CARBON SEQUESTRATION:

A BETTER ALTERNATIVE FOR CLIMATE CHANGE?

INTRODUCTION

There are three basic strategies the nations of the world can employ to mitigate the accumulating carbon dioxide in the earth's atmosphere:

1. **Reduce the Total Amount of Energy Used** -- Adopt more energy efficient technologies or cut back on total consumption of goods and services that require energy for their use and production.

2. **Substitute Among Forms of Energy towards Greenhouse Efficient Sources** -- Substitute energy sources that emit fewer greenhouse gases; for example, substitute natural gas for coal in electricity generation.

3. **Capture and Sequester Greenhouse Gases** -- Capture carbon dioxide (and potentially other greenhouse gases) from the atmosphere and then sequester the carbon dioxide (or carbon) in some fashion. This capture and sequestration of carbon can be accomplished through biological mechanisms, such as plant photosynthesis, or by direct chemical and mechanical means.

By now, a large literature has been produced discussing the threat of climate change posed by greenhouse gases and the potential actions that could be taken to mitigate this threat. Much of the debate has concerned the extent of the threat and the degree of scientific certainty that human beings are changing world climate. This subject is outside the scope of this report. It is simply taken for granted here that there is a potential problem and that prudence requires the development of technological and policy methods of addressing this problem in the future, should the actual need arise.

On the assumption that measures may have to be taken at some time to mitigate human impacts on world climate, the greatest amount of policy discussion to date has focused on the first of the alternatives above, reducing total energy use. A smaller but still considerable amount of public discussion has been devoted to the second of the alternatives, substitution among forms of energy toward sources with lower greenhouse emissions. By comparison, there has been much less attention given to the third alternative, capture and sequestration of carbon and other greenhouse gases. For many people, carbon sequestration remains a little known or considered alternative.

The limited attention to carbon sequestration does not reflect any lack of promise in sequestration methods. Indeed, as this report will explore, sequestration appears in some respects to be the most promising of the three alternative basic methods for mitigating the effects of greenhouse emissions on world climate. It can accomplish this mitigation at a cost comparable to or lower than other methods of mitigating climate change and with less disruption to current patterns of consumption and production in American society.

There are four main alternatives at present for carbon capture and sequestration:

1. **Agricultural** -- Changes in farming methods could result in greater sequestration of carbon in soils.

2. **Biomass Energy** -- Plant materials could be used for renewable energy production. Because plants sequester carbon while they grow and then release the carbon when burned, they approximate a carbon neutral energy generation cycle -- in contrast to large net outflows of carbon dioxide when conventional fossil fuels are burned.

3. **Mechanical "Scrubbing" Removal of CO_2** -- Carbon dioxide emissions can be separated from and captured in the emission streams of power plants, much as scrubbers currently capture sulfur dioxide. The carbon dioxide can then be stored either underground or in the ocean, where it can remain for very long periods. Although the best methods of long-term storage are still being studied, it is believed that safe and cheap methods will be available in the future.

4. **Forestry** -- Forests sequester large amounts of carbon both in trees above ground and in the soils of the forest floor. Establishment of new forests or changed management of existing forests could result in increases in carbon sequestered in forests.

Table 1 shows current estimates of the potential for carbon sequestration in the United States from each of these four methods of sequestration. To set a frame of reference, the total current U.S. emissions of carbon dioxide each year from industrial, automotive, and other sources equal about 1,550 million metric tons carbon (MMTC). In order to comply with the terms of the Kyoto Protocol (requiring a seven percent reduction from a 1990 baseline), the United States would have to achieve annual emission reductions of about 500 to 600 MMCTE from the existing baseline projections of carbon emissions through year 2010. Hence, as shown in Table 1, the potential magnitudes of carbon sequestration is substantial relative to current U.S. carbon emissions and future greenhouse policy objectives.

Table 1. U.S. Annual Carbon Sequestration Potential, by Method

Method of Sequestration	Sequestration Potential (MMTC per yr)	Percent of US Kyoto Reduction Target
Agricultural Soils	88 - 232	15 - 40%
Biomass	136 - 218	24 - 38%
Carbon “Scrubbing” from Power Plant Emissions	347 - 417	60 - 72%
Forests	40 – 60	7 – 10%

By itself, sequestration of greater amounts of carbon in agriculture has the potential to yield up to one-third of the total burden of US annual carbon reductions needed to comply with the terms of the Kyoto Protocol. A sharp turn towards biomass production of energy could yield up to 38 percent of needed reductions. Capture and storage of carbon dioxide from power plant emissions has the potential to fulfill 72 percent of U.S. Kyoto obligations. Although forestry has received the greatest public discussion with respect to its sink capacity, in the United States it has the lowest likely capacity to sequester carbon of the four alternatives -- up to 9 percent (internationally, there is potential to sequester much greater amounts of carbon in forests).

