UNITED STATES Carbon Sequestration Council

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# Is $CO_2$ Sequestration Safe?

## Introduction

This paper addresses the question of whether the storage of carbon dioxide in deep underground geological structures is safe. This paper is another in a series of educational papers developed by the U.S. Carbon Sequestration Council (USCSC) on subjects related to $CO_2$ capture and storage, and draws extensively (with the author's permission) from the work of Professor Sally Benson (Stanford University), a member of the USCSC. For additional information please refer to Professor Benson's paper on the subject (Benson, Sally, *Carbon Dioxide Capture and Storage: Assessment of Risks from the Storage of Carbon Dioxide in Deep Underground Geologic Formations*, Lawrence Berkeley National Laboratory, 2006).

## What is Carbon Dioxide ($CO_2$)?

$CO_2$ is a gas that is one part carbon and two parts oxygen. Carbon is one of the essential building blocks of life. It can be readily found virtually everywhere (including in the human body). We inhale oxygen and exhale $CO_2$. Plants absorb $CO_2$ and through photosynthesis convert it to oxygen which they release back into the atmosphere. $CO_2$ is found in nature in the air we breathe, in the ground below our feet, and in the oceans and other bodies of water around the world. It is also found in the carbonated beverages we drink. When frozen it forms dry ice which we widely use to keep foods and other items cold. In the ground, nature geologically stores or sequesters the $CO_2$ permanently. This naturally occurring, geologically sequestered $CO_2$ can be found in the U.S. (e.g., Colorado and Utah) and in other parts of the world. $CO_2$ can also be found in natural gas reservoirs, where it has safely remained for millions of years. Carbon is also a key component of many fuels, including coal, oil, natural gas and biomass fuels (wood and animal waste). Coal, oil, and natural gas are named fossil fuels because they are made from the buried remains of plants and animals that lived millions of years ago. The majority of U.S. and global electricity comes from fossil fuels. Indeed, over 85% of the world's energy needs are provided by fossil fuels, and the U.S. Department of Energy (DOE) projects that fraction to remain constant through 2030.

## What is the issue with $CO_2$?

As discussed in a previous USCSC paper, "Is CCS Needed?" the world is experiencing a rapid growth in population and economic prosperity (despite the recent down turn in global economies). This leads to increased use of energy. This rapid growth in energy demand necessitates the utilization of all available forms of energy, many of which release $CO_2$ into the atmosphere and contribute to global warming. However, most of this $CO_2$ can be captured and stored (sequestered) and thereby eliminated from the atmosphere.

***What are the safety risks from the geologic storage of $CO_2$?***

Some have asked whether captured $CO_2$ can be stored in a safe manner -- whether stored $CO_2$ may leak out of its intended confinement space and either contaminate drinking water supplies or escape to the atmosphere. "Most detectable leaks that lead to elevated $CO_2$ concentrations, and virtually all hazardous leaks, occur in volcanic areas that are highly fractured and therefore unsuitable for $CO_2$ storage" (Benson, 2006). Good site selection, comprehensive site characterization, proper injection rates, appropriate site monitoring, operation of the facility within established safety envelopes, coupled with the implementation of remedial measures if leakage is detected, assures the safe geologic storage of $CO_2$. There are three large-scale $CO_2$ storage projects (injecting 1-2 million tons of $CO_2$ per year) that have now been operating for many years. The Sleipner project in Norway began injecting $CO_2$ in 1996. The Weyburn Project in Canada began in 2000. The In Salah project in Algeria began in 2004. These three projects have a cumulative operating experience of about 24 years through 2008 with no $CO_2$ safety or health effects.

***Can geologic $CO_2$ storage contaminate ground water?***

No known contamination of groundwater has occurred from the capture and geologic storage of $CO_2$ and it should not occur in the future. Storage sites must be properly selected/designed, fully characterized, and appropriately monitored. If a site was to be improperly characterized or designed and leakage occurred that was not subsequently controlled, then $CO_2$ could migrate to the near surface. To further reduce the possibility of this occurring, any project proposing to inject $CO_2$ underground must receive an environmental permit pursuant to EPA's long established Underground Injection Control (UIC) Program. This program is focused on protection of underground sources of drinking water. EPA has recently proposed regulatory changes targeted specifically at $CO_2$ injection, including enhanced site characterization, monitoring, and development of leak mitigation and remediation plans.

