide adequate deterrence against the risky activity.[9] In the event that a firm goes bankrupt, there will be no funds available to continue site monitoring and maintenance, or to address any problems that arise. This can be an acute problem in cases where firms become insolvent as the result of the financial obligations arising from some catastrophic environmental or safety mishap.

A third problem with liability is the time horizon between cause and effect (Shavell 1986; Ringleb and Wiggins 1990). Given the time horizons for sequestration, there could be an extended latency period before any underground seepage or surface leaks occur. This presents several problems. First, a responsible party may no longer be in the position to address the damages by the time that problems arise. Second, because problems may only arise after some extended period, firms might lack the incentive to take necessary precautions to ensure the long-term integrity of the storage facility.

[9] Shavell (1986) describes the limitations of liability in internalizing external costs. Ringleb and Wiggins (1990) argue that large firms form subsidiaries as a means to protect assets of parent firm from environmental and safety liabilities. Grant and Jones (2003) examine this contention using U.S. Toxic Release Inventory data, and find significantly higher emission rates for subsidiaries.

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3.1 Bonding as a Complement to Liability and Regulation

The need for bonding (or other financial assurance requirements) stems from the standard moral hazard problem – if there are high costs of monitoring performance, firms may respond by "shirking" on their environmental and safety obligations. The primary concern is that the public will be saddled with the responsibility to remediate environmental damages and safety risks. Liability and bonding mechanisms each provide financial incentives for firms to address such effects. Under liability, a damaged party initiates litigation to recover damages for any harm caused, and the possibility of a damage award is the incentive to ensure due care. However, the deterrent effect of tort liability is insufficient if the firm lacks enough assets to cover damages. In effect, the firm's assets are the upper bound on liability. In this case the firm is said to be "judgment-proof," and *ex post* damage awards will not provide adequate deterrence against the risky activity.[10]

Bonding has several distinct differences from reliance on a liability rule. First, the bond is posted up-front as opposed to being settled after-the-fact. Second, if the firm fails to comply with agent fails to perform, the forfeited collateral is immediately available to remedy the performance failure. Third, the bond shifts the burden of proof from the regulator proving that harm was done to the firm to prove that compliance criteria were met. Finally, the public sector is only protected up to the amount of the bond posted, not for the full amount of potential damages. If the firm remains solvent, regulators can seek a remedy through the courts.

[10] Shavell (1986) describes the limitations of liability in internalizing external costs. Ringleb and Wiggins (1990) argue that large firms form subsidiaries as a means to protect assets of parent firm from environmental and safety liabilities. Grant and Jones (2003) examine this contention using U.S. Toxic Release Inventory data, and find significantly higher emission rates for subsidiaries.

An important caveat is that a performance bond is not the same as insurance. Insurance premiums are calculated to cover expected payments, whereas sureties provide bonding on the basis of credit principles, with the bond premium covering underwriting expenses and assuming a small chance of default. Surety providers may respond to uncertainty by requiring a higher percentage of the bond amount as a premium, requiring substantial collateral, or simply refusing to underwrite the bond. This could have the advantage of reducing possibility that firms will shield liability by contracting to subsidiaries.

3.2 Public Ownership

One of the major issues for long-term CO_2 storage will be that in the long-term it seems unlikely that any legislative or regulatory structure would give private firms long-term storage responsibilities in perpetuity. Instead, there will likely be some period where firms are liable, and then the long-term responsibility is turned over to the public sector. Under the current regulatory framework (40 CFR 144-146) an operator must submit a well closure and abandonment plan that identifies steps for closing the well (plugs, cement, cost) and any subsequent post closure monitoring activity. While a performance bond is required to ensure proper plugging and abandonment, in the vast majority of cases no long-term monitoring is required and the bond is released upon well closure.

4 Bonding: Limitations and Challenges

There are a number of potential problems associated with bonding (Shogren et al. 1993; Boyd 2002; Mooney and Gerard 2003). First, bonding is costly, both in terms of the associated transaction costs and in terms of the liquidity constraints imposed on firms. As is the case with liability, bonding becomes more costly as complexity increases, hence limiting its effectiveness.

If there are low costs of monitoring compliance and the firm poses a limited default risk, then mandatory bonding requirements could be a pure cost both to regulators and firms. One implication is that if bonding is costly there will be less of the regulated activity, and possibly fewer firms involved.

