A Perspective On The Potential Role Of Geologic Options In A National Carbon Management Strategy

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Abstract. Carbon sequestration is the critical "third-option" for addressing greenhouse gas emissions, along with increased energy efficiency and expanded use of low-carbon fuels. Together with technology progress, these three options can provide the Nation with the ability to sustain economic growth through affordable energy, while meeting environmental and carbon emission goals (Beecy and Kuuskraa, 2000).

Carbon sequestration in geologic formations, one of the options for carbon management, entails adapting natural processes that have been storing CO_2 and methane (CH_4) (another greenhouse gas) for geologic times. Some nearly pure CO_2 is extracted from geologic formations (or industrial processes) and reinjected back into geologic formations to enhance recovery of oil and coalbed methane. Future research may even unlock the process for converting CO_2 back into methane. As such, there are both near-term opportunities and longer-term possibilities for geologic sequestration to be a major option for carbon management.

Introduction. As concerns increase about the adverse impacts of anthropogenic emissions of greenhouse gases on global climate, it may become necessary to significantly reduce these emissions. From the perspective of fossil fuels, the source of a substantial portion of these anthropogenic greenhouse gas emissions, the industry has three major options: (1) improving the efficiency of energy production and use; (2) reducing the carbon content of fuels through increased use of natural gas and non-carbon fuels (eg. renewables and nuclear); and, (3) sequestering the emission of carbon dioxide. The third option, carbon sequestration, is increasingly seen as a cost-effective strategy for achieving deep reduction in carbon dioxide (and carbon) emissions (Herzog, Drake and Adams, 1997).

Carbon sequestration is a relatively new field of science and technology. However, interest in it has been growing rapidly. In 1998, the Department of Energy's Office of Fossil Energy (DOE/FE) and Office of Science (DOE/OS) set forth their joint "roadmap" for carbon sequestration as an option for addressing climate change concerns.

The roadmap identifies several alternatives for sequestering carbon including enhancing natural carbon sinks, capturing CO_2 and storing it in geologic formations or the deep ocean, and converting CO_2 to benign solid materials or fuels through biological or chemical processes. The DOE's Office of Fossil Energy, in partnership with industry, the International Energy Agency's Greenhouse Gas Research and Development Programme and others, has underway a Carbon Sequestration Research and Development Program that addresses a broad range of sequestration options. In parallel and closely coordinated, the Office of Science has launched their Carbon Management Science Program.

Vision for Geologic Sequestration. The vision for the Sequestration R&D Program is to develop the essential scientific understanding of sequestration and develop cost efficient options that ensure environmentally acceptable sequestration to reduce anthropogenic CO_2 emissions.

- In the near term, the program will emphasize options for "value-added" geologic sequestration with multiple benefits, such as using CO_2 for enhanced oil recovery and coalbed methane production.

- Over the long-term, the program will pursue R&D on biogenic conversion of CO_2 to methane, first by better understanding the natural conversion processes that have been underway over geologic time. The program will also examine the feasibility of other value-added sequestration options such as enhanced gas recovery and will seek to better understand the options for CO_2 storage provided by the nation's extensive saline formations. The program seeks to use early successes in niche, value-added applications to attract industry interest and participation in advanced sequestration concepts and R&D.

Putting the Carbon Back in the Ground. With the passage of time, plus temperature and pressure, the carbon in plants and fossils buried underground has been converted to petroleum, coal and other fossil fuels. These are the same fossil fuels that are the source of the carbon dioxide emissions that we now seek to reduce. The vision for geologic sequestration is "putting this carbon back in the ground."

Under the surface of the earth, in the U.S. and many areas of the world, are structures that once were filled with oil and gas but now have space that could be used for storing CO_2. Under the right geologic setting, a portion of this injected CO_2 may be converted to fixed minerals or, in the presence of methanogens, back to methane (Beecy and Ferrell, 2000).

Other structural settings, lacking the presence of hydrocarbons, are filled with saline waters left over from pre-historic seas. These structures could also serve as sites for carbon dioxide storage, displacing the water in the structures or becoming dissolved in the saline water itself, much as is the case with natural mineral water – "mit gaz."

