

## **Research Priorities for Sequestration of Carbon Dioxide In Deep Geological Formations**

Testimony before the U.S. Senate Committee on Commerce, Science and Transportation  
Subcommittee on Science, Technology and Innovation  
Hearing on “Research Priorities for Safe and Efficient Carbon Sequestration Technologies”  
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Oral Testimony

Good afternoon. Senator Kerry and members of the sub-committee, thank you for the opportunity to talk with you today. I am Sally Benson, a Professor at Stanford University and Executive Director of Stanford’s Global Climate and Energy Project.

### **The Science Behind Safe and Effective Sequestration**

The science behind safe and effective carbon dioxide sequestration builds on concepts developed from over a century of experience in the oil and gas and groundwater supply industries. Safe and secure sequestration can be achieved by injecting carbon dioxide into porous rocks and trapping it underneath thick and continuous fine-textured rocks or so-called “seals.”<sup>1</sup> Two mechanisms are responsible for trapping<sup>2</sup> and we know they are effective because these are the exact same mechanisms that are responsible for the existence of oil and gas reservoirs.

On this basis, it is straight forward to conclude that sequestration in oil and gas reservoirs is feasible. So what about the other types of formations that have been proposed for sequestration?

Saline aquifers are extremely important sequestration resources because they have the largest capacity and are located closer to more emission sources. The sealing mechanisms for saline aquifers are the same as for oil and gas reservoirs—but here we need scientific proof that the seals are sufficiently thick, have uniformly good sealing properties, and are not penetrated by active faults.

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<sup>1</sup> Since the density of carbon dioxide is less than water, unimpeded, when injected underground, it would migrate back to the land surface. Therefore “seals” are needed to trap carbon dioxide underground.

<sup>2</sup> Two mechanisms are responsible for effective trapping by seals: extremely low permeability—which limits the rate of flow through the seals; and extremely high capillary entry pressure—which prevents any separate phase carbon dioxide from moving into the seal (IPCC Special Report on Carbon Dioxide Capture and Storage, 2005, Cambridge University Press).

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While, in principle, sequestration is straight forward—in practice there is a great deal of science and engineering that underpin safe and effective sequestration, for example: geophysical imaging to locate and assess sequestration reservoirs and seals; computer simulation models to predict sequestration performance; and geophysical monitoring technology to assure that the carbon dioxide remains sequestered.

In addition, while there many reasons to conclude that sequestration is feasible—the question of scale cannot be ignored. Today there are three active sequestration projects<sup>3</sup>. To make a significant impact on emission reductions, thousands of projects will be needed—and each of the projects will be from 5 to 10 times larger than any of the existing projects. The potential for unforeseen consequences of large scale sequestration must be assessed and methods to avoid them developed.

### **Progress on Research and Development**

World-wide, public and private research efforts continue to make steady progress on basic and applied research that address these issues. For example:

- Last summer, the Department of Energy funded an experiment to answer the question—what is the smallest leak that could be detected<sup>4</sup>? Field testing results proved that a number of existing and innovative techniques could detect and quantify extremely low leakage rates—and have the sensitivity needed for reliable monitoring.
- As another example, over the past several years, the U.S. DOE has funded two pilot tests in Texas—the so-called Frio I and Frio II tests<sup>5</sup>. These tests demonstrated that high-resolution seismic methods successfully tracked migration of the plume and that, after calibration, computer simulation models could predict where and how fast the carbon dioxide moved. The U.S. DOE Regional Partnerships will replicate these types of tests in a number of different geological environments, providing valuable first-hand knowledge and experience for state and local regulators who will one day be called upon to oversee these projects.

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<sup>3</sup> The three existing sequestration projects are the Sleipner Project off-shore of Norway, the Weyburn Project in Saskatchewan, and the In Salah Project in Algeria. The Sleipner Project began in 1996 and sequesters 1 Mt/year of CO<sub>2</sub> in a saline aquifer. The Weyburn Project, which began in 2000, is a combined CO<sub>2</sub>-EOR and sequestration project that injects about 2 Mt/yr into an oil reservoir. The In Salah Project began in 2004 and sequesters about 1 Mt/yr in a depleting gas reservoir. A fourth project, the Snohvit Project, is expected to begin injecting 0.7 Mt/yr into a saline aquifer under the Barents Sea in 2007.

<sup>4</sup> The Detection Verification Facility is collaboration between several Universities and National Laboratories lead by Montana State University. The experiment showed that leakage of 100 kg/day over a 100 m long feature could be detected and quantified using flux accumulation chambers. A second experiment demonstrated that 300 kg/day could be detected and quantified by several methods

<sup>5</sup> The Frio Pilot Tests, lead by the University of Texas at Austin, are a collaboration between University and National Laboratory scientists. The first test in 2003 injected about 1,600 tons of carbon dioxide. The second test in 2006 injected about 500 tons. Extremely valuable scientific results were gained from the small-scale pilot tests, including new methods for tracking migration of carbon dioxide movement in the surface, fundamental insights about multi-phase flow of carbon dioxide and brine, and geochemical interactions between carbon dioxide and the reservoir rocks.

