A U.S. NGO’s Perspectives on Monitoring of Saline and EOR Geologic Carbon Injection and Sequestration Sites.

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Abstract

Geologic carbon sequestration offers both the potential to provide a permanent sink for industrial CO₂ emissions, and added value to tertiary enhanced oil and gas recovery (EOR). Subsurface injection of carbon dioxide is a proven technology developed in the EOR industry over the past three decades. However, EOR efforts have not focused on monitoring, reporting and verification (MRV) of permanent geologic sequestration of CO₂. The challenge, particularly for early deployment of MRV, will be the implementation of protective monitoring plans that do not become unnecessary barriers to commercialization of geologic carbon sequestration. For well-characterized low risk sites, a three-tiered MRV structure could serve to improve cost-effectiveness and encourage commercial-scale development of CCS and geologic sequestration technologies. For these low risk sites, early first-tier MRV would be comprised of narrowly focused subsurface and surface monitoring techniques designed to test CO₂ behavior against the reservoir model. A finding of steady-state predictable injection, consistent with the objectives set out in the operating permit, would require minimal MRV expense and few, if any, airside tools. MRV at these steady-state sites would be periodically re-evaluated for operation cost-effectiveness, eliminating monitoring techniques that yield either redundant or minimally useful subsurface information. However, evidence of adverse migration of the CO₂ plume pressure front, or mechanical failure of cap rock would “trigger” advanced MRV. This second pre-planned tier of MRV would be used to evaluate short and long-term risk to drinking water, air and other resources. This, in turn would either lead to modification of injection strategies, once re-initiated, to mitigate identified risk, or permanent injection shut down and third and final stage static post-injection MRV. Saline and EOR-based geologic carbon sequestration should be treated under the same overarching principles, however MRV may require different approaches.

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1. Introduction.

Since the industrial revolution nearly 3 centuries ago, the atmosphere has seen a 36 percent increase in carbon dioxide (CO₂)[1]. Carbon dioxide-related warming could result in profound effects such as the progressive melting of glaciers critical to world water supplies, the melting of the Greenland ice sheet and rising sea level, and the recent opening of the fabled Northwest Passage. Reducing the rate of atmospheric CO₂ release into the atmosphere is therefore a worldwide and U.S. domestic priority. With the pace of increasing fossil energy demand across the globe, a variety of strategies will be needed to meet the challenge of slowing the rate of CO₂ emissions. Capture and geologic sequestration of CO₂ is one such strategy that is gaining momentum as a bridge technology. Public acceptance of this technology will require reassurance that underground injection of CO₂ is permanent and safe. For emission reductions credits, sequestered CO₂ volumes will also need to be quantified. To accomplish these objectives, vigilant monitoring reporting and verification (MRV), with reasonable public access to records will be required. Particularly for early movers, the challenge of MRV will be development of protective monitoring plans that meet the needs of security yet do not unnecessarily become a barrier to commercialization of geologic carbon sequestration.

What is secure sequestration? Based on published models of geologic carbon sequestration in fields such as Sleipner and Weyburn, IPCC suggests [2] that CO₂ retention in geologic reservoirs is “likely to exceed 99 percent over 1000 years” a statement that has, in the absence of any other criteria, become a default benchmark for geologic CO₂ sequestration performance. For example, the State of Washington [3] requires that the “applicant must demonstrate… that the geology, including geochemistry, of the site and all proposed plans developed for the permit application will provide permanent sequestration” defined as: “a high degree of confidence that substantially ninety-nine percent of the greenhouse gases will remain contained for at least one thousand years.” Texas legislation language [4] suggests a similar IPCC-based but less stringent standard: “a reasonable expectation that the operator's planned sequestration program will ensure that at least 99 percent of the anthropogenic carbon dioxide sequestered will remain sequestered for at least 1,000 years...” Despite these performance standards, monitoring tools available today are not capable of quantitatively tracking changes in CO₂ volumes with any degree of accuracy and precision. If MRV methods must achieve the impossible standard of quantifying leakage to 1% or less, MRV could prove to be a hurdle for commercial GCS. However, while the lack of accurate technical tools might seem problematic, in fact, if it can be demonstrated that the CO₂ is predictably contained within the confining zone below a robust seal, that means that the plume is adequately contained and long-term leakage risk is extremely low [5]. This paper recognizes a need for overarching principles governing cost-effective monitoring of geologic carbon sequestration sites to ensure long term security and accounting of injected CO₂ and to protect human health and the environment. In this paper a simple conceptual model is presented that attempts to address both public health protection and cost effectiveness, and harmonize approaches to MRV.