***Will $CO_2$ storage cause earthquakes?***

Early research in the 1950s showed that the injection of fluids at sufficiently high pressures can cause "hydro-fracturing" or fault activation or slippages along pre-existing fractures (in places where faults already existed). These could induce small-to-medium-sized earthquakes. Based on an improved understanding of local and regional stresses in the earth's crust, guidelines have been developed to prevent injection-induced micro-seismicity. Now, regulatory agencies limit injection rates and pressures to avoid unintentional hydro-fracturing. Micro-seismic monitoring is often done early in a project to establish safe operational parameters for injection.

Carbon dioxide sequestration projects will operate under similar guidelines. Storage site locations will be carefully selected to avoid such problems. In addition, there have been decades of experience with EOR (using $CO_2$ injection) and natural gas storage projects without encountering such problems. There is also some limited experience in Japan, where a $CO_2$ storage site was subjected to two earthquakes (unrelated to the stored $CO_2$) in the 6.8 range on the Richter scale and experienced no leakage.

***Could a Lake Nyos situation occur with geologic $CO_2$ storage?***

No, the Lake Nyos event was not associated with geologically sequestered $CO_2$. Lake Nyos, a lake in a volcanic crater located in the African country of Cameroon, accumulated very large amounts of naturally occurring $CO_2$ of volcanic origin (especially in the deep cold water of the lake) that was very suddenly released. This was due to the overturn of this lake--i.e., the deep cold water in the lake with high $CO_2$ concentrations was suddenly brought to the surface. A lake overturn mechanism is very different from the possible $CO_2$ seepage mechanisms from wells or fractures from fully characterized underground geologic storage sites. Geological storage structures are highly unlikely to lead to sudden releases of large volumes of $CO_2$ over short time periods. Geologic storage sites would be carefully selected and fully characterized to determine their $CO_2$ storage suitability. The storage site also would be fully instrumented to easily detect a $CO_2$ build up of the Lake Nyos size (and far smaller amounts) and thereby prevent any unlikely safety consequences.

## *Is $CO_2$ sequestration safe? Evidence indicates that it is.*

***Prior experience with stored CO2 and natural gas has been safe.***

In the petroleum producing areas of the United States, oil and gas deposits, as well as naturally occurring $CO_2$ gas, have been trapped within subsurface geologic formations for millions of years. With proper engineering design and monitoring, these same geologically sealed formations should also prevent the upward migration of stored manmade $CO_2$. The United States is also fortunate to have extensive experience with natural gas storage, where gas is injected underground during the summer and then recovered to heat homes in the winter. That geological and engineering experience can be applied to $CO_2$ sequestration as well. $CO_2$ is a much safer, non-combustible gas when compared to natural gas. By understanding where natural gas storage has been safe and successful, we can apply that knowledge to safely store $CO_2$.

A second type of experience related to safe storage of $CO_2$ is our extensive history of injecting $CO_2$ for enhanced oil recovery (EOR). EOR has been conducted safely for over 20 years in the United States.

A third type of relevant experience is the injection of acid gases, primarily $CO_2$ and hydrogen sulfide, into saline geological structures in Alberta, Canada. These projects are typically much smaller in scale than storage of $CO_2$ from a power plant, but these storage projects have operated for many years without incident.

Thus, there are many decades of experience with natural gas storage, naturally occurring $CO_2$, and injection of $CO_2$ from non-power plant industrial activities. This history indicates, that when properly done, the injection and storage of man-made $CO_2$ underground (or geologic sequestration) from power generation should be equally safe. In geologic sequestration of man-made $CO_2$, as with naturally occurring, geologically sequestered $CO_2$, the $CO_2$ would be stored in deep underground formations. Such formations include depleted oil and gas reservoirs, un-mineable coal seams, and deep saline formations. Many of these formations have naturally stored carbon dioxide and other gases and fluids (*i.e.*, petroleum) for millions of years. They have the potential to store hundreds of years' worth of human-generated $CO_2$.

***Natural phenomena will help make $CO_2$ storage permanent over the very long term.***

In nature, over very long time periods, $CO_2$ slowly reacts with mineral matter to form very stable compounds. There was a large reduction of $CO_2$ in the atmosphere from Cretaceous to post-Cretaceous (after the age of dinosaurs) times. Natural processes caused these reductions, such as weathering of silicates to carbonates, and calcium carbonate (limestone and chalk) formation from $CO_2$ deposition. While $CO_2$ mineralization is an ongoing natural process, it is a very slow process when left to nature. There has been research aimed at accelerating these reaction rates (research at the National Energy Technology Laboratory/Albany and elsewhere) to be able to capture and store $CO_2$ in a solid mineral form. This can provide another safe, long-term repository for $CO_2$.

