Viewpoint

Regulating *the* Geological Sequestration *of* CO_2

DREAMSTIME/RHONDA SAUNDERS

As greenhouse gas emissions rise and the impacts of climate change grow, the need for safe and effective CO_2 capture and sequestration becomes ever more urgent.

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Once CO_2 enters the atmosphere, much of it remains there for >100 years (*1*, *2*). For this reason, even if emissions were stabilized today, the atmospheric concentration would continue to grow. To stabilize atmospheric concentrations, global CO_2 emissions must be reduced from today's level by about an order of magnitude. Energy conservation, improved end-use efficiency, appropriate use of renewable energy, and nuclear power can all contribute to a portfolio of low-emission power generation. However, many of these strategies have significant technical limitations or high cost, or—in the case of wind and solar—present operational difficulties, such as intermittency. For countries such as the U.S. and Germany, which today produce more than half of their electricity from coal, or China and India, where a large majority of the electricity is generated from coal, it is difficult to see how cost-effective and politically viable emission reductions can be achieved during the next several decades without at least some continued use of coal.

By separating carbon from coal, either via gasification before combustion or by removing it from the flue gas after combustion, technology for carbon capture and deep geological sequestration (GS) holds the promise to dramatically reduce the CO_2 emissions associated with the use of coal. The resulting stream of CO_2 can be injected into carefully selected deep (>1 km) geological formations, such as saline aquifers, where geologists believe that it can be safely and indefinitely sequestered (*3*). Of course, for deep GS to be safe and secure, with minimal risk of leakage, surface disruption, or contamination of other geological resources (*4*), appropriate care and monitoring are needed. To ensure that this happens, regulation will be necessary.

The U.S. and many other countries already inject large volumes of fluid underground (*4*, *5*). However, the nature of CO_2, its role in climate change, and the fact that global emissions trading markets may soon exist, all mean that regulating deep GS will require special attention and some degree of international coordination.

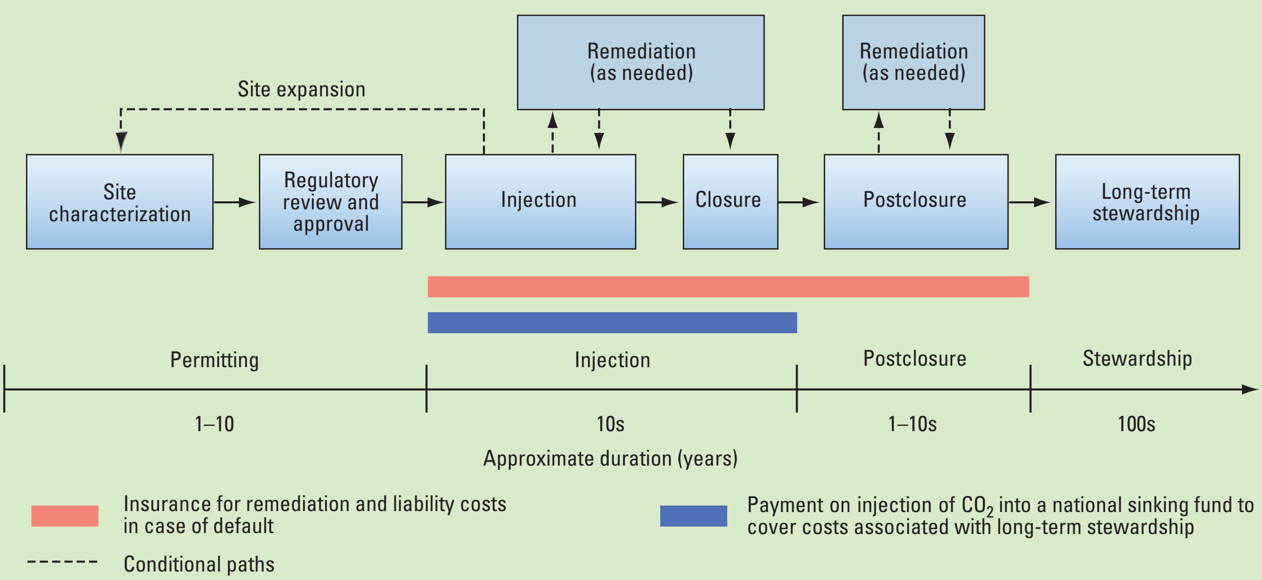
The life cycle of a GS project (Figure 1) will involve four separate stages (*6*): site characterization and permitting before any injection; site operation; postclosure operations by the site operator; and long-term stewardship. If large-scale GS is to proceed, the competing needs and interests of the public, project developers, financial and insurance institutions, government regulatory agencies, nongovernmental organizations, and national and international agencies managing CO_2 trading must be appropriately balanced. The goal is to create an efficient regulatory regime that ensures safe and responsible GS deployment, protects local health and environments, meets the needs of national and international climate frameworks, and is cost-effective.

