Technical feasibility of rapid deployment of geological carbon sequestration

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"Carbon Capture and Sequestration: An Overview"
Written Testimony

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Mr. Chairman, Representative Hastert, and members of the Committee: Thank you for inviting me to testify today on the technical aspects of carbon capture and sequestration. I am pleased to be here in my capacity as leader of the Carbon Management Program at the Lawrence Livermore National Laboratory to testify on this important technology pathway which could help continue to meet America's domestic energy needs while dramatically reducing the emission of greenhouse gases. Carbon capture and sequestration can be a vital element of a comprehensive energy strategy that includes efficiency gains, conservation, and carbon free energy supplies such as renewable or nuclear power. It can also support environmentally sound development of domestic transportation fuels including biofuels, coal-to-liquids, and hydrogen, and a smooth transition to a carbon-free energy infrastructure.

Carbon capture and sequestration (CCS) has two components. The first is the separation and concentration of CO_2 from point source flue gases, which are produced at power plants, refineries, ethanol plants, fertilizer plants, and other sources like cement factories. This step is needed to bring CO_2 concentrations up to 95 percent before the second step, sequestration. Geological carbon sequestration (GCS) or carbon storage, involves injection of CO_2 into porous rock formations deep below the surface. The goal is to keep CO_2 out of the atmosphere so as to avoid atmospheric warming and the consequences of climate change while allowing the continued use of fossil fuels for power generation and industrial purposes.

Over the past two years, much has been written on the subject of CCS. The Intergovernmental Panel on Climate Change (IPCC) 2005 special report includes a 135-page chapter on GCS. The MIT Report on the Future of Coal in a Carbon Constrained World, released next week, discusses geological sequestration in detail. Shortly, the National Petroleum Council will publish its 30 year strategy that includes a chapter on GCS. These documents and others listed at the end of this testimony serve as resources to those interested in learning more about the technical details that underlie my testimony.

Overview of Geological Carbon Sequestration

Basically, geological carbon sequestration involves compressing CO_2 to elevated pressures and injecting it into geological formations that are from 3,000 to 20,000 feet deep. The most promising reservoirs are *porous and permeable rock bodies*, generally at 1 km depth and pressures and temperatures where CO_2 would be in a supercritical phase in which it behaves like a very dense, liquid-like gas. These potential reservoirs include:

- *Saline formations*, which contain brine in their pore volumes, commonly of salinities greater than 10,000 ppm.
- *Depleted oil and gas fields* which have some combination of water and hydrocarbons in their pore volumes and a demonstrated seal. Injection of CO_2 into these reservoirs can stimulate enhanced oil recovery (EOR) or enhanced gas recovery and increase domestic fuel supply; substantial CO_2-EOR already occurs in the US with both natural and anthropogenic CO_2.
- *Deep coal seams*, often called unmineable coal seams, which comprise organic minerals with brines and gases in their pore and fracture volumes.

Once the CO_2 is injected into the subsurface, it will flow throughout the storage formation where it will remain trapped. This trapping will keep those greenhouse gases out of the atmosphere indefinitely. The IPCC issued a special report in 2005 on the topic of carbon sequestration, stating that if a site is chosen well and operated well, then it is highly likely (>90%) to store 99.9% of injected CO_2 in place for 100's of years, and likely to store 99% for 1000's of years.

The Earth's shallow crust is well suited to the indefinite trapping and storage of CO_2 because of its physical and chemical properties. This is because four different mechanisms trap CO_2 in the subsurface. To begin, CO_2 sequestration targets will have *physical barriers* to CO_2 migration out of the crust to the surface. These barriers will commonly take the form of impermeable layers (e.g., shales, evaporites) overlying the reservoir target and act immediately to limit CO_2 flow. At the pore scale, *capillary forces* will immobilize a substantial fraction of CO_2 as tiny, isolated bubbles trapped as a residual phase. Over a period of tens to hundreds of years, CO_2 in the formation will *dissolve* into other pore fluids, including hydrocarbon species (oil and gas) or brines, where the CO_2 cannot be released without active intervention. Over longer time scales (hundreds to thousands of years) the dissolved CO_2 may react with minerals in the rock volume to *precipitate* the CO_2 as new carbonate minerals. Finally, in the case of organic mineral frameworks such as coals, the CO_2 will physically *adsorb* onto the rock surface, sometimes displacing other gases (e.g., methane, nitrogen). These trapping mechanisms have been documented and observed in natural analogs (e.g., the natural CO_2 domes in Colorado) and laboratory experiments, and they have been simulated in integrated geological models. Although substantial work remains to characterize and quantify these mechanisms, they are sufficiently well understood today to trust estimates of the percentage of CO_2 stored over the timeframes discussed by the IPCC.

Because of their large storage potential and broad distribution, saline formations are likely sites for most geological sequestration. However, initial projects probably will occur in depleted oil and gas fields, accompanying EOR, due to the density and quality of existing subsurface data and the potential for economic return; the Weyburn EOR and storage project in Saskatchewan is one example. Availability of pore volumes in suitable formations for sequestration may be considered a natural resource. Areas that have this resource in abundance have a competitive advantage in a carbon constrained world compared to those that lack storage capacity.