A bonding requirement can also tie up the operating capital funds of a firm, imposing liquidity constraints on firms. This liquidity constraint becomes more binding as the deposit amount increases. The use of a third party provider, such as a surety, is one means to reduce – but not eliminate – the liquidity constraint. The firm must pay an annual premium, and the bond amount is also a liability on the firm's balance sheet that adversely affects the firm's credit. These premiums depend on a number of factors. In the case of hardrock mining, for example, the premium is often one to five percent of the face value of the bond, though large firms can secure a surety by posting less than one percent, and small firms may face premiums of 15 to 20 percent or higher (Gerard 2000).

In some cases, a third-party (e.g., a surety provider) will post a bond on behalf of the firm, agreeing to cover the payment in the event of a default. In such cases, there is typically not an actual transfer of funds; rather the surety must cover the default amount if the firm fails to comply with its obligations. The presence of the third party has the advantage of transferring a portion of the default risk from the public to the private sector. However, the third-party is only liable for the amount of the bond, although remediation costs may far in excess of the amount of the bond. Any excess costs are likely to be absorbed by the public – either the problem is not addressed, or the costs are borne by the public purse. In some instances, regulations require the use of a third- party provider. Even if a surety provider covers the obligation, the firm has to pay annual premiums and the bond amount remains an accounting liability.

A potential disadvantage of reliance on liability rules and/or bonding as deterrence mechanisms is the potentially long latency period between the firm activity and the potential harm (Shavell 1986; Ringleb and Wiggins 1990), for example, the injection of the CO_2 and the realization of the leakage. This could lead to two possible problems. For long time horizons this is a problem because the responsible party may go out of business before the damage occurs. In the context of environmental bonds, the constraint of having capital tied up for long periods of time is a problem. In addition, because of uncertainty as time horizons expand, surety providers are unlikely to underwrite bonds over time horizons where there is considerable uncertainty.

As is the case with liability rules, the long latency period between the firm activity and the potential harm can present problems for bonding mechanisms. Not only is it possible that responsible parties will go out of business before the damage occurs, the bonding obligations could tie up capital indefinitely. Because of uncertainty as time horizons expand, surety providers are unlikely to underwrite bonds over time horizons where there is considerable uncertainty. CCS projects will require clearly delineated time frames and levels of responsibility.

4.1 Setting the Bond Amount

Setting the level of the bond is a central dimension of bonding requirements. Because of the costs involved on the side of the firm and the potential public liabilities, it is often a contentious issue. Gerard (2000) provides a simple model to illustrate that firms with deep pockets are likely to comply with regulatory requirements even if the amount of the bond posted is less than the expected compliance costs. In many cases, firms and regulators interact on a number of projects, and the repeated interactions and reputation effects act as a check on opportunistic behavior. In addition, firms are liable for damages or risk reduction, then defaulting on a bond will only lead to subsequent litigation. An implication of these reputation effects and liability rules is that the firm's financial position should be a factor in determining whether a bond is appropriate. A second implication is that rather than setting bond amounts at the worst-case scenario (as is often advocated by environmental interests), compliance can be induced even if bond requirements are less than expected remediation costs. Being able to estimate remediation costs is a crucial component for setting the bond amount.

In the following sections we will discuss how financial assurance requirements can augment current system of regulation and liability applied to UIC programs. Certainly, public policy will be contingent on if and when long-term responsibility for storage facilities reverts from private firms to the public sector.

5 Adapting Current Regulations for Carbon Sequestration Projects for Long-Term Care

The regulatory experience with oil and gas production wells dates back to the beginning of the 1900s, with the establishment of state conservation commissions to limit waste in fossil fuel production. By the 1930s, state regulation required firms to using underground injection wells to dispose of produced oil and gas waters. Federal regulations for underground injection were promulgated in 1990 and today both federal and state regulatory regimes address underground injection for a wide-variety of materials in a number of different geologic environments. While oil and gas production well regulation is largely implemented by the states, current federal Underground Injection Control (UIC) regulations underpin all state programs, and address all fluids that are injected underground. In both federal and state programs, there are essentially no post-closure monitoring requirements. This regulatory framework provides a likely starting point for CCS programs, as pilot sequestration projects are currently managed under this regime. However, there are a number of key differences that will require adaptation of current regulations to accommodate carbon sequestration projects.

5.1 Closing a Carbon Sequestration Facility

Given the need to prove long-term sequestration coupled with the buoyancy of injected CO_2, closure of a sequestration project may differ markedly from current UIC practice. Unlike injection under current UIC regulations, post-closure monitoring could be an essential part of the program. Monitoring to identify CO_2 leaks to the surface for both climate and local environmental health and safety considerations will be essential for establishing site performance. Such monitoring will also validate whether the behavior of the sequestered CO_2 is consistent with predicted *in situ* behavior. If leakage to the surface does occur, additional remediation might be required. Depending on monitoring requirements, the project closure can proceed with the removal of surface facilities and the plugging and abandoning of injection wells.