- As a final example, the Global Climate and Energy Project at Stanford University<sup>6</sup> has developed new theoretical concepts to predict how quickly secondary trapping mechanisms<sup>7</sup> could permanently immobilize carbon dioxide—thus further reducing the potential for leakage, even if, for example, degrading cement in an old abandoned well breached the reservoir seal.

There is also an urgent need for demonstration projects—at a scale commensurate with sequestering the 5 to 10 million tons of carbon dioxide emitted annually from a typical coal-fired power plant. Plans have been announced or are now underway in the U.S. for a number of publicly<sup>8</sup> and privately<sup>9</sup> funded mid-to-large scale demonstration projects—and it is important they get started now. Without definitive results from these and even larger scale tests, policy makers, investors and society will not have the confidence needed to proceed with widespread deployment of CCS.

## **Barriers to Implementing Geological Storage**

As interest in sequestration has grown, so too has the concern about long term stewardship and liability grown. Who will be responsible for long term monitoring? Who will pay to remediate a site if it starts to leak 100 years from now? The prospects for long term stewardship and long term financial responsibility make investors nervous—and if not addressed they will create a barrier to widespread deployment. In part, answers to these questions are legal and institutional in nature. However, scientific research has a large role to play in bounding the potential for unforeseen events and providing a scientific framework for addressing these issues.

In particular, naturally occurring secondary trapping mechanisms such as dissolving carbon dioxide into water, forming minerals, and capillary trapping can provide additional storage security—and these processes become more effective as time passes. Fundamental research is needed to quantify the potential and timeframe for completely reducing the risk of leakage and for learning how to accelerate these processes if needed. Long term stewardship and financial responsibility are much less daunting if the risk of unforeseen events can be shown to predictably decrease with time.

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<sup>6</sup> The Global Climate and Energy Project at Stanford University funded by ExxonMobil, GE, Toyota and Schlumberger, performs fundamental breakthrough research to develop a wide range of low-carbon and carbon-free energy supply technologies—including carbon sequestration. <http://gcep.stanford.edu/>.

<sup>7</sup> Secondary trapping mechanisms include dissolutions of CO<sub>2</sub> in brine, capillary trapping and mineralization (IPCC Special Report on Carbon Dioxide Capture and Storage, Cambridge University Press, 2005).

<sup>8</sup> Federally funded projects include FutureGen and 3 recently announced sequestration projects carried out by the Plains Carbon Dioxide Reduction Partnership; Southeast Regional Carbon Sequestration Partnership; and Southwest Regional Partnership for Carbon Sequestration. All will conduct large volume tests for the storage of one million tons of carbon dioxide (CO<sub>2</sub>) in deep saline reservoirs.

<sup>9</sup> Announcements for privately funded mid-to-large scale projects in the U.S. have been made by a number of companies. Examples include the BP Carson project and AEP's projects in West Virginia and Oklahoma. All of these are in the planning stage.

## Gaps in Public and Private Research Activities

Now, coming to your final question—are there gaps in public and private research activities? Certainly, growth in federal support for sequestration research has been impressive over the past decade—increasing from nearly nothing ten years ago to over \$100 M in 2007. Industrial support is also growing. But, while growing interest and support is encouraging, at the current pace of progress, convincing answers about safety and effectiveness may not be available for more than a decade. Accelerating the pace of progress requires commitment to a parallel development pathway, simultaneously

- building a strong fundamental scientific program<sup>10</sup>;
- providing sufficient financial resources for the pilot projects in order to learn as much as possible from them; and
- expediting full-scale demonstration projects.

Effective communication and coordination of these three parallel development pathways will also maximize progress and ensure efficient use of resources.

In closing, carbon sequestration is a promising and necessary technology. Thank you very much for the opportunity to discuss this important topic with you.

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<sup>10</sup> DOE's Office of Science conducted a workshop in research opportunities in the geosciences related to sequestration (Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems, [http://www.sc.doe.gov/bes/reports/files/GEO\\_rpt.pdf](http://www.sc.doe.gov/bes/reports/files/GEO_rpt.pdf)). Five priorities for improving our understanding of multiphase flow were identified:

- New approaches are needed to accurately predict migration of multiple fluid phases in environments that are highly heterogeneous, from the pore scale to the basin scale—over large spatial scales and long time frames.
- Methods to quantify and predict rates of geochemical reactions between multi-phase, multi-component fluids and minerals are needed to understand how quickly dissolution and mineralization will occur.
- Fundamental scientific understanding of basin-scale geomechanical processes is needed to predict shallow crustal deformation and basin scale brine displacement caused by large and rapid anthropogenic perturbations such as injection or extraction of multiphase fluids in the subsurface.
- A new multi-disciplinary approach is needed to assess the multi-phase flow properties of membrane seals, faults and fractures—in order to determine whether or not a geological reservoir has an adequate seal.
- Dynamic field-scale imaging is needed to test and validate multiphase flow models.