



Carbon Sequestration

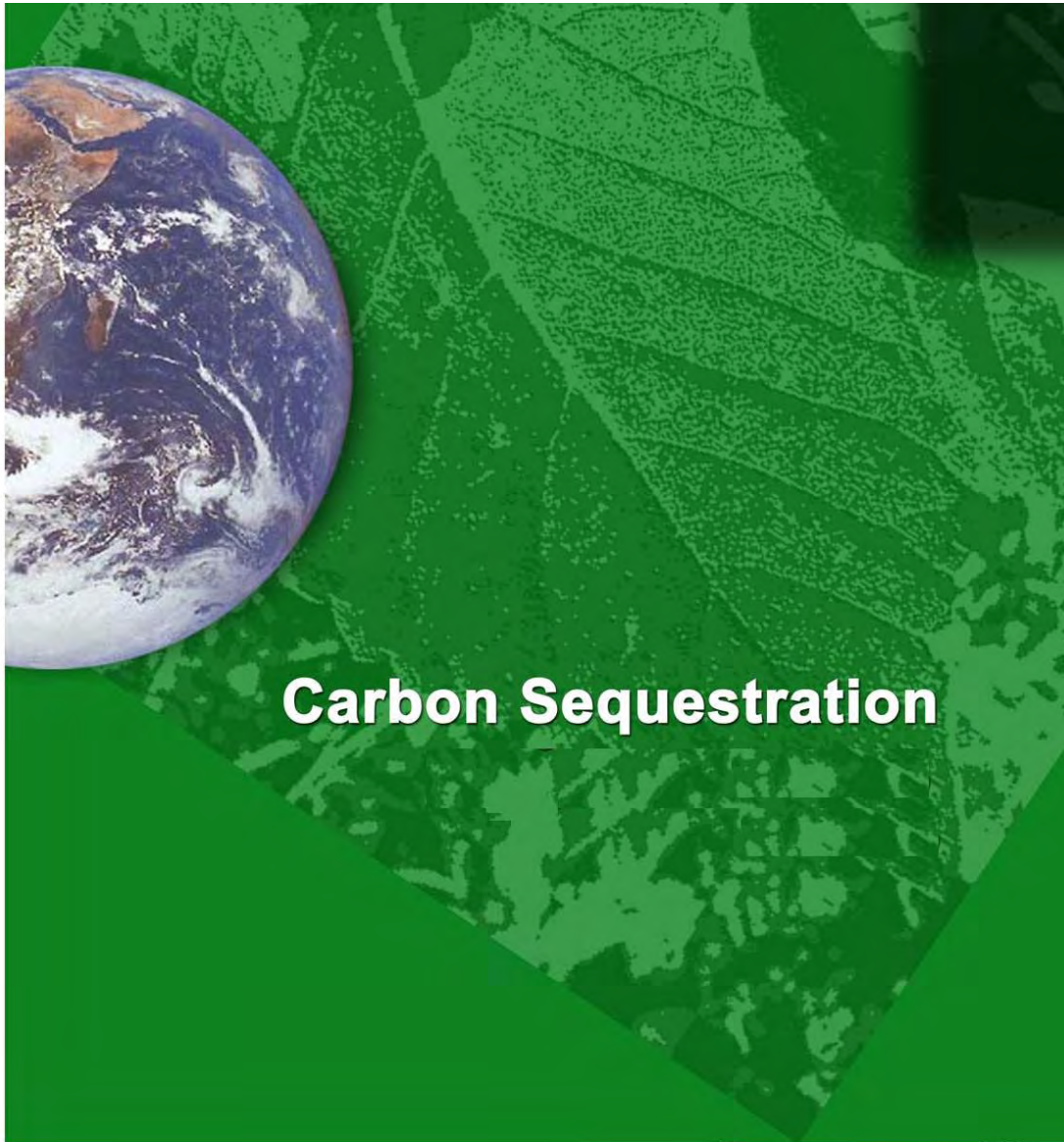
An Online Continuing Education Course for Engineers

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Carbon Sequestration

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Introduction

Predictions of global energy use in the next century suggest a continued increase in carbon emissions and rising concentrations of carbon dioxide (CO₂) in the atmosphere unless major changes are made in the way we produce and use energy—in particular, how we manage carbon. For example, the Intergovernmental Panel on Climate Change (IPCC) predicted in its “business as usual” energy scenario that global emissions of CO₂ to the atmosphere, which currently is 7.4 billion metric tons of carbon (GtC) per year will double by 2050. Although the effects of increased CO₂ levels on global climate are uncertain, many scientists agree that a doubling of atmospheric CO₂ concentrations could have a variety of serious environmental consequences.

There are generally three ways to manage carbon emissions,

1. Reduce the need for fossil fuel combustion through increased energy efficiency.
2. Use alternative low-carbon and carbon-free fuels and technologies such as nuclear power and renewable sources.
3. Capture and securely store carbon emitted from the fossil fuel combustion, which is known as carbon sequestration.

The purpose of *carbon sequestration* is to keep carbon emissions from reaching the atmosphere by capturing them, isolating them, and diverting them to secure storage. Any viable system for sequestering carbon must be safe, environmentally benign, effective, and economical. In addition, it must be acceptable to the public.

This concept is truly radical in a technology context. The development of today’s fossil-energy-based system is rooted in the Industrial Revolution. For over 200 years, the development of energy technology has been focused on lowering costs through increased efficiency to support economic growth. Because of their abundance, availability, and high energy content, coal, oil, and natural gas have proved to be attractive energy sources to produce electricity, run industrial processes, propel transportation vehicles, and provide energy for residential and commercial applications. As fossil energy use increased and adverse environmental effects became apparent, energy technology also evolved to minimize them. However, all of this enormous technology development has assumed that the free venting of CO₂ to the atmosphere was environmentally harmless.