These tasks would be part of a "post-injection operation" (Keith and Wilson 2002) characterized in Table 1. After injection of CO_2 is completed, the formation pressure will begin to subside and monitoring for storage integrity can continue. Once these conditions are met, a "post-closure" phase begins, with a plan of operation suitable to the risk profile of the site. Regulations could be tailored towards the management of both global and local risks, including the probability of a site leakage, the potential magnitude of such leakages, and current and future population exposures. Monitoring and verification would serve the dual purpose of managing local risks and accounting for global mitigation targets.

Given the long storage times necessary for CCS projects (hundreds to thousands of years), mechanisms to ensure post-closure monitoring and verification of storage sites is a key component of any future regulatory scheme. The required length of long-term monitoring will depend on policy and technical factors; including the type of storage facility, the size of the project, whether or not the site experienced persistent leakage; and the knowledge about the long-term behavior of the subsurface CO_2. It is expected, for example, that abandoned gas fields will be more predictable than saline aquifers because of their proven record as a gas trap (Benson 2007). Initial research suggests that storage projects will become more secure over time, as natural mechanisms decrease buoyancy driven flow and any initial problems undergo remediation, and injection pressures decrease (IPCC 2005). Institutional factors, such as ecological risk or populations affected by leakage or whether there are on-going legal disputes, could also affect nature of long-term monitoring requirements. It is not clear who will be responsible for the indefinite stewardship, but regulatory authorities or other public governing bodies are likely candidates.

5.2 Adapting Current Closure Regulations to Carbon Storage Projects: A three-tiered approach

Many current oil and gas production wells and all wells regulated under the UIC program require the use of bonds to help ensure proper plugging and abandonment of injection wells. For UIC disposal wells, the bond is released after plugging and abandonment procedures have been satisfied. Closure of oil and gas production wells differs significantly across jurisdiction, with some states releasing the bond six months after successful oil production and others waiting until the well is actually plugged and abandoned. The time frame covered by all of these bonds stretches at most, for the operational lifetime of the well, tens of years. This time frame appears to be appropriate for the operational phase of CCS projects and can encourage proper site management and well closure. However, it is unlikely that that bonding, as it is used today, could be effectively applied for the duration of the post-closure CCS project. Bonding mechanisms are considered effective for medium-term and fixed time horizons, especially where there is some explicit task to be completed, and not the centuries-long time horizons for sequestered CO_2 (Shogren et al. 1993). Any long-term care program must be flexible enough to not discourage private investment in CCS, yet robust enough to ensure care of public and environmental health and not place an undue burden upon the public.

An alternative possibility would be to develop a blended approach toward managing long-term risk and liability. This approach would define different post-closure management duties, with environmental and public health concerns covered by one set of instruments, and long-term climate considerations by a complimentary set.

Temporally, a tiered structure allows for a clear division of responsibility. In the first phase, active operator funded bonding covers all risk management; in the second phase active bonding by the operator would end, yet liability from an unanticipated accident would continue. During this phase, MMV activities would be covered by publicly run or pooled financial mechanisms, potentially supported through funds collected during the active phase of the project. The third phase would culminate in public assumption of care—both management and liability—and ensuring long-term standards of care are met. Such an approach could be directly linked to a project's evolving risk profile and would allow for a post-closure care regime to tailor itself to business system demands and specific site risk yet ensure that public interest and welfare is protected. These periods could be delineated by either performance-based (e.g., pressure levels in injection reservoir or percentage of CO_2 dissolved into formation fluid) or prescriptive criteria (after 10 or 25 years).

For the first period of post-closure care, the project operator would be responsible for posting a bond and liable for any potential damage. Monitoring and verification of site performance would be regular and validate geological formation performance. The operator would be responsible for remediation of environmental health and safety risks during this period and any surface leakage would need to be offset under a climate regime. As CCS project security is projected to increase with time, after established prescriptive (10 to 25 years after plugging and abandonment) or performance parameters (formation pressure, geophysical or geochemical measurements) were met, the bond could be released and the project would move onto the second phase of post-closure monitoring. This allows for a clear delineation of responsibility and liability over a set time period, key components for any bonding mechanism.

During this second phase, the operator would still bear liability for unexpected accidents, but they would not be required to post a bond. At this phase, some public or private pooled financial assurance mechanism could be employed. Again, transition from this phase to the next would occur when safety was proven and continued monitoring was deemed unnecessary and could be linked to either performance or prescriptive measures. The advantage here is that capital would be available for other investments. The pooled public or private funds could be collected over the active injection phase of the project.

