Congressional Research Service

The Carbon Cycle: Implications for Climate Change and Congress

Peter Folger
Specialist in Energy and Natural Resources Policy

February 18, 2009

Congressional Research Service
7-5700
www.crs.gov
RL34059

CRS Report for Congress
Prepared for Members and Committees of Congress

Summary

Huge quantities of carbon are actively exchanged between the atmosphere and other storage pools, including the oceans, vegetation, and soils on the land surface. The exchange, or flux, of carbon among the atmosphere, oceans, and land surface is called the global carbon cycle. Comparatively, human activities contribute a relatively small amount of carbon, primarily as carbon dioxide (CO_2), to the global carbon cycle. Despite the addition of a relatively small amount of carbon to the atmosphere, compared to natural fluxes from the oceans and land surface, the human perturbation to the carbon cycle is increasingly recognized as a main factor driving climate change over the past 50 years.

If humans add only a small amount of CO_2 to the atmosphere each year, why is that contribution important to global climate change? The answer is that the oceans, vegetation, and soils do not take up carbon released from human activities quickly enough to prevent CO_2 concentrations in the atmosphere from increasing. Humans tap the huge pool of fossil carbon for energy, and affect the global carbon cycle by transferring fossil carbon—which took millions of years to accumulate underground—into the atmosphere over a relatively short time span. As a result, the atmosphere contains approximately 35% more CO_2 today than prior to the beginning of the industrial revolution. As the CO_2 concentration grows it increases the degree to which the atmosphere traps incoming radiation from the sun, which further warms the planet.

The increase in atmospheric CO_2 concentration is mitigated to some extent by two huge reservoirs for carbon—the global oceans and the land surface—which currently take up more carbon than they release. They are net *sinks* for carbon. Currently, most of the total global carbon sink is referred to as the *unmanaged*, or background, carbon cycle. Very little carbon is removed from the atmosphere and stored, or sequestered, by deliberate action. If the oceans, vegetation, and soils did not act as sinks, then the concentration of CO_2 in the atmosphere would increase even more rapidly.

Congress is considering legislative strategies to reduce U.S. emissions of CO_2 and/or increase the uptake of CO_2 from the atmosphere. Congress may also opt to consider how land management practices, such as afforestation, conservation tillage, and other techniques, might increase the net flux of carbon from the atmosphere to the land surface. Some land management practices may be eligible to receive carbon offsets in cap-and-trade legislation that is under consideration. A cap-and-trade system designed to include carbon offsets would likely need an accurate and precise accounting for the tons of carbon sequestered deliberately by land management practices. How the ocean sink could be managed to store more carbon is unclear. Iron fertilization and deep ocean injection of CO_2 are in an experimental stage, and their promise for long-term enhancement of carbon uptake by the oceans is not well understood.

Of additional concern is how the ocean and land surface sinks will behave over the coming decades and longer, and whether they will continue to take up more carbon than they release. The uncertainty in the future behavior of carbon sinks implies that accurately predicting the concentration of atmospheric CO_2 in the future is also uncertain, even if the amount of CO_2 emitted to the atmosphere could be controlled precisely.

Contents

Figures

Tables

Contacts

Introduction

Congress is considering several legislative strategies that would reduce U.S. emissions of greenhouse gases—primarily carbon dioxide (CO_2)—and/or increase uptake and storage of CO_2 from the atmosphere. Both approaches are viewed by many observers as critical to forestalling global climate change caused, in part, by the buildup of greenhouse gases in the atmosphere from human activities. Others point out that the human contribution of carbon to the atmosphere is a small fraction of the total quantity of carbon that cycles naturally back and forth each year between the atmosphere and two huge carbon reservoirs: the global oceans and the planet's land surface. A key question is how CO_2 emissions from human activities are changing the global carbon cycle—the exchange, or flux, of carbon between the atmosphere, oceans, and land surface—and how the changes affect the rate of CO_2 buildup in the atmosphere.[1]

Most climate scientists agree that human perturbations to the carbon cycle are a main factor driving climate change over the past 50 years. For most of human history, the global carbon cycle has been roughly in balance, and the concentration of CO_2 in the atmosphere has been fairly constant at approximately 280 parts per million (ppm). Human activities, namely the burning of fossil fuels, deforestation, and other land use activities, have significantly altered the carbon cycle. As a result, atmospheric concentrations of CO_2 have risen by over 35% since the industrial revolution, and are now greater than 380 ppm.[2]

An understanding of the global carbon cycle has shifted from being of mainly academic interest to being also of policy interest. Policy makers are grappling with, for example, how to design a cap-and-trade system that accurately accounts for carbon sequestration by components of the land surface sink, such as forests or farmland. A cap-and-trade system that limits emissions, and is designed to keep atmospheric CO_2 below a specific concentration, would depend inherently on continued uptake of carbon by the oceans and land surface. Yet how much CO_2 forests or farmland are capable of taking up in the future, and for how long, is not clear. How the ocean and the land surface carbon reservoirs will behave in the future—how much CO_2 they will take up or release and at what rate—are topics of active scientific inquiry.