## *Is $CO_2$ sequestration safe? The U.S. Department of Energy (DOE) considers it to be safe.*

The DOE's National Energy Technology Laboratory's (NETL) web page includes the following assessment of the safety of sequestration:

***"With proper site selection based on available subsurface information, a monitoring and verification program, regulatory system, and appropriate mitigation to stop or control $CO_2$ releases should they arise, environmental and safety concerns are minimal. Local health, safety, and environmental risks of geological storage would be less than the risks of current activities such as natural gas storage and enhanced oil recovery due to the fact that $CO_2$ is not toxic, flammable, or explosive."***

There is additional sequestration information on the NETL web site to support such a conclusion (see www.netl.doe.gov/technologies/carbon_seq/index.html).

## *Is $CO_2$ sequestration safe? Thirty two international authors have concluded that it is.*

The International Panel on Climate Change (IPCC) won the 2007 Nobel Peace Prize for their work on climate change. Their 2006 IPCC assessment of $CO_2$ capture and storage authored by 32 experts from around the world concluded that, for large-scale $CO_2$ storage projects (assuming that sites are well selected, designed, operated and appropriately monitored) it is likely the fraction of stored $CO_2$ retained is more than 99% over the first 1,000 years. Moreover, the expected long retention times, combined with a wealth of related experience with large-scale injection, lead these authors to conclude:

***"With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control $CO_2$ releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas"*** *(IPCC, 2006).*

## *Is $CO_2$ Sequestration safe? The attached scholarly analysis supports its safety.*

The attached paper (Benson, 2006) finds that*:*

*" **The results of the IPCC assessment, taken with actual operating experience from the three (ongoing, large-scale) $CO_2$ storage projects with a collective operating experience spanning 17 years*** **[now 24 years through 2008],** ***suggests that $CO_2$ storage in deep geologic formations can be carried out safely and reliably."***

In addition," *for large-scale operational $CO_2$ storage projects, assuming that sites are well selected, designed, operated, and appropriately monitored, the balance of available evidence suggests the following":*

- *"It is very likely that the fraction of stored $CO_2$ retained is more than 99% over the first 100 years" (IPCC, 2006).*
- *"It is likely that the fraction of stored $CO_2$ retained is more than 99% over the first 1000 years" (IPCC, 2006).*
- *"There are multiple lines of evidence regarding the security of geological storage of $CO_2$. Evidence from naturally occurring hydrocarbon accumulations, $CO_2$-EOR, natural gas storage, fundamental scientific*

*studies, model predictions and actual $CO_2$ storage projects provide evidence for short- and long-term storage security."*

- *"Naturally occurring oil, gas and $CO_2$ reservoirs demonstrate that buoyant fluids such as $CO_2$ can be trapped underground for millions of years."*

- *"Industrial analogues such as natural gas storage, $CO_2$-EOR, acid gas injection, and liquid-waste-disposal operations have developed methods for injecting and storing fluids without compromising the integrity of the caprock or the storage formation."*

- *"Fundamental principles of multiphase flow of $CO_2$ in the subsurface indicate that several mechanisms contribute to long-term storage security, including physical trapping beneath low-permeability rocks such as silts, clays and evaporates; dissolution of $CO_2$ in brine; capillary trapping of $CO_2$; adsorption on coal, and mineral trapping."*

- *"The relative importance of these mechanisms will vary from site to site, depending primarily on the geological structure and mineralogical makeup of the rocks. Together these trapping mechanisms increase the security of storage over time, thus further diminishing the possibility of potential leakage and surface release."*

- *"Finally, early experiences at the Sleipner Project in the North Sea (9 years of operation), the Weyburn Project in Saskatchewan (six years of operation), Canada and the In Salah Project in Algeria (2 years of experience) have been successful, with no evidence of leakage or safety problems. We have the benefit of over 17 years of cumulative experience* [now 24 years through 2008] *from which we can draw conclusions regarding the risks of $CO_2$ storage projects."*