The third and final post-closure phase would transfer CCS project liability and managerial responsibility to the state. By this phase, the project performance should be 'proven' and public assumption of liability will be focused primarily upon record keeping and administrative duties. Established operational experience and site performance data will allow for a better understanding of when the transition from active to passive project management could take place.

In effect, bonding mechanisms would be used twice; first, as they are today during the operational phase to ensure proper well plugging and abandonment procedures are followed, and second, in a tiered system, for adequate post-closure care.

6 Bonding Provisions for Oil and Gas Production and UIC Class II Disposal Wells

Within this context, it is important to evaluate the effectiveness of current bonding mechanisms. Both the UIC regulations and state oil and gas production wells require bonds be posted when the operator is granted a permit to create incentives for following plugging and abandonment procedures. While this analysis is important for understanding the role of bonding, it is also important for assessing security of future CCS sites. Improperly abandoned wells are potential conduits for CO_2 migration to the surface and greatly decrease the security of stored CO_2.

We examined bonding practices by reviewing legislation and regulatory code, analyzing available data, and interviewing state regulators for UIC Class II disposal wells and oil and gas production wells in Texas, California, and Illinois. These states were chosen because of their potential role in deploying CCS technology. Both Illinois and Texas are finalists in the DOE's FutureGen project, and California is the site of a new British Petroleum initiative which aims to burn petroleum coke, capture the CO_2 and sell it for enhanced oil recovery. This is relevant both because early CCS projects are likely to be linked with enhanced oil and gas recovery projects and this is the largest and most active well class that provides the broadest representation of permitting and bonding.

6.1 Bond Amounts and Release Provisions

The basic regulatory provisions for the three states are listed in Table 2 and show substantial variation across states. Wells are plugged to ensure that fluids from other strata do not migrate up the well bore and contaminate underground sources of drinking water, and each state requires operators to plug wells to ensure groundwater protection. Each state has financial assurance requirements, whereby operators have to post cash, a surety bond, or a certificate of deposit. Texas and Illinois also allow letters of financial assurance to be provided. The available data did not allow for an analysis of the role of self-insurance by a company.

Although federal regulations do not require any specified bond amount, many of the state statutes do, ranging from $4,000 to $15,000 per well and providing blanket bonds to cover entire well fields. California requirements are substantially higher than in Texas and Illinois, but provisions for release of the bond vary substantially. In Texas, for example, a bond is released only after proof of plugging and abandonment. Curiously, both California and Illinois release production-well bonds prior to well closure – six months after the start of operation in some California cases, and two years after proper compliance with oil and gas requirements in Illinois. For federally regulated UIC Class II disposal wells, states only release the bond or financial instrument after all plugging and abandonment requirements are met.

6.2 Preliminary Descriptive Statistics

Bonding involves a tradeoff between encouraging regulatory compliance (plugging) and discouraging non-compliant activity. Figure 2 shows both the number and the distribution of bonded and unbonded operators in Texas, and illustrates possible evidence of a tradeoff between bonding and number of operators. The phase-in of a universal bonding requirement led to most operators being bonded, the number of active wells dropped 15 to 20 percent. Even so, the Texas financial assurance requirements do not cover the full costs of plugging orphaned wells. There are approximately one to two bond forfeitures in Texas each month. While average plugging costs for 2006 are roughly $5,900 per well (Texas 2006), the forfeited bonds typically cover only 25 percent of the cost of plugging an abandoned well (Poe 2006).

A second question involves the type of financial instrument used. Table 3 shows the distribution for the 241 active operations in California since 2004. The descriptive statistics show a 4:1 ratio between cash and surety bonds, and that surety bonds cover a much higher dollar amount than operations covered by cash. A third issue is whether bonds ensure compliance with plugging requirements, which is not comparable given the summary statistics available. Overall, the ratio of orphaned wells to active wells is 9 percent for Illinois, 4 percent for Texas, and 1 percent for California.

In addition to collecting fees for bonding, most states also have an "orphan well program" to ensure funds are available to plug wells that have been abandoned. Such programs receive their funding from the state legislature, fees from oil and gas permits and operations, and forfeited bonds. In Texas, forfeited bonds made up approximately $1.5 million of the $20 million Oilfield Cleanup Fund in 2004 and 2005 and are expected to be larger in 2006 (Poe 2006). In both California and Illinois, this number is not actively tracked and is not a major program funding source. Politics governing the funds available for plugging orphaned wells also vary significantly, with Texas currently placing a high priority on plugging abandoned wells (Poe 2006). These figures show significant variation in the operation of state programs for managing oil and gas wells within states where CCS projects are likely.