At its heart, GCS is similar to oil and gas production (especially EOR), natural gas storage, hazardous waste disposal, and acid gas management. It is highly analogous to the injection of CO_2 for enhanced oil recovery, which has been done in the US for over 30 years. These activities use the same technologies as GCS, and their technical basis provides confidence in the viability of commercial GCS deployment. In addition, natural accumulations of CO_2 have demonstrably retained large CO_2 volumes for 10's to 100's of millions of years. This provides confidence in the possibility of long-term storage of CO_2 in suitable rock formations.

A key difference between GCS and applications mentioned above is that the GCS goal is to keep the CO_2 in the reservoir. This new application will have new requirements, such as a monitoring and verification (M&V) program. A site M&V program to support GCS should provide these services:

- to identify any early concerns or problems (as mentioned below) and protect public health and safety;
- to assign credits or offsets for commercial GCS, especially under a cap-and trade regime;
- to validate simulations and current understanding of sequestration science; and
- to guide any necessary mitigation efforts.

There are many technologies used in industry today that can monitor CO_2 in the subsurface and the surface, including time-lapse reflection seismic surveying, use of tracers, and electrical soundings. Some of these approaches have been tested in commercial and experimental projects. However, there has been little comprehensive application of these technologies to monitor CO_2 to date.

Several hazards could affect CCS operations at a site. These hazards, such as well failure or CO_2 seepage along faults, could lead to problems such as atmospheric release of CO_2 or groundwater contamination. Pre-existing wells present the largest risks as potential leakage paths, but leakage through wells is the simplest to detect and mitigate. Preliminary analyses through analog studies and simulation, which have been performed by industry, academia and national laboratories, suggest that the risks posed by these hazards are both very small and manageable. As such, carbon capture and sequestration can be safely and effectively deployed widely within the US. Key steps to avoiding hazards are careful site characterization before injection and appropriate M&V programs during injection.

The scale of commercial GCS

Today, the US emits annually 2 billion tons CO_2 from large point sources, and 25 percent of US CO_2 emissions come from coal power generation (~1.5 billion tons). To help you appreciate the scales involved, 1 billion tons is greater than the mass of all human beings on earth. Alternatively, the volumes of CO_2 at depth represented by this mass exceed current US oil and natural gas production combined. A single 1000 MW coal power plant will emit from 5 to 8 million tons CO_2 each year, roughly the same emissions as a 25,000 barrel/day coal-to-liquids plant. With sequestration in an appropriate geological formation, a 50 year injection program for one of these plants would accumulate in excess of 2 billion barrels of CO_2.It is the necessary scale of sequestration projects and enterprise that present challenges to deployment.

The good news is that it appears that the US has more than enough capacity to deploy CCS at large scale. Conservative estimates (including some I've published) are that the US has 2,200 billion tons capacity. Large sequestration resources occur in the mid-west, Texas, and the intermountain west, and substantial opportunities also exist in California, the Dakotas, Michigan, and offshore of the eastern US. The largest of these resources lie in saline formations and depleted oil and gas fields. While these published estimates are uncertain, it is likely that they substantially underestimate total US capacity. Said another way, we appear to have enough capacity to comfortably inject all of our current point source CO_2 emissions for more than 100 years, and are likely to be able to do so comfortably for more than 1000 years.

Commercial projects in carbon storage are underway elsewhere in the world. Three of them (Sleipner in Norway, In Salah in Algeria, and Weyburn in Canada) annually inject over 1 million tons of CO_2 from anthropogenic sources. Several more will come on line in 2008 in Norway and Australia, and nearly a dozen are on track world-wide for completion and injection before 2012. In the US, BP has announced a project in Carson California that will inject 4 million tons of CO_2 each year while producing 500 megawatts (MW) of zero-emission power. Xcel Energy has announced a project to generate 600 MW of zero-emission coal power using CCS. A few of these are enhanced oil recovery projects, which will produce additional liquid fuels. Most of these projects will inject into saline formations, which represent the largest potential CO_2 sinks in the US and the world. These activities demonstrate tremendous technical readiness in the US and the world for commercial deployment.

Potential climate abatement and cost

CCS has the potential to substantially reduce US and global greenhouse gas emissions. From a technical basis, that potential is only limited by the characteristics of the geology. Three conditions are important, sometimes called the ICE characteristics:

- I: sufficient *injectivity* to receive large volumes of CO_2 rapidly (up to several million tons CO_2/year for each project).
- C: sufficient *capacity* to accept large volumes of CO_2 (for some projects, in excess of 300 million tons over the project lifetime)
- E: *effectiveness* in trapping CO_2 for long time spans (100's to 1000's of years).

Based on these characteristics, it appears that both the US and world have abatement potential for CCS between 15 and 55 percent of global emissions reduction by 2050, based on current understandings of global geological options and energy supply infrastructure. The high reductions can be achieved through advanced technology options which connect the transportation sector to a decarbonized electric power sector that includes CCS (e.g., plug-in hybrid deployment, biofuels, or hydrogen). Importantly, this is a very attractive option for rapidly developing countries like China and India with large coal resources.