## Is $CO_2$ Sequestration safe? NRDC testimony supports its safety.

The Natural Resources Defense Council's (NRDC's) prepared testimony (page 15) of November 13, 2007 before the Senate Committee on Environment and Public Works supported the safety of $CO_2$ sequestration, observing that ***"expert studies have concluded that we have the knowledge base now to proceed safely with geologic disposal of carbon dioxide in the amounts produced by the typical coal fueled power plant."*** One of the referenced studies was the IPCC report referenced earlier in this paper. Another referenced study was the MIT 2007 report, "The Future of Coal." With regard to the MIT report, the NRDC testimony (page 15) also included the following:

*"The MIT report's lead authors, Professors John Deutch and Ernest Moniz, had this to say about the safety of multi-million ton injection projects to the Senate Energy and Natural Resources Committee in March 2007: " … **We have confidence that megatonne scale injection at multiple well-characterized sites can start safely now**, but an extensive program is needed to establish public confidence in the practical operation of large scale sequestration facilities over extended periods and to demonstrate the technical and economic characteristics of the sequestration activity."* [*Deutch, emphasis supplied], … U.S. Senate, Energy and Natural Resources Committee, "Future of Coal," March 22, 2007, S. Hrg. 110-69 at 9, 11."*

## Summary

**As previously referenced, the IPCC (32 noted authors) concluded that $CO_2$ can be safely sequestered in geologic formations; that $CO_2$ sequestration is as safe as activities that have been ongoing for decades, such as EOR, natural gas storage, and deep underground disposal of acid gas** (IPCC, 2006)**.**

The successful sequestration of $CO_2$ will require proper site selection using accurate subsurface information, an effective monitoring and verification program, and a reasonable legal and regulatory framework. The latter was the subject of a companion USCSC educational paper. Several states have already adopted laws and regulations requiring government review and approval of storage sites prior to initiation of $CO_2$ injection. Federal rules also apply for protection of groundwater deposits, and EPA has proposed additional rules that reflect the specific characteristics of $CO_2$ injection and storage. Careful project siting will ensure that no geologic formation with an unsafe or uncharacterized geologic seal will be used for $CO_2$ sequestration. Storage safety can be further enhanced by means of appropriate mitigation measures to stop or control $CO_2$ releases should they arise, however unlikely they may be. The available evidence indicates that the geological storage of $CO_2$ is as safe as natural gas storage and enhanced oil recovery. $CO_2$ is not toxic, flammable, or explosive. There is already a strong base of industry experience in enhanced oil recovery, where water and $CO_2$ are pumped into depleted oil wells to re-pressurize wells and increase oil production.

***What more needs to be done?***

***"There is consensus that $CO_2$ storage in deep underground geologic has great technological potential and may be deployable on a widespread basis. However, there are still substantial financial, institutional, regulatory, and technical challenges that remain. To address these challenges, multiple integrated $CO_2$ capture and storage system projects are needed to prove out the technology. Also needed is an array of small, and intermediate and large-scale $CO_2$ injection field tests in diverse geologies to adequately characterize and validate the U.S. geologic resource"*** (Position Paper of the Coal Utilization Research Council on the Status of Technology for Carbon Capture and Storage (CCS), 2008).

Building on the extensive experience with EOR and natural gas storage, the U.S. Department of Energy, led by NETL and the seven U.S. Regional Carbon Sequestration Partnerships, is pursuing in partnership with industry and academia a critically important Sequestration Research, Development, and Demonstration Program. This program includes key field tests throughout the U.S. and Canada to fully characterize geologic storage sites, to validate models, to validate prior findings, to develop Measurement, Monitoring and Verification (MMV) instrumentation. This, in turn, will lead to the completion of the overall data base necessary to assure that we can safely and effectively store large volumes of $CO_2$. Rapid progress is being made, however the work is not yet complete and more remains to be done, especially to support the broad, large scale $CO_2$ capture and storage system deployment that would be necessary to achieve large reductions in $CO_2$ emissions from fossil-fuel fired power plants.

The field-scale investigations underway as part of the Regional Carbon Sequestration Partnership program will provide direct observations on the behavior of $CO_2$ underground, building confidence that the key phenomena are well understood and that $CO_2$ can be injected and stored safely. U.S. DOE is initiating a comprehensive effort on risk assessment that will utilize these investigations (along with a strong science base) to develop a sound framework for ensuring that each specific storage site is chosen and developed for safe, long-term storage.