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TECHNICAL
REPORT

The Industrial Base for Carbon Dioxide Storage

Status and Prospects

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Summary

Carbon capture and storage (CCS) is the process of capturing carbon dioxide (CO_2) prior to its being emitted into the atmosphere, then either using it in a commercial application or storing it in geologic formations for hundreds to thousands of years. CCS is one means of reducing anthropogenic emissions of CO_2 into the atmosphere.

The oil industry already uses CO_2 for enhanced oil recovery (EOR) operations, in which CO_2 is injected into a depleted oil field to liberate more oil from the reservoir. Many of the systems needed to expand or make possible CCS are in commercial use or are in advanced development and demonstration. The U.S. Department of Energy (DOE) directs a research program to develop and commercialize technologies for the cost-effective capture of CO_2 from major sources and for geologic storage. As part of the DOE's Regional Carbon Sequestration Partnership (RCSP) program, seven large-scale demonstrations for storing CO_2 in geologic formations are either being planned or are under way. Since the 1970s, a network of pipelines has been constructed to transport CO_2 for EOR operations. Currently, most of the CO_2 supplied for EOR operations comes from natural reservoirs. If policies mandating the reduction of emissions of CO_2 from industrial and power plants were to be enacted, CO_2 could be captured from these sources. More EOR or geologic storage would be needed to accept the CO_2.

If such a policy were to be enacted, how quickly could the industrial base supporting the transportation and sequestration of CO_2 be expanded? To answer this question, the National Energy Technology Laboratory (NETL) asked RAND to assess the industrial base for transportation and injection for CO_2–EOR and geologic storage. NETL asked RAND to identify and quantify the activities, equipment, and labor required for the following:

- to transport CO_2 from a power plant or other source to an injection site
- to engage in EOR by CO_2 flooding
- to permanently store CO_2 in a geologic formation.

RAND was also asked to identify parts of the industrial base related to utilizing and sequestering CO_2 that have already been developed and are currently utilized by the oil and gas industry, as well as those that are unique to carbon storage and EOR operations. In this analysis we did not evaluate the capabilities of the industrial base to capture CO_2; this decision was made to limit the scope of the study so that the analysis could focus on the activities supporting transportation for EOR, and storage of CO_2.

Approach

The industrial base supporting CO_2 storage is the collection of capabilities—including equipment, productive capacity, expertise, and labor—that support the development and deployment of CO_2 pipelines, EOR operations, and geologic storage of CO_2. In the United States, there are already robust industries supporting the manufacture of pipeline components and the construction of pipelines, as well as an oil and gas industry actively engaged in EOR operations, and other outfits capable of developing CO_2 storage sites. Determining the capabilities of the U.S. industrial base supporting CO_2 transport and storage specifically required that we perform three analytical tasks.

Define the Activities That Compose the CO_2 Storage Industrial Base

To disaggregate the CO_2 storage industrial base from related industrial bases supporting natural gas pipelines and oil and gas development, we first identified the activities that specifically support CO_2 storage. These activities fall into three areas:

- the design, construction, and operation of CO_2 pipelines[1]
- CO_2–EOR operations
- geologic storage.

Once these activities were defined, we determined if they were unique to CO_2 storage or employed in other sectors, particularly the oil and gas sector. For example, while there are specific requirements for the construction of CO_2 injection wells for geologic storage, the techniques for drilling the wells are by and large the same as those used in the oil and gas sector. The activities unique to CO_2 storage cannot be fully developed without engaging in actual storage operations. We then quantified the labor and equipment requirements to support each of the activities.

Generate Scenarios Under Which the CO_2 Storage Industrial Base Would Have to Respond

The second step in our analysis was to determine a range of futures bounding the potential demand for CO_2 storage. We defined four scenarios resulting from two primary drivers: (a) the existence of a regulatory requirement to reduce emissions of CO_2 and a lower relative cost for capture and storage than other technologies for complying with the regulations; and (b) the pace of activity in the oil and gas sector. The first driver determines whether there is a need to develop geologic storage of CO_2 on a large scale. The second driver determines the degree to which those developing geologic storage will have to compete for labor, materials, and equipment with the oil and gas sector. These scenarios determined the amount of CO_2 that would need to be stored and how much might be consumed for EOR operations. Prior studies conducted by and for NETL were used to bound these scenarios.