In its report Monitoring, Verification, and Accounting of CO₂ Stored in Deep Geologic Formations, the U.S. Department of Energy’s National Energy Technology Laboratory (NETL) outlines a step-by-step detailed best-practices decision tree for pre-operational and operational MVA [6]. In its proposed 2009 Underground Injection Control (UIC) rule [7], and its 2010 Greenhouse Gas Reporting rule [8] EPA proposes site-specific approaches to drinking water and
air protection. Our decision tree represents a case-by-case approach, allowing for broader technology options and imposing additional efficiency. Like the NETL rubric, the foundation of the tree is contingency-based, but in contrast, emphasizes the objective of maximizing early site characterization that will, in turn, minimize unnecessarily burdensome MRV operations. Built on top of robust site selection, we envision a phased as opposed to “kitchen sink” [9] approach to MRV that puts a heavy responsibility on predetermined methods instead of a focus on problem solving. MRV should instead be implemented with only the needed tools needed to test and validate the robustness of the reservoir model that the injection permit is based upon. This is accomplished by identifying site-specific performance targets and then adoption of monitoring techniques fit to those objectives. At the outset, each facility would have its own tailored MRV plan, including the advanced second stage contingency plan that would be deployed only if needed. So, rather than a “one-size-fits-all” prescriptive regulatory approach that requires routine deployment of costly tools such as 4-D seismic or crosswell seismic tomography, at every facility, all of the time, only the appropriate tools needed to track the CO2 plume and pressure front, formation injectivity, cap rock mechanics and integrity, geochemical changes above the seal would be initially required. For each of these parameters/tools, baselines and performance standards would be set. If these standards are not met, the pre-planned second stage intensive MRV is launched to determine the magnitude of the risk, and potential modifications to injection strategies to mitigate the identified problem.

At the site approval stage, sites with significant risk would need to be catalogued and avoided—no matter how pressing the regional need for sequestration of anthropogenic CO2 might be. Baselines should then be established. Early first stage monitoring would cross check CO2 flux in the subsurface against the reservoir model supplied as part of the permitting application for the facility. If injection results in a predictable steady-state plume, and first stage techniques indicate that condition will be indefinitely sustained, our approach recommends periodic review and possible scale-back of costly techniques that prove ineffective or redundant. The facility permit would include built-in thresholds specific to deployed monitoring tools that would trigger the second stage of advanced MRV methods and potentially suspend injection, if the reservoir model targets are unmet. If monitoring tools identify threats to drinking water (USDW) or air, advanced monitoring would be implemented to evaluate short and long-term risks. Unacceptable short-term risks would require immediate shutdown and remediation if needed. For example, if monitoring wells or above-zone (above seal) monitoring detects an unexpected increase in pressure or salinity, a short-term risk is indicated and injection should be shut down and advanced MRV implemented. For long-term risks, such as unexpected migration toward a project boundary or spill point, injection may or may not continue, depending on the gravity of the threat. Injection patterns and strategies may then be modified based on the intensive MRV methods, injection being suspended until it can be determined whether the identified potential long-term risk can be avoided. If not, then injection is shut down permanently with third-stage static monitoring until the field stabilizes and is ready for permanent closure.

Every injection plan and facility permit should also anticipate potential for site shutdown and therefore a secondary sequestration option should be included within the plan. This need could be met by injection at different discrete sealed reservoir intervals in stacked sequestration, or alternatively by contracting to connect to a nearby pipeline. Identifying potential redundant sequestration options is critical to ensure that the source-sink relationship remains uninterrupted avoiding unnecessary shut off of injection and venting of CO2 to the atmosphere. However, where the sink is from the outset an enhanced oil or gas recovery (EOR) field connected by pipeline to the source, secondary sequestration options may be unnecessary.
3. The Role of MRV for Enhanced Oil and Gas Recovery (EOR).