6.3 Implications for CCS and Bonding

There are clearly differences between the way that bonding is used now and what will be necessary to cover the needs for long-term care for CCS. The tiered system proposed could allow for an adaptation of bonding to cover long-term CCS care. By delineating responsibility and establishing clear time-frames for risk and liability transfer, this framework establishes several necessary components for bonding.

How the CCS risk profile evolves over time and across different geologic formations is a necessary component to establishing appropriate indemnification strategies. It is possible to imagine CCS project operator focused upon actively managing the site risk profile if she were able to lower project financial costs, especially long-term capital costs. Additionally, bounding the cost of site remediation activities is crucial for setting bond amounts. Experience with oil and gas wells informs this discussion, though further research clarifying CCS specific risks and costs will support the use of bonding in long term CCS care.

Another consideration is proving compliance and establishing when the bond can be released. Clear tasks or conditions for bond release and proving compliance are necessary for the system to function. Whether prescriptive or performance-based criteria are more compatible for bonding requirements depends primarily on their ability to provide clarity for proving compliance. Bonds are but one financial mechanism that could be used to ensure responsibility over the post-closure period. Further examination of other financial mechanisms and the advantages and disadvantages of each for CCS needs to be further examined.

7 Conclusions

There are a number of conditions where bonding is likely to be an effective mechanism for ensuring compliance. These are factors related to low transaction costs (well-defined agreements and agreed upon definitions of compliance and non-compliance, a high probability of detecting non-compliance, a limited number of contracting parties, and a well-defined time horizon for regulatory compliance); a low bond value relative to the regulated firm’s assets, and no irreversible environmental effects. To some extent, these factors are in place for the closure of carbon sequestration projects, though there are clear difficulties with monitoring requirements. Due to the ambiguous time horizons and absence of a clearly-defined compliance task, the likely effectiveness of bonding for a post-closure period is much less clear.

In principle, it appears that current regulatory policies in the U.S. should be able to accommodate carbon sequestration projects using and adapting frameworks similar to those in place in the UIC program.

However, there has been little in the way of rigorous empirical analysis of the effectiveness of bonding programs that might be applied to carbon sequestration projects. A key challenge of further empirical investigation will be to explore whether and how bonding might be applied in the post-closure period and over a longer time horizon. The limitation of these data in the context of carbon sequestration is that they do not cover any post-closure period. Given the high stakes of public acceptance for the implementation of sequestration projects, this should be a fruitful avenue for exploration.

References

Benson S M, Gasperikova E, Hoversten G M, 2004, "Monitoring protocols and life-cycle costs for geologic storage of carbon dioxide" *Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies (GHGT-7), September*: 5–9

Benson S M, 2007, "Monitoring Geologic Storage of Carbon Dioxide" in *Carbon Capture and Sequestration Integrating Technology, Monitoring, Regulation*. Wilson E J,Gerard D (Blackwell Academic, Ames, IA)

Benson S M, Gasperikova E, Hoversten G M, 2004, "Monitoring protocols and life-cycle costs for geologic storage of carbon dioxide" *Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies (GHGT-7), September*: 5–9

Bliss K, 2005 *Final Report: A Regulatory Framework for Carbon Capture and Geological Storage,* Interstate Oil and Gas Compact Commission (Oklahoma City, OK)

Boyd J, 2002, "Financial Responsibility for Environmental Obligations: Are Bonding and Assurance Rules Fulfilling Their Promise?" *Research in Law and Economics*

Cornwell L, Costanza R, 1994, "An Experimental Analysis of the Effectiveness of an Environmental Assurance Bonding System on Player Behavior in a Simulated Firm" *Ecological Economics* **11**: 213-226

Costanza R, Perrings C, 1990, "A flexible assurance bonding system for environmental management" *Ecological Economics* **2**(1): 57-75

CRC, 1979 *CRC Handbook of Chemistry and Physics, 60th edition* (CRC Press,

de Figueiredo M A, Reiner D M, Herzog H J, 2003, "Framing the Long-Term Liability Issue for Geologic Carbon Storage in the United States" *Mitigation and Adaptation Strategies for Global Change* **10**(4): 647-657

FutureGen Industrial Alliance Inc., 2006 *Request for Proposals for FutureGen Request Facility Host Site*, (Washington DC)