Quantify the Response of the Industrial Base to the Scenarios

The final step in our analysis was to determine how the industrial base supporting CO_2 storage would likely respond under the four major scenarios. The responses include estimates of the

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[1] Prior to transmission by pipeline, captured CO_2 must be purified, dehydrated, and compressed into a fluid (ICF International, 2009).

CO_2 pipelines that would need to be constructed, the number of EOR and geologic storage sites to be developed, and the amount of key support services that would be needed. Based on these estimates, we were able to determine the ability of the CO_2 storage industrial base, in aggregate, to meet potential demands. Using these results, we drew out the major implications for NETL programs.

To support the analytical steps outlined above, we developed a number of detailed cost models using empirically derived data on labor, materials, and capital costs as of 2009, and used these models to generate future cost estimates. We also conducted a set of interviews with industry participants regarding their perceptions of the CO_2 storage industrial base, its challenges, and potential.

Our approach relies on two key assumptions. First, we assume that systems to capture CO_2 from coal-fired power plants and other stationary sources will be available and deployed in the coming decades, thus providing sufficient CO_2 for EOR operations and geologic storage. Whether such systems are actually deployed depends on them being commercially available and the most economic means for achieving compliance with policies and regulations requiring reductions in CO_2 emissions. Second, we assume that current efforts to demonstrate the long-term feasibility of geologic storage, monitoring, verification, and accounting of CO_2 are successful, thus paving the way for development of this industry.

Key Findings

The Activities Supporting the CO_2 Storage Industrial Base Are Largely Shared with the Oil and Gas Sector

The CO_2 storage industrial base comprises three core activities: transportation of CO_2 by pipeline, EOR by CO_2 flooding, and geologic storage.

- *Pipelines.* The industrial base used to build and maintain natural gas and petroleum product pipelines is the same industrial base that would be used to build and maintain pipelines to transport CO_2. The same steel is used in pipelines in both industries. Pipeline construction techniques, and hence costs, are very similar. The major differences between pipelines used to transport CO_2 and natural gas and petroleum products concern the coatings and seals used for CO_2, the installation and operation of pumps needed to maintain pressure, and the presence of control valves to allow sections to be isolated for maintenance and to limit releases of CO_2 in case of a rupture. According to our analysis, the differences in costs between CO_2 pipeline equipment and equipment used in natural gas and petroleum product pipelines do not appreciably affect the ability of the industry to construct CO_2 pipelines.
- *CO_2–EOR.* Oil recovery by CO_2 flooding is already widely deployed commercially by the oil and gas industry. Oil companies survey, prepare sites, drill injection wells, engage in well workovers, and plug wells used in EOR. Activities that are unique to EOR, as opposed to other drilling operations, include storing and injecting CO_2. Storage and injection involve receiving CO_2 from a bulk pipeline, distributing it throughout the field, injecting it into the field, and separating CO_2 from the produced crude oil.
- *Geologic storage.* Many activities supporting geologic storage are shared with the oil and gas sector, including geologic surveying, site preparation, and drilling wells. Injecting

CO_2 is an activity shared with CO_2–EOR operations. Post-injection monitoring, verification, and accounting (MVA) operations must occur both at CO_2–EOR sites intending to demonstrate permanent storage and at geologic storage sites. These activities are unique to carbon storage; the necessary technologies are being demonstrated but have not yet been deployed commercially.

CO_2–EOR Can Facilitate the Development of Geologic Storage Industrial Capabilities

NETL, through the RCSP, is demonstrating geologic storage of CO_2 and developing and testing technologies, systems, and protocols for carrying out MVA activities. From an equipment perspective, injecting CO_2 into a deep saline formation is similar to injecting CO_2 into a depleted oil reservoir. When CO_2–EOR is used for permanent storage, key supporting capabilities are developed. These supporting capabilities include detailed reservoir characterization; operational monitoring of the injected plume of CO_2; ensuring that CO_2 does not migrate into underground sources of drinking water; and long-term MVA activities.