There are even further possibilities for carbon sequestration, such as iron fertilization of the oceans to increase the growth of algae, which results in an increase in total ocean sequestration of carbon. However, study of algae fertilization and other newer options is in a preliminary phase.

The desirability of carbon sequestration depends on the acceptability of costs as well as the technical feasibility of sequestration methods. Table 2 shows current estimates for ranges of expected costs for the main sequestration categories currently being studied. Many economists believe that a carbon tax might have to be in the range of $50 to $100 per ton, or perhaps higher, to achieve carbon reductions sufficient to meet international obligations through the more conventional methods of energy use reduction or energy substitution. Hence, any method of carbon reduction with costs in the range of or below $50 per ton of carbon can be considered potentially attractive. By this measure, as shown in Table 2, carbon sequestration has the potential to be cost-effective.

Table 2. Sequestration Costs

Method Of Sequestration	**Cost ($ / ton of carbon)**
Agricultural Soils	$0 - ?
Biomass	$20 - $320
Separation From Power Plants	$60 - $300
Forests	$1 - $25

For example, a number of working prototypes of power plant separation and capture of carbon dioxide are already available that are achieving carbon sequestration at low end estimated costs near $60 per ton of carbon. In other words, if these capture technologies were implemented on all US fossil fuel power plants at this cost, much of the emissions reductions needed to comply with the terms of Kyoto could be achieved at a total cost of approximately $30 billion. This represents about one-fifth of the total costs of US fossil fuel energy generation, which is about $150 billion per year. To put this in further perspective, this estimated cost would be less than the total amount currently being spent by the United States each year to address the problem of air pollution. Given the likely reductions in costs as more experience accumulates with these methods and new power plants are designed with sequestration in mind, carbon dioxide "scrubbing" of power plant emissions is an especially promising technology.

Carbon sequestration's major advantage is that it may require less dramatic changes in American lifestyles than other methods of greenhouse mitigation (although some participants in the climate change discussions may see the opportunity to change current American society through climate change policy as an asset rather than a liability). Scrubbing of flue gas emissions from power plants to remove and sequester carbon dioxide would raise electricity prices -- by about 20 percent under plausible cost assumptions -- but otherwise would have few impacts on existing living patterns. In a number of cases, carbon sequestration could have positive side benefits. For example, a main method of agricultural sequestration of carbon -- increasing use of conservation tillage methods of farming -- is already being pursued for other reasons, especially the need to control runoff from farm fields to reduce phosphorus, nitrogen, and other sources of water pollution.

Admittedly, many uncertainties still exist with respect to both the scientific workings of proposed methods of carbon sequestration and the levels of costs that would be incurred. However, the information currently available indicates the need for a reordering of priorities in U.S. climate change spending. More manpower and funding should be devoted to research on the potential for sequestration, as it quite possibly may be the most effective method of reducing the accumulation of carbon dioxide and other greenhouse gases in the atmosphere of the earth. Instead of the step-child of U.S. climate change policy, exploration of carbon sequestration alternatives should become a top priority of the United States government.

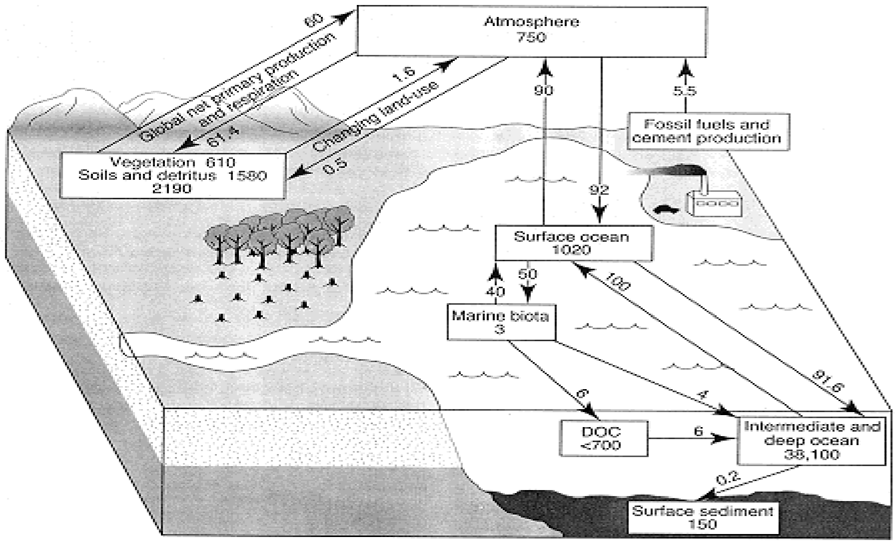
Although the federal government has thus far committed few resources to development of improved sequestration technologies or to the study of sequestration policy options, it has taken a lead in international climate change negotiations to keep open the possibility of carbon sequestration as a means of complying with international obligations. To date, the focus of discussion at the several Conferences of the Parties (COPs) has been on sequestration methods that involve forestry. At COP meetings there has been little assessment of the possibilities -- perhaps more promising than forestry, at least within the boundaries of the United States -- for agricultural, biomass energy, or direct scrubbing methods of carbon sequestration. At present these sequestration methods are not being directly addressed in Kyoto or other international climate change documents.