Many of the building blocks for proper GS regulation are already in place, but the technological promise of GS could founder on the shoals of in-

FIGURE 1

Four phases of a CO_2 geological sequestration project

The life cycle of a GS project for CO_2 will involve four phases (*6*). In addition to the site operator and the financial and insurance organizations that support the project, two different government entities will have roles. In order to avoid potential conflicts of interest, the regulatory organization responsible for reviewing and approving the creation of a site, monitoring its operation, and certifying its satisfactory closure should be separate from the government entity that ultimately assumes responsibility for long-term stewardship.



adequate and incoherent regulatory strategies. As explained in the next section, existing regulatory systems are not well suited to address some of the issues that arise in the GS of CO_2. Of course, one could argue that the needs for careful site characterization, monitoring, and long-term stewardship are inadequately met for many existing large-scale injection activities. However, the need to do things right is even greater in the case of the injection of CO_2, because the volume of fluid will be higher than in many other injection projects and because, at the time of injection, CO_2 is a buoyant fluid. Moreover, most present and past injection activities have not attracted the same level of attention that will likely be associated with the sequestration of CO_2.

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The needed regulatory framework will not emerge on its own. That will require thoughtful informed design. Before finalizing a regulatory framework, we first need to learn from real-world experience, so that we do not create regulations that lock in inappropriate features or ignore key issues (*7, 8*). A two-stage strategy is needed in which experience is gained under (slightly modified) existing regulations, after which a regulatory framework appropriate for large-scale commercial deployment is developed and implemented.

Pilot projects will be modest in number. Most will involve injection rates of 1 million metric tons per year (t/yr) or less and will operate for only a few years (*9*). In contrast, full-scale commercial operation will likely involve large numbers of sites, each injecting several million metric tons per year and operating for many years.

Existing regulatory frameworks

Several existing international and national regulatory frameworks are being adapted to manage potential health, safety, and environmental risks in early GS projects in Canada, the U.S., Australia, and several European countries. For example, the U.S. EPA has issued guidance documents to regulate GS pilot projects as Class V experimental wells through the Underground Injection Control program (*6*, *10*) and hopes to release the draft of additional regulations this summer. The Interstate Oil and Gas Compact Commission, an association of oil- and gas-producing states, has issued model regulations for GS; so far, however, these have not been adopted. The regulatory context in the U.S. is likely to be especially complex because regulatory authority will be shared by environmental and oil and gas authorities, and between the federal government and the states. Recent amendments to the London Protocol and the Northeast Atlantic OSPAR Marine Treaty allow submarine, subsurface injection of CO_2. The U.K.'s Petroleum Act and the Australian Petroleum (Submerged Lands) Acts, informed by the Regulatory Guiding Principles, can both be used to manage early deployment of pilot projects (*11*). The U.K. is scheduling a consultation and parliamentary time for legislation on regulation by the end of 2008. The European Commission issued a draft directive on the geological storage of CO_2 in January 2008 (http://ec.europa.eu/environment/climat/ccs/eccp1_en.htm).