Additional technologies need to be deployed to support geologic storage of CO_2. More subsurface mapping is needed because typically less is known about the geology in the case of geologic storage than for EOR operations, which benefit from detailed knowledge of the production history and geology of the field. Second, tracking and monitoring the CO_2 stream during injection will be different in geologic storage applications because there are no producing wells through which oil and CO_2 are recovered. Third, the quantity of CO_2 that would be injected into a single well is greater than that for a typical EOR injection well. When practiced for the purpose of carbon storage, CO_2–EOR advances industrial capabilities for carbon storage, but does not fully develop them.

The Carbon Storage Industrial Base Has Largely Demonstrated the Capacity to Meet the Development Needs for EOR and Geologic Storage

Because so much of the industrial base for EOR and CO_2 storage is the same or similar to that currently drawn upon for the natural gas and oil industries, we find no major barriers to ramping up operations to support CO_2 storage. In particular, we find:

- *The United States has already demonstrated the ability to lay likely needed lengths of pipelines for both EOR and CCS.* To support both EOR and deployment of carbon storage in a timeframe of 2030–2035, a high-end estimate is that up to 32,000 miles of CO_2 pipelines would need to be constructed between 2025 to 2035—roughly 3,200 miles per year. The United States has laid similar lengths of natural gas pipeline in the recent past. For example, the U.S. natural gas industry completed 3,600 miles of pipeline in 2008, and 21,000 miles between 2001 and 2010.
- *U.S. industry is likely to be able to hire sufficient workers with the skills needed to lay the potential length of pipeline needed to support both EOR and CCS.* The number of workers in the oil and gas pipeline construction industry grew by about 60 percent from 2005–2008, demonstrating the ability of the industry to quickly recruit and train labor during periods of high demand. In order to meet the upper-bound estimate of CO_2 pipeline additions and provide lengths of natural gas pipelines similar to the highest recent annual additions, the capacity of the pipeline construction industry would need to approximately double by 2025. Given the lead time available to build these pipelines

and the likelihood that demand will actually be lower than this upper bound, the U.S. industrial base would likely have sufficient time to expand capacity to meet this demand.

- *We found no constraints on U.S. drilling capacity to expand EOR operations in our high-end EOR scenario*. From 2006 to 2010, an average of seven new EOR projects per year came online. We estimate that a maximum of 120 projects, or approximately 24 per year, would need to come online in the 2030–2035 timeframe. In the context of the overall capabilities of the oil and gas sector, this constitutes a relatively small amount of activity. For example, we estimate the total number of drilling rigs required to support the highest pace of development to be 55, or slightly more than two active rigs per site. Currently, there are almost 2,000 onshore drilling rigs in operation in the United States; the number of rigs required to support EOR development would be a small fraction of the total.
- *We also found no constraints on the availability of drilling rigs or seismic crews to develop geologic storage in our high-end scenario.* Assuming that carbon capture systems are widely deployed soon and that the pace of deployment accelerates, 240 geologic storage sites may need to be opened in the five-year period from 2025–2030, an average of 48 sites per year, to accommodate growing volumes of CO_2. We estimate 84 drilling rigs would be required to open 48 sites per year—a small fraction of the total onshore rigs currently available in the United States. We estimate that the number of active seismic survey teams needed to support this scale of development is approximately six, or one-tenth of today's active teams.

Concluding Thoughts

The NETL RCSPs are in the process of demonstrating geologic storage at commercial scales and in a range of geologies. The partnerships also focus on the development of protocols for monitoring, verification, and accounting for the stored carbon during and after CO_2 injection operations. Our analysis indicates that significant expansion of geologic storage capacity is required after 2025 under most scenarios. If we allow several years for permitting and siting of those operations, we conclude that there are approximately ten years before significant injection operations need to begin. Based on the current activity of the partnerships, it appears, from a technical perspective, that the development of geologic storage is on track to meet this goal.

The industrial base for carbon transport and storage could be strained by demand for labor or equipment, much of which is shared with the oil and gas industrial base. During the RCSP demonstrations, NETL has the opportunity to collect data on project activity timelines and overall schedules, the number of qualified bidders, prices for critical equipment, and detailed labor costs. With these compiled data and a comparison with external conditions in the oil and gas market, NETL will be able to ascertain whether the preliminary observed constraints on widespread deployment of carbon transportation and storage are likely to be binding, and determine appropriate and specific R&D strategies or recommended policy responses to alleviate these constraints.