Most experts see CCS as a bridging technology. This means that it is actionable immediately and could be sustained for many years, allowing us to dramatically reduce greenhouse gas emissions while maintaining the economic benefits of fossil fuel power generation and making use of the current infrastructure. Most experts envision a subsequent future transition away from CCS as new carbon free technologies grow in the market place, including renewables, advanced fission and fusion power, and other developing technologies. CCS could be sustained in the US for a century serving as an affordable interim measure to buy time while an energy strategy and infrastructure is developed to support long-term needs.

Others testifying here today have discussed the costs of carbon capture and separation. By comparison, the costs of sequestration are much lower. For most US targets, the estimated cost of storage injection projects ranges from $1 to 12 per ton CO_2, but average cases range from $5 to 8 per ton CO_2. This is roughly 10% the total cost of capture and separation. The cost of monitoring and verification is much lower, with estimates from $0.25 to 1.00 per ton CO_2. The costs of assessment and site characterization are even less, estimated to be much less than $0.001 per ton CO_2.

Technical needs

I was asked to comment on what we know about carbon sequestration as an option for addressing climate change and what we don't know. I was also asked what work needs to be done to understand those things we don't know. To better bound the 15 to 55 percent estimate of potential greenhouse emission abatement through carbon sequestration, we need to increase the current understanding of global and national geological storage resources. Ultimately, GCS potential will depend on local geological conditions and energy infrastructure choices. Future energy infrastructure decisions (e.g., plant type and location) should be informed by understandings of storage resources. Assessment of this resource can be accomplished through careful and detailed geological studies and validated by a handful of large-scale demonstrations in representative geology. Those demonstrations should both confirm the safe and effective storage of CO_2 in the key formations and should provide the technical basis for future regulatory framework and operation protocols.

An assessment of geological storage resources should provide several key pieces of technical information:.

- A uniform, documented methodology that allows intercomparisons of geologic opportunities and accounts for the different trapping mechanisms.
- A capacity estimate for each region or state and for the nation as a whole.
- A relative ranking of potential sites by storage effectiveness, and their associated capacities.

- Rate information indicating the likely maximum sustainable injection rates for formations and regions.
- Data needed to develop economic models for GCS projects.

In short, a national capacity assessment would provide the same kinds of information that the national hydrocarbon assessments offer in mapping out the natural resources of the country with respect to this purpose. In this context, available pore volume to store CO_2 is such a resource.

The Australian GEODISC program conducted such an assessment four years ago, and this information provided businesses and government with the information needed to make investment and policy decisions. That information has led to Australia's international leadership in GCS and buy-in from major industries such as coal mining and petroleum production. It also provided much information that entered into their regulatory framework, passed into law last month. GEODISC cost only $10 million and took only 3 years.

Because of the enormous scale required for commercial CCS operation, large projects are crucial to confirming our understanding of how CO_2 is trapped and stored, refining deployment operations, and demonstrating success. Smaller projects provide a partial learning platform; however, the key unresolved questions pertaining to commercial-scale injections can only be resolved at large scale. This is due to the hydrological, chemical, and mechanical response of the crust to changes in pressure and fluid composition from CO_2 injection. Many important responses only occur when thresholds are reached, and these will not be reached by small-scale injections. For example, the pressure build-up could cause mechanical failure of the caprock, faults, or wells only when their yield strength is exceeded. That cannot be tested with small-scale injections. Similarly, the rock heterogeneities that control flow in target reservoirs do not become apparent until large volumes are injected for long periods of time.

These issues could be resolved by a select number of large-scale experimental projects (on the order of 1 million tons CO_2/year injection) in target reservoirs of different characteristics that are instrumented, monitored, and analyzed to verify the practical reliability and implementation of sequestration. In addition, the technical results from such large-scale projects could inform the development of operational protocols and regulations. This would require an appropriate, integrated science and technology program to provide the needed analysis. Large experiments will provide the critical segue way to commercial operation and significant abatement of CO_2 in our atmosphere.

Summary

Opportunities for rapid deployment of GCS exist in the US. There is enough technical knowledge to select a safe and effective storage site, plan a large-scale injection, monitor CO_2, and remediate and mitigate any problems that might arise (e.g., well-bore leakage). This knowledge derives from over 100 years of groundwater resource work, oil and gas exploration and production, studies of geological analogs, natural gas storage site selection and operation, and hazardous waste disposal. A careful operator could begin work today at a commercial scale and confidently select and operate a site for 30 to 50 years.

National deployment of commercial CCS poses technical challenges and concerns due to the operational scale. An aggressive research, development, and deployment program could answer all the key technical questions within 10 years and could advise the formation of a legal and regulatory framework to protect the public without undue burden to industry.

Thank you again for the opportunity to present. I look forward to answering questions you might have, and to the real-time deployment of large-scale carbon management in the US.

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