Gale J, Kaya Y, Eds. 2003, *Greenhouse Gas Control Technologies*. New York, Pergamon

Gerard D, 2000, "The Law and Economics of Reclamation Bonds" *Resources Policy* **26**(4): 189-197

Herzog H, Smekens K, Dadhich P, Dooley J, Fujii Y, Hohmeyer O, Riahi K, Akai M, Hendriks C, Lackner K, Rana A, Rubin E, Schrattenholzer L, Senior B, 2005, "Chapter 8: Costs and economic potential" in *IPCC Special Report on Carbon Dioxide Capture and Storage*. IPCC (IPCC, Geneva) 8-1 to 8-37

IEA, 2004. "CO_2 Geological Storage Demonstration Projects." CO_2 Capture and Storage Retrieved June 29, 2004, 2004 from http://script3.ftech.net/~ieagreen/searchresults.php4?keyword=&project_type=CO2+Geological+Storage+Demonstration+Projects&project_category=---select---

IPCC, 2005 *IPCC Special Report on Carbon Dioxide Capture and Storage*, IPCC (Geneva)

Itaoka K, Saito A, Akai M, 2004, "Public Acceptance of CO_2 Capture and Storage Technology: A survey of public opinion to explore influential factors", in Seventh International Conference on Greehnouse Gas Technologies, Vancouver, Canada, Elsevier

Keith D W, Giardina J A, Morgan M G, Wilson E J, 2005, "Regulating the Underground Injection of CO_2" *Environmental Science and Technology* **39**(24): 499A-505A

Keith D W, Wilson M, 2002 *Developing Recommendations for the Management of Geologic Storage of CO_2 in Canada,* Prepared for Environment Canada, Saskatchewan Industry and Resources, Alberta Environment and British Colombia Energy and Mines

Macauley M K, 1992 *In Pursuit of a Sustainable Space Environment: Economic Issues in Regulating Space Debris*, Resources for the Future (Washington, D.C.)

McElfish J M J, Bass S P, Bernstein T, Sheldon E, 1996 *Hard Rock Mining: State Approaches to Environmental Protection* (Environmental Law Institute, Washington, DC)

Mooney S, Gerard D, 2003, "Using Environmental Bonds to Regulate the Risks of GM Crops: Problems and Prospects" *Environmental Biosafety Research* **2**(1): 25-32

National Energy Technology Laboratory, 2005 "Carbon Sequestration FY2005 Budget Total." Carbon Sequestration Project Portfolio **Volume**, DOI, Retrieved Access Date, Access 2005 from http://www.netl.doe.gov/publications/carbon_seq/project%20portfolio/project_portfolio2/Gen_Ovr_2005%20Budget.pdf

Palmgren C R, Morgan G M, Bruin W B d, Keith D W, 2004, "Initial Public Perceptions of Deep Geological and Oceanic Disposal of Carbon Dioxide" *Environmental Science and Technology* **38**(24): 6443-6450

Poe T, 2006, Texas Rail Road Commission, Wilson E, Personal communication with author on August 29, 2006

Pruess K, Garcia J, Kovscek T, Oldenburg C, Rutqvist J, Steefel C, Xu T, 2004, "Code Intercomparison Builds Confidence in Numerical Simulation Models for Geologic Disposal of CO2" *Energy* **29**: 1431-1444

Ringleb A H, Wiggins S N, 1990, "Liability and Large Scale, Long Term Hazards" *Journal of Political Economy* **98**(3): 574-595

Schively C, Ed. 2007, *Siting Geologic Sequestration: Problem and Prospects*. Carbon Capture and Sequestration: Integrating Technology, Monitoring, Regulation. Ames, IA, Blackwell Publishing

Shavell S, 1984, "Liability for harm versus regulation of safety" *Journal of Legal Studies* **13**: 357-374

Shavell S, 1986, "The judgment proof problem" *International Review of Law and Economics* **6**(45-58)

Shogren J F, Herriges J A, Govindasamy R, 1993, "Limits to Environmental Bonds" *Ecological Economics* **8**: 109-133

Texas R C o, 2006, October 6, 2006. "Railroad Commission Plugs Record Number of Abandoned Wells in Fiscal Year 2006." News Release Retrieved April 20, 2007 from http://www.rrc.state.tx.us/news-releases/2006/100606.html

Tsang C-F, Benson S M, Kobelski B, Smith R E, 2002, "Scientific Considerations Related to Regulation Development for CO2 Sequestration in Brine Formations" *Environmental Geology* **42**: 275-281

Weersink A, Livernois J, 1996, "The Use of Economic Instruments to Resolve Water Quality Problems from Agriculture" *Canadian Journal of Agricultural Economics* **44**: 345-353