Role of Natural Analogs. One of the main issues surrounding geologic sequestration is its reliability for long term CO_2 storage. Opportunities exist for understanding the long term behavior and safety of these underground carbon dioxide storage sites from rigorous study of "natural analogs." In certain geologic and high temperature settings, the hydrocarbons in a reservoir have been converted to carbon dioxide. In other settings, carbon dioxide from deeper sources has migrated and become trapped in these underground structures. In either case, the carbon dioxide in these "natural analogs" has existed and been stored for millions of years. Understanding the interactions of carbon dioxide with formation water, rock and minerals and assessing the seals and leakage (if any) of natural CO_2 storage sites can provide valuable insights and data obtainable in no other manner.

Value-Added Geologic Sequestration. As introduced above, some of the geologic settings offer the potential for value-added byproducts, helping defray some of the costs of carbon sequestration. Notable examples are the injection of carbon dioxide for enhanced oil recovery and enhanced coalbed methane production. Numerous barriers still exist in using these options for carbon dioxide storage, such as reconciling the conflicts between achieving lowest cost oil/methane recovery and maximizing CO_2 sequestration. In all cases, adding appropriate long term monitoring and verification to the CO_2 injection and storage process will be essential.

The adaptation of these existing technologies can provide viable near term options for geologic sequestration. In the longer term, considerable research and technology demonstration will be required to fully define and lower the costs of advanced options, such as saline formation storage, biomineralization, or even CO_2 conversion through methanogens or biomimetic approaches.

Capacities of Geologic Sinks. Numerous natural sinks exist for storing carbon in the form of carbon dioxide -- depleted oil and gas reservoirs, deep coal seams, saline formations, rock caverns and mined salt domes. These geologic sinks hold considerable capacity, both in the U.S. and worldwide, sufficient to store all expected increases in carbon dioxide emissions for the next many hundreds of years.

The technology for injecting carbon dioxide back into the ground is established. Oil producers in the Permian Basin of West Texas and in the Rocky Mountains have been injecting carbon dioxide for enhanced oil recovery (EOR) for more than 25 years. In addition, the operation of the underground natural gas storage system, with its annual cycles of natural gas injection and withdrawal, offers a considerable base of geologic and engineering experience relevant to carbon dioxide injection and sequestration.

Depleted Oil and Gas Fields. Depleted oil and gas fields provide some of the largest, geographically diverse value-added geologic sinks. The "value-added" is from the additional production of oil (and possibly natural gas) which would help defray some of the costs associated with carbon dioxide transportation and injection.

A recent study by Advanced Resources Int. for the International Energy Agency's Greenhouse Gas R&D Programme and the Department of Energy assessed the potential for sequestering CO_2 in depleted oil and gas fields (Stevens, Kuuskraa and Taber, 1999). This study established that 98 billion metric tons (Bt) of CO_2 (27 Btc) storage capacity exists in the U.S. with 923 Bt of CO_2 (252 Btc) storage capacity worldwide, Table 1.

Currently, an estimated 30 million metric tons (MMt) of CO_2 (8 MMtc) is injected annually into oil fields as part of enhanced oil recovery, including 6 MMt of CO_2 (2MMtc) of high purity anthropogenic waste CO_2 from gas processing, fertilizer and coal gasification plants. One of the most visible new international field projects is in the Weyburn oil field, Saskatchewan, Canada where vented CO_2 from the Dakota Gasification Plant in North Dakota is transported by a 300 kilometer pipeline to the field site. A total of 20 MMt of CO_2 (6 MMtc) will ultimately be sequestered at Weyburn.

Deep Coal Seams. Deep, unminable coal seams offer a second set of geologic sinks for sequestering carbon dioxide. As in oil fields, the injection of carbon dioxide can lead to enhanced recovery of methane from these coal seams, providing a second value-added storage site. An update to an earlier study by Advanced Resources Int. (Stevens and Kuuskraa, 1998) shows that deep coals have 52 Bt of CO_2 (15 Btc) storage capacity in the U.S. with 220 Bt of CO_2 (60 Btc) of storage capacity worldwide, Table 2.

Currently, a field scale demonstration pilot involving injection of carbon dioxide into coals for enhanced coalbed methane recovery is underway in the deep Fruitland Formation of the San Juan Basin. Burlington Resources, the operator of the demonstration pilot, is injecting approximately 70 thousand metric tons of CO_2 annually into the deep coal formation with promising results. A second, smaller enhanced coalbed methane R&D project involving CO_2 injection is being conducted by the Alberta Research Council in Canada, and a new, field based ECBM effort is being launched in the San Juan Basin involving Advanced Resources, BP and Burlington Resources.