Although existing law can be used to cope with experimental projects, full-scale commercial deployment will require a much more comprehensive approach to selecting sites and allocating responsibility, more appropriate rules for accounting and monitoring, and minimum standards to ensure an adequate level of safety wherever GS is deployed worldwide. Indeed, past experience suggests that simply scaling up existing regulations for commercial-scale GS projects can have serious pitfalls. For example, the U.S. experience in Florida, where wastewater that had been injected underground migrated into underground sources of drinking water, illustrates both the problems that can arise when very large quantities (~3 Gt/yr of wastewater) are injected into unsuitable geological formations and the subsequent difficulties that can result from making ad hoc modifications to an existing regulatory regime (*12*). In addition, the current EU and U.S. regulatory regimes do not deal adequately with preinjection site characterization, ongoing monitoring during site operation, large-scale fluid displacement, continued postclosure site monitoring, long-term liability, and other issues (*13*). Many existing schemes do not clarify subsurface property ownership of pore space or subsurface trespass (by postinjection CO_2 movement) laws, which vary significantly across jurisdictions (*5*). Although specific rules will vary across nations, these and other issues must be addressed before large-scale deployment will be possible (*4*, *12*).

Long-term liability

Experts from the insurance industry indicate that existing health, safety, and environmental liability frameworks can cover the potential risks of GS, with the notable exception of risks associated with long-term stewardship. Because most firms do not last for centuries, there is wide agreement that long-term responsibility for the stewardship of closed sites must be assumed by national governments or institutions designed to last for many hundreds of years.

However, handover of responsibility should not occur immediately upon site closure. Once injection ceases, the operator should continue to have some legal and economic responsibilities for at least several decades or, better yet, for a time period linked to the decrease in project risk as determined by the decay of reservoir pressure or other performance measures. The costs of long-term stewardship should be borne by income from a national sinking fund paid into by the site operators during the active and closure phases of the project. To avoid conflicting incentives, the agency responsible for stewardship should not be the same agency responsible for the approval of new sites and regulatory oversight during the operation and closure phases of existing sites.

Some industry experts have argued that once a site is closed, responsibility should be transferred to the government immediately. Two arguments counter this thinking. First, if operators continue to bear some responsibility for the site during the initial postclosure decades, they will be better motivated to ensure that the site is characterized, operated, and monitored in a safe and secure way. Second is the issue of public perception. Although the empirical evidence is mixed (*14–16*), there is at least some basis to believe that public concerns may complicate the deployment of GS. For example, opposition led to the delay and probable failure in the California State Legislature of regulatory bill AB 705, which would have required the state to develop regulations for GS (*17*). Operators who argue that sites are perfectly safe, while rushing to hand off all responsibility to the government, will not be credible with the public.

The risks of many other waste materials may not decrease and may even grow with time. In contrast, the risks associated with injected CO_2 will likely decline with time. On timescales of decades, injected CO_2 will lose its buoyancy as it becomes isolated in pores by capillary (residual saturation) trapping and becomes dissolved in brackish groundwater. On much longer timescales (10^3–10^4 yr), it may become permanently immobilized through mineralization.

Need for field experience

Most of the CO_2 injection projects now operating are small (<100 kt/yr) and short-term. Only four are operating at full scale (>1 Mt/yr): Sleipner (since 1996) and Snøhvit (began injection in 2007) in the North Sea, run by Statoil; In Salah (since 2004) in Algeria, run by BP; and Weyburn, an enhanced oil recovery project operated by EnCana in Canada. Given the pivotal role of GS in reducing CO_2 emissions worldwide, there is an urgent need to expand the knowledge base on which governments can build an appropriate long-term regulatory framework. At least a dozen large-scale pilot projects should be initiated within the next few years. These projects should be carefully and intensively instrumented to collect all the data necessary to characterize and learn from performance. In the U.S., phase three of the Department of Energy (DOE) Regional Carbon Sequestration Partnerships is now developing projects that will inject ~1 Mt/yr (*9*). DOE recently withdrew its support from the proposed FutureGen project and now says it plans to support the incremental costs of adding capture and sequestration to commercial projects. The European Commission has proposed the creation of up to 12 large-scale demonstration projects in its 2007 Energy Policy for Europe (*18*). These proposals are a good start. However, it is unclear whether all of these bold plans will be backed with both money and commitment—including the needed monitoring and transparency of data. The commission is proposing that early projects that share data will be eligible for government funding from member states, as part of an EU network. Financial support has been announced from the U.K., Norway, and The Netherlands and is being sought from Poland, Germany, and Spain. Given the urgency of reducing CO_2 emissions, continued efforts to accelerate and expand these programs are essential, as are attempts to induce other nations, as well as private firms, to undertake similar large-scale projects.