Wilson E, Johnson T, Keith D, 2003, "Regulating the Ultimate Sink: Managing the Risks of Geologic CO_2 Storage" *Environmental Science and Technology* **37**: 3476-3483

Wilson E J, Gerard D, 2007, "Geologic Sequestration Under Current U.S. Regulations" in *Carbon Capture and Sequestration: Integrating Technology, Monitoring, Regulation*. Wilson E,Gerard D (Blackwell Publishing, Ames, IA)

Wilson E J, Gerard D, 2007, "Risk Assessment and Management for Geologic Sequestration of Carbon Dioxide" in *Carbon Capture and Sequestration: Integrating Technology, Monitoring, Regulation*. Wilson E, Gerard D (Blackwell Publishing, Ames, IA)

Table 1: Characterizing the "Post-Closure" Period of a Sequestration Site

Post-closure Period	Activities	Time-frame
1) Post-closure bond	Active monitoring and verification program to ensure programmatic compliance to larger climate and environmental health and safety goals.	Either performance determined or linked to other operational variables, or expiring after a specified time period
2) Bond release, liability in tact	Monitoring as needed to ensure compliance, as the risk-profile will be reduced, liability covers unexpected accidents.	Between bond release and public assumption of liability
3) Public assumption of liability	Monitoring as needed. Public assumption of liability for any unforeseen accidents.	Public assumption of liability could be based on performance-specific measures or on a pre-determined time-frame.

Table 2: Variation in State Bonding Requirements for Plugging Oil and Gas Wells

State	Bond amounts	Mechanisms/Amount
Illinois 255 ILCS 725/6, 62 Ill.Admin.Code 240.1500, Plugging and Restoration Fund Program	Individual Wells: • $ 1,500 - < 2,000 feet; • $ 3,000 - > 2,000 feet. Blanket Bonds: • $ 25,000 - < or = 25 wells • $ 50,000 - > or = 50 wells • $ 100,000 - all wells	*Instruments:* surety bonds, cash, CDs, letters of credit *Amount:* *Bonding companies:* *Active oil and gas wells:* 32,100 Class II injection: 10,500 Natural gas storage: 1,750 Operators: 1,500 *Orphaned wells:* 4,000
California DOGGR Code 3208 Idle and Orphan Well Program	Individual Oil and Gas Wells (onshore surface location) • $15,000 - < 5,000 feet • $20,000 - 5,000 < X < 10,000 feet • $30,000 - > 10,000 feet Onshore Wells Covered by Blanket Bond • $100,000 (< 50 wells / operator) • $250,000 (> 50 wells / operator) • $1,000,000 (all operator wells, including those idled) Individual Class II Commercial Waste-Water Disposal Wells - $50,000 • Class II commercial well covered by a $250,000 individual or $1,000,000 blanket bond. Additional Class II commercial wells must be covered by individual bonds. Individual Five-Year Idle Wells - $5,000 Operators may file a $5,000 individual indemnity or cash bond to cover idle wells under PRC Section 3206.	*Instruments:* Surety bonds, cash, certificates of deposit *Amount*: $17 million from approximately 240 bonds placed since January 2004, of these 85% of projects use cash, this is 50% of the $17 million value. *Bonding companies*: 12e surety companies are active in bonding CA wells. *Active oil and gas wells:* 49,153 (2004) (Division of Oil Gas and Geothermal Resources 2004) *Orphaned wells:* 502
Texas 16 T.A.C. §3.78(e)	Individual wells • $2 / foot (e.g., a 2,000 ft. well requires $4,000). Blanket bonds, tiered structure • < 10 wells - $25,000; • 10 < X < 100 - $50,000; • > 100 - $250,000 Off-shore costs are much higher and calculated differently.	*Instruments:* Letters of credit, surety bonds and cash *Bond Amounts:* $221 million, roughly 5% cash, 32% surety bonds, 63% letters of credit. Proportion shifting to surety since new regulations came into effect. *Bonding companies:* 48 active surety companies in Texas. *Active oil and gas wells:* 249,961 (TRRC, 2006, July 29) *Orphaned wells:* 10,547 (TRRC, 2006, July 2006)

Table 3: Bonds for Plugging Oil and Gas Operations in California since January 2004

	Number of Bonds	Average Amount	Median	Min	Max
Surety	43	$200,233	$100,000	$15,000	$1,000,000*
Cash	198	$43,207	$20,000	$5,000	$250,000
Total	241	$71,224	$20,000		

*5 cases of $1,000,000 bonds.