EOR provides the foundation and thirty-year track record underpinning geologic carbon dioxide injection and sequestration. EOR functions largely as a closed system where injected CO₂ is retained and permanently sequestered by capillary trapping in the reservoir rock plus solution trapping in reservoir fluids, and through progressive production, separation and recycling. EOR is attractive as a permanent sequestration option, not only because it is proven, but because CO₂ is more soluble in hydrocarbon pore space as compared with saline pore space and therefore a greater percentage of CO₂ may be stored in a smaller given pore volume resulting in more efficient sequestration [10]. GCS in EOR fields benefits from known reservoir properties and also the fact that the oil reservoirs/basins are proven structural or stratigraphic traps in place for thousands or millions of years. Because the traps in these reservoirs have effectively sequestered oil or gas over geologic time, it is reasonable to assume that injected CO₂ is permanent, assuming the existing wellbores in the field are secure. Indeed, field studies completed by the Texas Bureau of Economic Geology [11] suggests three decades of CO₂ injections in SACROC field in West Texas with no evidence of leakage or adverse impacts.

Decades of industry experience in EOR and demand for increased EOR CO₂ supply means that early efforts aimed solely at CO₂ sequestration will benefit from existing reservoir knowledge and lower cost of utilizing pipelines to EOR fields. The presence of numerous production and injection wells mean that plume movement and pressure front behavior can be controlled. In the U.S., EOR can provide geologic sinks for early carbon capture projects, and help prove this critical technology. Commercialization of saline reservoirs then can bring online the capacity to accept the large volumes of CO₂ needed to sequester industrial CO₂ particularly where there is inadequate pipeline capacity to transport the CO₂ to EOR fields. However, Kuuskraa [12] suggests that in the U.S., EOR is capable of playing a major role in CCS, with the CO₂ sequestration equivalent potential of 94-156 1000 MW coal plants for 30 years based on an estimated 10 to 28 billion metric tons of sequestration capacity. Hundreds of millions of tons of CO₂ have already been injected into reservoirs in the U.S. alone. More recent analysis by Ming and Melzer [13] suggest that EOR fields may indeed allow far more volume that originally predicted, based on the potential in residual oil zones and stacked sequestration. Maximizing the potential of EOR for CCS means that development of CO₂ pipelines must be a priority.

Saline and EOR-based geologic carbon sequestration MVA should be treated under the same overarching principles, however there are some contrasts that should be recognized by regulators in order to avoid unnecessary barriers to development of EOR GCS. In EOR fields, target reservoirs are well known and therefore should require substantially less MVR. In contrast, saline fields will likely be drilled in areas where the subsurface geology and reservoir rock properties are more poorly characterized relative to areas with oil and natural gas production, and therefore more comprehensive and costly subsurface imaging methods will be required. For saline sites, plume management will be inherently more difficult due to fewer injection and monitoring wells and lack of water production. For EOR operators, the regulatory basis for GCS should not interfere with operations. However, earning emissions reductions credits for EOR will require a higher level of due diligence than for many current operations. So, becoming a sequestration site will require additional metering and monitoring to document retention of the CO₂. Most importantly, EOR operators that “opt in” to GCS status will need to ensure that old wellbores in the area of review are identified and wellbore integrity confirmed. In order for that level of confidence to be achieved, review must include mechanical integrity testing and the evaluation of need for surface monitoring methods. In addition, EOR MRV will also need to concentrate more effort on tracking plume migration offsite into adjacent project areas and fields, and investigate and closely monitor rock mechanics for mechanical anisotropies which
could result in a breach of the trap—especially if the objective is to “pack CO₂ to the brim” at the end of the productive life of the well.

While EOR boasts a long track record for geologic carbon dioxide injections, little attention has been given to understanding and documenting retention, the process by which CO₂ is progressively trapped in the reservoir rock. Therefore, regulatory research, conducted, to the extent possible, with the support of the petroleum industry, should be aimed at documenting CO₂ retention in current EOR fields. This will help build confidence in EOR, lead to improved accounting for volumes of sequestered CO₂ and help develop new retention strategies.

Figure 1. Early first-tier MRV would be comprised of narrowly focused subsurface and surface monitoring techniques designed to test CO₂ behavior against the reservoir model. Steady-state predictable injection following objectives set in the operating permit would require minimal MRV expense and few, if any, airside tools. MRV at steady-state sites would be periodically re-evaluated for operation cost-effectiveness. Adverse migration of the CO₂ plume pressure front, or mechanical failure of cap rock would “trigger” advanced MRV, and possible suspension of injection, to evaluate short and long-term risks. This, in turn would either lead to modification of injection strategies, or permanent injection shut down and third and final stage static post-injection MRV.
4. List of References.