The Carbon Cycle

The scientific basis for the concept of carbon sequestration stems from the basic global carbon cycle. As shown in Figure 1, this dynamic system keeps carbon in constant motion. At any given time, large amounts of carbon are stored in atmospheric, terrestrial, and ocean "sinks." There are also significant flows of carbon continually moving from one sink form to another. For example, the flow of carbon from the atmosphere to the oceans amounts to 90,000 MMTC per year. There is a return flow from the atmosphere to the oceans of 92,000 MMTC per year. The difference is a net ocean sink of 2,000 MMTC each year that is stored for long periods in the oceans.

There is also a flow from terrestrial sources into the atmosphere and vice versa. Figure 2 below shows the key elements of the world carbon cycle. The carbon entering the atmosphere of the earth and contributing to the accumulation of greenhouse gases is the residual of the amount of carbon released into the atmosphere and the amount reabsorbed back into ocean and terrestrial forms of carbon sequestration. Measured in millions of metric tons of carbon equivalent (MMTCE), the human use of fossil fuels each year adds about another 5500 (+/-500) MMT? of carbon to the atmosphere. Humans are also responsible for adding another 1,500 (+/-700) MMTCE per year resulting from deforestation and other land changes, the great majority of this occurring outside the United States.

Figure 1. CO2 and Climate Change



*source: (Schimel et al., 1995)

The oceans are estimated to store about 2,000 (+/-800) MMCTE? per year in additional carbon. The net change in the atmospheric content of carbon dioxide is equal to 3,300 (+/-200) MMTCE? per year. If the known additions of carbon are balanced against the known sequestrations, there should be a much larger atmospheric increase in concentrations of carbon dioxide than is in fact observed. This discrepancy has given rise to a recognition that apparently there must be an "unknown sink" of 1,800 (+/-1,200) MMCTE per year that is absorbing sufficient carbon to balance the equation.

Figure 2. The World Carbon Cycle Equation

Atmospheric increase	=	emissions from fossil fuels	+	net emissions from changes in land use	-	oceanic uptake	-	missing carbon sink
3.3 (+/-0.2)	=	5.5 (+/-0.5)	+	1.6 (+/-0.7)	-	2.0 (+/-0.8)	-	1.8 (+/-1.2)

The fact that there is such a large unknown element in such a basic scientific consideration for world climate change reflects the significant scientific uncertainties that remain regarding all the influences on world climate behavior.

The contribution of the United States to the world carbon cycle is only known with precision for fossil fuel emissions. The U.S. contributes 1,550 MMTC per year, equal to about 30 percent of the total world fossil fuel emissions of greenhouse gases. The U.S. terrestrial sink, consisting of plants, trees, organisms, and soils, absorbs carbon through photosynthesis and either stores it in living systems or sequesters it in soils via decomposition. Estimates of U.S. sink magnitude span a very large range. By one recent estimate, the actual sink capacity of the North American continent may exceed its fossil fuel carbon additions to the atmosphere. Although much more study is required, it is possible that the North American continent is currently reducing rather than adding to net greenhouse warming (Fan et al., 1998).

Aside from the yearly carbon exchanges, relatively stable carbon pools exist in several places. Two-thirds of all terrestrial carbon can be found below ground in carbon pools where the turnover is very low over thousands or millions of years, because the carbon is well protected. The atmosphere holds 750,000 MMTCE, the ocean 38,100,000 MMTCE, soils 1,580,000 MMTCE, and the deep earth holds 5,000,000-10,000,000 MMTCE in the form of fossil fuels.

Carbon Sequestration and the Kyoto Protocol

The United States has a large capacity to sequester additional carbon, but the U.S. capacity is only a small fraction of the world potential. Around the world, deforestation alone is adding about one-third of the global net emissions of greenhouse gases. If this level of deforestation could be slowed or altogether arrested, it would mean a large increase in total carbon levels sequestered in the forests of the world. The potential to plant trees and increase total forest cover is much higher worldwide than in the United States alone. The possibilities for changing agricultural practices to sequester more carbon in soils are similarly much greater worldwide.