Source: California Division of Oil, Gas, and Geothermal Resources

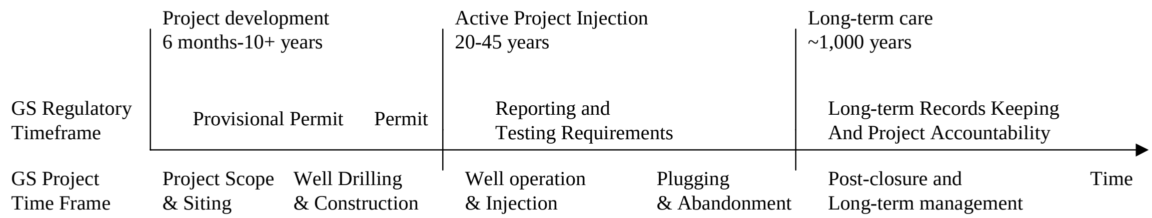

Figure 1: Geologic sequestration project time-line. Bonding mechanisms currently play an important role towards ensuring wells are properly plugged and abandoned. They could also play a role during the long-term care phase.

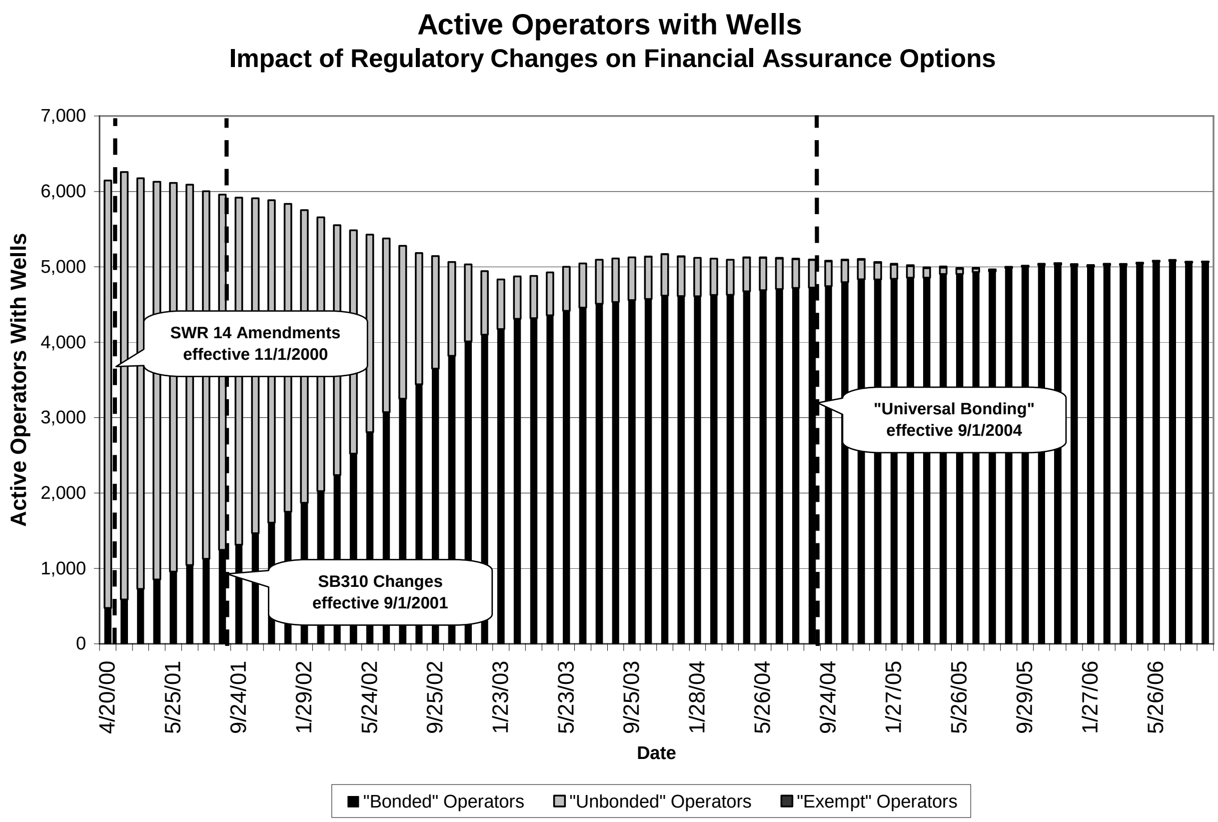

Figure 2: Shift towards bonded operators after passage of SB310 in Texas
Source: Texas Railroad Commission (2006)