THE BUSINESS OF GLOBAL WARMING: OPPORTUNITIES FOR THE OIL AND GAS INDUSTRY IN GREENHOUSE GAS MITIGATION

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Overview

Mitigating the effect of anthropogenic emissions of carbon dioxide will require multiple technologies, including fuel switching and storage of carbon dioxide in subsurface geologic formations. Using natural gas instead of coal for power generation will become more attractive in a carbon-constrained world. An important advantage of geologic storage is that know-how and hardware needed for large-scale storage are available “off-the-shelf” in the oil & gas industry. But the economics of byproduct disposal differ from the economics of resource extraction. Moreover geologic storage involves intrinsic technical uncertainties. Thus geologic storage will require new modes of interaction between technology, risk assessment and regulation. Managing these interactions will demand a notable, perhaps unprecedented, degree of collaboration and communication between engineers, geoscientists and lawyers. Indeed, the greatest challenge for mitigating carbon dioxide emissions will be developing a regulatory environment that helps, rather than hinders, the cause.

This paper briefly reviews the reasons that fuel switching and geologic storage must contribute of any serious effort to mitigate greenhouse gas emissions. The role of fuel switching has significant implications for supply and demand of natural gas. Evaluating the size of a geologic storage industry is crucial, because the scale of that industry is the single most important factor driving policy, regulation and technology. A non-technical description of four technical aspects of geologic storage follows, setting the context for a discussion of the cross-disciplinary cooperation needed to enable a storage industry.

Methods

Fuel switching and sequestration of carbon dioxide in geologic formations must be implemented at a very large scale – thousands of gigawatts of power generation capacity and billions of tons of CO_2 per year -- in order to mitigate emissions of greenhouse gases. Thousands of sequestration projects will be needed, so a prerequisite to implementation is a project certification framework that is simple to apply. The most challenging aspect of such a framework is the assessment of risk associated with CO_2 migration after closure. The physics of the CO_2/brine/rock intereaction is distinctive and strongly influences the balance between migration and immobilization of CO_2. Regulations informed by these physical realities are likely to be much more cost-effective. This is an important consideration, as both cost and security of storage will be critical factors in public acceptance. However regulations that allow for concepts such as “effective trapping” entail greater flexibility and uncertainty than is customary in waste disposal operations. This paper discusses the potential benefits of feedback between the technical and the regulatory communities, illustrating the tradeoffs between three different aquifer storage schemes

Detailed numerical simulations of several CO_2 storage schemes in deep saline aquifers were conducted. The simulations cover two periods: the injection phase (typically thirty years) followed by one thousand years during which the injected CO_2 can move by buoyancy. Three schemes are compared: the standard approach (injection of CO_2 into the full thickness of an aquifer), the “inject low and let rise” approach (injection of CO_2 only into the lower part of an aquifer), and a surface dissolution approach (captured CO_2 is dissolved into brine in surface facilities, and the CO_2-saturated brine is injected into the aquifer). For each case, the primary mode of CO_2 immobilization (brine dissolution, residual phase trapping, hydrodynamic trapping, stratigraphic trapping) is identified and the period of time needed to achieve that immobilization is estimated. Each mode of trapping presents unique requirements for monitoring and veification. The implications of these requirements for a certification framewok are examined. The relative costs for each scheme are also quantified, enabling a qualitative analysis of the costs and benefits of regulations associated with the scheme.

Results

The standard scheme of CO_2 injection will have the least operating and capital costs. The inject-low-and-let-rise scheme will have somewhat larger costs, as it may require more wells to be constructed. Because it requires many brine extraction wells, the surface dissolution approach would have about 50% greater operating costs and 100% greater capital costs than the standard scheme.

The long-term security of the CO_2 increases as the cost of the scheme increases. For the standard scheme, much of the CO_2 is held beneath a sealing stratum (a situation analogous to a hydrocarbon reservoir). The CO_2 will remain indefinitely (diffusion and dissolution into underlying brine would occur over tens to hundreds of millenia) as long as the integrity of the seal is intact. If the seal is breached, the CO_2 wll escape. This scheme therefore imposes a long-term obligation to monitor the integrity of the seal. The key difficulty with this approach is that the Earth's crust is intrinsically leaky. Convincing regulators and the public that a particular seal will remain intact for very long periods of time will be difficult.

The inject-low-and-let-rise scheme relies on the buoyancy of CO_2 relative to brine to cause controlled migration of the plume after injection. The migration necessarily increases residual phase trapping within the plume and increases dissolution trapping at the leading edge of the plume. The migration leads to nearly complete immobilization of the injected CO_2 over a few centuries to a few millennia. The immobilization is independent of the integrity of any seal. This scheme requires monitoring to ensure that the migration is proceeding as planned.

The surface dissolution schcme completely eliminates the chance of buoyancy-driven migration of the CO_2 plume. It therefore requires no monitoring and in principle could be regulated as wastewater disposal is regulated. No additional time is required for immobilization after injection ends. The footprint of the CO_2 plume is much larger than the CO_2 plume for the other schemes. However, the footprint of *brine* displacement is 30% smaller than the standard approach. The benefit depends on whether groundwater or bulk phase CO_2 is the subject of regulation.

The inject-low-and-let-rise scheme is based on physical principles (gravity, capillary pressure) that are guaranteed to apply. In essence, it states that controlled migration after injection ends increases the degree of immobilization that requires no further monitoring. If regulators were to impose a strict no-migration requirement, analogous to the Underground Injection Code for wastewater, operators would not be able to implement this scheme, despite its advantage relative to the standard scheme. The issue here is not that one scheme is better than the other, but that regulation could inadvertently favor one over another. Similarly, were regulators to prescribe monitoring measurements intended to ascertain mobile CO_2 saturation, an exemption should be made explicitly for the surface dissolution scheme.

The self-limiting nature of certain types of CO_2 plume migration leads to the concept of "effective trapping". The term connotes migration of the CO_2 from the original storage volume within a formation that does not cause harm. The impact to be considered would primarily be in other regions of the subsurface such as hydrocarbon reservoirs, mines, underground sources of drinking water, extending to the near subsurface and then to the atmosphere. This concept is deliberately more flexible than the familiar containment or no-migration approaches. To regulate storage with this concept would demand a new level of understanding and transparency.

Conclusions

A regulatory framework for permitting, monitoring and abandoning CO_2 storage projects is urgently needed; such a framework and a carbon price structure are the two main prerequisites to launching a CO_2 storage industry. Assessment of risk associated with migration of stored CO_2 must be a major component the regulatory framework. Secure storage of CO_2 in geologic formations can be achieved in a variety of ways. Ironically, one way (the inject-low-and-let-rise scheme) involves controlled migration of CO_2 as a method of ultimately immobilizing the CO_2.

Of the three types of storage schemes considered here, higher operating costs lead to smaller risks associated with CO_2 migration and thus lower monitoring costs. Monitoring costs themselves may be a small fraction of the overall cost of geologic storage and thus avoiding them may not pay for the higher operating costs. But the degree of immobilization of CO_2 may command a premium in public acceptance and in the business reinsurance industry. Thus storage schemes that rely on guaranteed secure mechanisms of immobilization (residual phase trapping, dissolution trapping) may be preferred to those that rely on holding a buoyant fluid beneath a seal. The regulatory framework needs to be constructed with enough flexibility to allow operators to design schemes that make business sense and technical sense. Thus preconceived notions of secure storage, borrowed from other kinds of waste disposal, should be examined carefully before being incorporated into a CO_2 storage regulation.