Only recently has the increasing concentration of CO₂ in the atmosphere been considered to represent a serious environmental problem. The consequence is that we have developed an intricate, tightly coupled energy system that has been optimized over 200 years for economy, efficiency, and environmental performance, but not for the capture and sequestration of its largest material effluent, CO₂.

Why is carbon sequestration important? Given the magnitude of carbon reductions needed to stabilize the atmosphere, capture and sequestration could be a major tool for reducing carbon emissions to the atmosphere from fossil fuels; in fact, sequestration may be essential for the continued large-scale use of fossil fuels. It will allow greater flexibility in the future primary energy supply.

Several available technologies are used to separate and capture CO₂ from fossil-fueled power plant flue gases. The use of existing technology for removing CO₂ is projected to raise the cost of producing electrical power from coal-fired power plants. In fact, capture and sequestration could double the cost of electrical power generation from coal. Thus although CO₂ is separated routinely, dramatic improvements are necessary to make the process economical. Techniques are needed to transform the captured CO₂ into materials that can be economically and safely transported and sequestered for a long time.

There are numerous options for the separation and capture of CO₂, and many of these are commercially available. However, none has been applied at the scale required as part of a CO₂ emissions mitigation strategy. Many issues remain regarding the ability to separate and capture CO₂ from sources on the scale required, and to meet the cost, safety, and environmental requirements for separation and capture. The three most promising methods of carbon storage include ocean sequestration, terrestrial ecosystem sequestration, and geologic formation sequestration.

The ocean represents a large potential storage location for carbon dioxide. One solution is to inject a relatively pure CO₂ stream that has been generated by a power plant directly into the deep ocean. The injected CO₂ may become trapped in ocean sediments or ice-like solids, called hydrates. Another option is to increase the net oceanic uptake from the atmosphere by enhancing the ocean ability to absorb CO₂ with iron fertilization. Active experiments are already under way in iron fertilization and other tests of enhanced marine biological sequestration, as well as deep CO₂ injection. These approaches will require better understanding of marine ecosystems to enhance the effectiveness of applications and avoid undesirable consequences. Terrestrial ecosystems, which are made up of vegetation and soils containing microbial and invertebrate communities, sequester CO₂ directly from the atmosphere.

The terrestrial ecosystem is essentially a huge natural biological scrubber for CO₂ from all fossil fuel emissions sources, such as automobiles, power plants, and industrial facilities. The ability of the ecosystem to sequester carbon can be significantly increased over the next few years to provide a critical “bridging technology” while other carbon management options are developed. The potential for terrestrial ecosystems to remove and sequester more carbon from the atmosphere could be increased by, for example, improving agricultural cultivation practices to reduce oxidation of soil carbon and enhancing soil texture to trap more carbon, and protecting wetlands.

Three principal types of geologic formations are widespread in the United States and have the potential for sequestering large amounts of CO₂. They are active and uneconomical oil and gas reservoirs, aqueous formations, and deep coal formations. Presently about 70 oil fields worldwide use injected CO₂ for enhanced oil recovery. CO₂ sequestration is already being practiced in a sub-seabed reservoir in the North Sea of Norway. The United States has sufficient capacity, diversity, and broad geographic distribution of potential reservoirs to use geologic sequestration in the near term. The primary uncertainty is the effectiveness of storing CO₂ in geological formations - how easily CO₂ can be injected and how long it will remain. Many important issues must be addressed to reduce costs, ensure safety, and gain public acceptance.

There are many technological issues to resolve before carbon sequestration will be a viable environmental option. In the following sections, we will look at the basics of the carbon cycle, carbon sequestration, and more details on the various methods of carbon sequestration.

I. The Basics of Carbon Dioxide Storage and Sequestration

Carbon sequestration is intimately tied to two carbon cycles—the natural and the fossil fuel cycles. Understanding aspects of both cycles provides a context for developing carbon sequestration options.

The Global Carbon Cycle

Oceans and terrestrial systems are considered *reservoirs* of CO₂. The *carbon budget* of a reservoir is its ability to retain CO₂. Decreasing atmospheric CO₂ concentrations by reducing CO₂ emissions or by changing the magnitude of the fluxes between reservoirs is controlled by the carbon budget of a reservoir. From a carbon sequestration perspective, understanding the potential to alter carbon budgets through the intervention of carbon sequestration technologies to reduce future atmospheric CO₂ concentrations is one of the principal challenges.

Human activities during the last decade contributed to an average annual emission of approximately 7.4 GtC into the atmosphere. Most of these emissions were from fossil fuel combustion (and small amount from cement production.) Because of photosynthesis, plant growth, and additional storage in the oceans, only about 3.5 GtC of the additional CO₂ has entered the atmosphere.

Table 1				
Global Carbon Flux				
Source	GtC	Sink	GtC	Difference
Respiration	60.0	Photosynthesis	61.7	-0.3
Land Use	1.4			
Fossil			-	6.0
Ocean			92.2	-2.2
Source			53.9	
			ence	3.5

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Looking at Table 1, and animal respiration and land use (e.g. deforestation) release of CO₂ is photosynthesis. The difference between respiration and photosynthesis results in a net reduction of 0.3 GtC per year. The oceans release 2.2 GtC per year. Fossil fuel production release 6.0 GtC per year. Summing the differences, we are left with 3.5 GtC of carbon that enters and remains in the atmosphere.

Figure 1 is a graphical view of the carbon cycle. The significance of understanding these complicated carbon exchanges is that developing the ability to alter these gross annual carbon exchanges of the global carbon cycle by a small percentage through carbon sequestration technologies would increase net storage of carbon in the major reservoirs and lessen atmospheric carbon concentrations.