The costs of sequestration are also likely to be much lower in many cases in other countries than the United States. Land values and labor costs are often much lower. The “opportunity cost” in converting lands from agriculture to forest cover will be lower in other nations. Because developing nations are only presently installing much of their infrastructure, it may be much less expensive to incorporate carbon mitigation measures now than it would be to retrofit existing power plants and other facilities.

Due to the much larger total sequestration potential and lower costs on a worldwide basis, it makes overall economic sense to take many of the possible steps to mitigate climate change in other countries ahead of the U.S. Per ton of carbon sequestered, the costs will be much lower elsewhere. Economists, therefore, have advocated the creation of a world trading market in carbon mitigation. If a power plant or other facility in the United States were mandated to achieve a certain carbon emissions reduction (or to sequester a certain portion of its carbon), it would be economical to allow that facility to transfer its burden to another carbon mitigating action in another country. In fact, the Clinton administration has actively promoted the development of international carbon trading mechanisms. In the Kyoto Protocol, partly because of insistence by the United States, it would be possible for a nation to meet its national carbon (and other greenhouse gas) targets by taking actions in other countries. The two principal means of accomplishing this are the Joint Implementation and the Clean Development Mechanisms.

Joint Implementation and the Clean Development Mechanism are not specifically designed for trading in carbon sequestration opportunities. However, some of the most promising possibilities for international carbon trading will involve sinks. By promoting sink opportunities in other nations, the United States may be able to significantly increase the total amount of carbon that is sequestered and simultaneously achieve this sequestration at costs per ton much below what would be incurring in projects located within the U.S.

The Clinton administration has thus aggressively pushed for acceptance of international carbon (and other greenhouse gas) trading options in the various Conferences of the Parties leading up to Kyoto and, most recently, the Buenos Airs meeting. Following the Geneva Convention in 1996, the U.S. submitted a paper to the Subsidiary Body for Scientific and Technological Advance, outlining its position on the Establishment of Intergovernmental Technical Advisory Panels. As a starting point, the U.S. suggested that work be done in the following areas: energy supply, industrial energy demand, agriculture, buildings, transport, **carbon sinks**, and other sectors (UNFCCC: Establishment of Intergovernmental Technical Advisory Panels, 1-6). In July 1997, the U.S. released its Climate Action Report to the United Nations Framework Convention on Climate Change (UNFCCC). The document made only a few references to sinks and their potential importance as a climate change mitigation strategy. The official U.S. government estimate is that U.S. carbon sequestration in forested lands offsets U.S. carbon dioxide emissions from all sources by about 8% (Climate Action Report, section 1). In short, the focus of U.S. mitigation strategies has not been on carbon sinks, but U.S. negotiators have pressed for their recognition and provision in future international climate change treaties.

In the Kyoto Protocol, the major items relating to carbon sequestration were Articles 3.3, 3.4, and 3.7, which officially referred to sinks as a possible means to meet U.S. and other national obligations. The language of each of these articles is shown separately in Figure 3 below.

Figure 3. The Kyoto Protocol Terminology

Article 3.3 The net changes in greenhouse gas emissions by sources and removals by **sinks** resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I.

Article 3.4 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules, and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by **sinks** in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex 1, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties.

Article 3.7 Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 emissions base year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by **sinks** in 1990 from land-use change for the purposes of calculating their assigned amount.

be eligible for consideration in international climate change compliance and how they would be measured. A subgroup of the Intergovernmental Panel on Climate Change (IPCC) has been charged with attempting to find solutions to a number of pressing definitional and policy issues relating to carbon sequestration, and is due to report by the year 2000.

In November 1998, the Parties once again convened in Buenos Aires. The United States became the 60th country to sign the Kyoto agreement (although the U.S. Senate has not ratified it and is not expected to anytime soon). Of particular importance to the Parties at the Buenos Aires meeting was that the IPCC write a report on carbon sequestration that will help governments interpret and implement the Kyoto language. An international workshop will be held in the U.S. in September 1999 to discuss specifically forest and agricultural sinks. Several critical decisions regarding the interpretation and implementation of sinks activities must be made in 2000, if sinks are to play a major role in any Kyoto compliance that may occur.   Realization of the full potential role for worldwide carbon sequestration in climate change policy will depend on building the necessary institutional infrastructure. Therefore, an evaluation of the science, economics, politics, and structure of sequestration programs will be extremely important in developing a sink policy that yields actual greenhouse gas reduction.