Gas Shales. Organically rich gas bearing shales, such as the Devonian shales in the Appalachian Basin, also provide an opportunity to store carbon dioxide while enhancing the recovery of gas from shales (EGSR). While substantial basic information and R&D are required to better understand the value-added opportunity, the carbon storage capacity of gas shales may approach that of deep coal seams.

Saline Formations. The largest but least defined of the geologic sinks occur in deep saline formations. Such formations are broadly distributed across the US and much of the world. While these sinks offer no value-added products, they have the advantage of being in close geographic proximity to CO_2 emission sources. The estimated carbon dioxide storage capacities for saline formations are large, though still to be defined, in the U.S. and several thousand billion tonnes worldwide.

An innovative test of CO_2 storage in saline formations is underway at Sleipner Field in the middle of the North Sea. Approximately 1 million metric tons of CO_2 is being injected annually into the saline Utsira Formation at Sleipner, with 2.5 million metric tons having been injected to date.

Summary. The currently defined storage capacity in geologic sinks is large, sufficient for many hundreds of years of carbon sequestration. Moreover, as these sinks are further assessed for maximizing carbon dioxide storage, these capacities will undoubtedly increase. The next major challenges for geological storage are to: (1) understanding the requirements and costs of adapting these sites for long term storage of carbon dioxide; (2) ensuring that the carbon dioxide will be stored in a safe and environmentally sound manner; and, (3) establishing the appropriate monitoring and verification systems for the broad geologic spectrum of storage options.

Current Status and Future Directions. Currently, the highest priority research activities for geologic sequestration are those which can help resolve technical, economic and environmental uncertainties that would enable CO_2 sequestration using enhanced oil and coal bed methane recovery to move forward to large-scale deployment. Major emphasis will be placed on developing acceptable monitoring and verification processes. As additional funding becomes available, research will begin to address value-added CO_2 storage options, such as gas-bearing shales and other gas reservoirs, and sequestration in deep saline formations.

For the longer term, we will seek to explore more challenging scientific frontiers. One area is to determine whether the emerging knowledge base about biogenic methane, produced by the reduction of CO_2, can lead to commercially viable processes for the conversion of man-made CO_2 to methane at sites specifically designed for that purpose. If economically viable concepts can be developed in this area, this could provide a pathway to a sustainable "methane economy".

The U.S. Congress has appropriated $19 million of R&D funds for fiscal year 2001, which started on October 1, 2000. R&D funding required to maintain the schedule of the 15-year plan, outlined in Table 2, is $40 million in 2002. The program is also exploring funding opportunities to expand technology deployment of carbon sequestration in cooperation with industry and developing nations.

In the coming years, the program will be seeking to expand its partnerships. In May 2001, the program is sponsoring the First National Carbon Sequestration Conference, in Washington, D.C. The conference theme is "Progress Through Partnerships" and will cover all aspects of sequestration. As the recently funded partnership projects get underway, the program will be exploring opportunities to expand collaborative R&D in cooperation with industrial partners, using these projects as "host-sites" for expanded international cooperation in a manner similar to what is occurring with the Sleipner Saline Formation CO_2 Storage (SACS) Joint Industry Program (JIP) in the North Sea.

We also look forward to expanding our existing cooperative efforts with the European Commission, Canada and Australia, including the GEODISC Consortia, and to building new "Partnerships For Progress".

If you are interested in working with the Carbon Sequestration Program, please visit the DOE or NETL website or establish contact with the persons listed below.

- DOE Carbon Sequestration Page @ http://www.fe.doe.gov/coal_power/sequestration/index.html
- NETL Carbon Sequestration Page @ http://www.netl.doe.gov/technologies

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Table 1. Capacities of Geologic Sinks				
	U.S.		Worldwide	
	CO_2 (Bt)	Carbon (Bt)	CO_2 (Bt)	Carbon (Bt)
Depleted Oil and Gas Fields	**98**	**27**	**923**	**252**
Deep Coals	**52**	**15**	**220**	**60**
Gas Shales	**equal to coal?**		**TBD**	**TBD**
Saline Formations	**large**	**large**	**very large**	**very large**

Table 2. 15-year Resource Requirements for the Carbon Sequestration Program (millions of 1999 U.S. dollars)															
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
9.2	19.5	40	57	63	73	75	80	85	80	75	70	60	50	45	40