Ensuring a two-stage strategy

It is one thing to advocate gaining experience before finalizing a new regulatory framework and quite another to make it happen. After several large demonstration projects are mounted, a transition to continued commercial development could occur without drawing on lessons learned and developing appropriate new national regulatory frameworks. To avoid this in the U.S., and to ensure a rapid transition to a more permanent regime, we propose the creation of an independent Federal Carbon Sequestration Commission. This commission should be given a fixed life, have a presidentially appointed chair, and consist of ~15 members drawn from a wide range of relevant experts and public and private stakeholders. Although it would observe and comment, the commission would not have administrative control over DOE or other injection projects and would have no regulatory authority.

This commission should be charged with tracking all U.S. and international projects and gathering data that could be used to develop recommendations for regulatory needs for commercial-scale operations. The commission should make annual progress reports to the administration and to Congress that would include recommendations on additional projects needed to gain insights. Ideally, variants of such an organization might be developed in other nations, with the result that at least an informal level of international cooperation and coordination might evolve, as has occurred in many other areas of international technical coordination. The commission should be required to provide recommendations to the administration and to Congress on the form that regulation for widespread commercial-scale operation should take, on or before a specified sunset date (e.g., 2015).

Need to be adaptive

The engineering of subsurface reservoirs suitable for GS will often be complex, and key information on subsurface CO_2 flow will become available only after injection has begun. Even with advances in site characterization and monitoring, surprises will occur. Any regulatory framework to manage GS should therefore be adaptive (*19*), without compromising the basic objectives of safety and climate policy.

Adaptive regulation must balance predictability with flexibility, a difficult challenge for regulatory bureaucracies. Regulatory agencies, operators, and financial communities all require clarity and predictability, yet these needs must be balanced with accountability for both climate and environmental health and safety demands. Regulatory institutions already face technical and legal challenges and challenges of public perception in their development and operation. Successful U.S. and global regulation of GS will pose new and important challenges to them. Now is the time to work on these issues of institutional design. If we delay, the chance to learn from experimentation and for international coordination will be greatly diminished.

Summary

Governments worldwide should provide incentives for initial large-scale GS projects to help build the knowledge base for a mature, internationally harmonized GS regulatory framework. Health, safety, and environmental risks of these early projects can be managed through modifications of existing regulations in the EU, Australia, Canada, and the U.S. An institutional mechanism, such as the proposed Federal Carbon Sequestration Commission in the U.S., should gather data from these early projects and combine them with factors such as GS industrial organization and climate regime requirements to create an efficient and adaptive regulatory framework suited to large-scale deployment. Mechanisms to structure long-term liability and fund long-term postclosure care must be developed, most likely at the national level, to equitably balance the risks and benefits of this important climate change mitigation technology.

We need to do this right. During the initial field experiences, a single major accident, resulting from inadequate regulatory oversight, anywhere in the world, could seriously endanger the future viability of GS. That, in turn, could make it next to impossible to achieve the needed dramatic global reductions in CO_2 emissions over the next several decades. We also need to do it quickly. Emissions are going up, the climate is changing, and impacts are growing. The need for safe and effective CO_2 capture with deep GS is urgent.

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