Thus the scientific understanding of the carbon cycle is integral to many aspects of the current congressional debate over how to mitigate climate change. This report puts the human contribution of carbon to the atmosphere into the larger context of the global carbon cycle. The report focuses almost entirely on CO_2, which alone is responsible for over half of the change in Earth's radiation balance.[3] According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 is the most important greenhouse gas released to the atmosphere from human activities.[4]

---

[1] The buildup of CO_2 in the atmosphere is also changing the chemistry of the ocean's surface waters, a phenomenon known as ocean acidification, which could harm aquatic life. For more information, see CRS Report R40143, *Ocean Acidification*, by Eugene H. Buck and Peter Folger.

[2] World Data Centre for Greenhouse Gases (WDCGG), *WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2005* (Geneva, Switzerland: 2006); at http://gaw.kishou.go.jp/wdcgg.html.

[3] See The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle, U.S. Science Program Synthesis and Assessment Product 2.2, ed. Anthony W. King, Lisa Dilling, Gregory P. Zimmerman, David M. Fairman, Richard A. Houghton, Gregg Marland, Adam Z. Rose, and Thomas J. Wilbanks (November 2007), p. 2, at http://cdiac.ornl.gov/SOCCR/final.html, hereafter referred to as SOCCR. Also see the Intergovernmental Panel on Climate Change, "Working Group I Contribution to the Fourth (continued...)

Carbon Storage, Sources, and Sinks

The atmosphere, oceans, vegetation, and soils on the land surface all store carbon. (See **Figure 1a**.) Geological reservoirs also store carbon in the form of fossil fuels, such as oil, gas, and coal.[5] Of these reservoirs (or pools), dissolved inorganic carbon in the ocean is the largest, followed in size by fossil carbon in geological reservoirs, and by the total amount of carbon contained in soils. (See **Figure 1a** and **Table 1**.) The atmosphere itself contains nearly 800 billion metric tons of carbon (800 GtC),[6] which is more carbon than all of the Earth's living vegetation contains.[7] Carbon contained in the oceans, vegetation, and soils on the land surface is linked to the atmosphere through natural processes such as photosynthesis and respiration. In contrast, carbon in fossil fuels is linked to the atmosphere through the extraction and combustion of fossil fuels.

The atmosphere has a fairly uniform concentration of CO_2, although it shows minor variations by season (about 1%)—due to photosynthesis and respiration—and by latitude.[8] Carbon dioxide released from fossil fuel combustion mixes into the atmospheric carbon pool, where it undergoes exchanges with the ocean and land surface carbon pools. Thus, *where* fossil fuels are burned makes relatively little difference to the average concentration of CO_2 in the global atmosphere; emissions in any one region affect the concentration of CO_2 globally.[9]

The oceans, vegetation, and soils *exchange* carbon with the atmosphere constantly on daily and seasonal time cycles. (See **Figure 1b.**) In contrast, carbon from fossil fuels is *not* exchanged with the atmosphere, but is transferred in a one-way direction from geologic storage, at least within the time scale of human history.[10] How much of the fossil fuel carbon ends up in the atmosphere, instead of the oceans, vegetation, and soils, and over what time scale, is driving much of the debate over what type of action to take to ameliorate global warming.

(...continued)

Assessment Report of the Intergovernmental Panel on Climate Change," Climate Change 2007: the Physical Science Basis (2007), at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html, hereafter referred to as 2007 IPCC Working Group I Report.

[4] Methane, black carbon, and organic carbon pollution are also part of the carbon cycle and have roles in human-induced climate change. Methane probably accounts for about an additional 20% of the change in the Earth's radiation balance.

[5] The Earth stores carbon mainly as carbonate minerals. Carbonate minerals are linked to the atmosphere by natural processes, such as erosion and weathering, and by metamorphism over geologic time scales.

[6] One metric ton of carbon is equivalent to 3.67 metric tons of CO_2. A metric ton (or tonne) is 2,204.6 pounds. One billion metric tons of carbon is one gigatonne, or GtC.

[7] William H. Schlesinger, *Biogeochemistry: an Analysis of Global Change*, 2nd Ed. (San Diego, CA: Academic Press, 1997), p. 360. Hereafter referred to as Schlesinger, 1997.

[8] Schlesinger, 1997, p. 56. Larger fluctuations by season occur in the northern hemisphere.

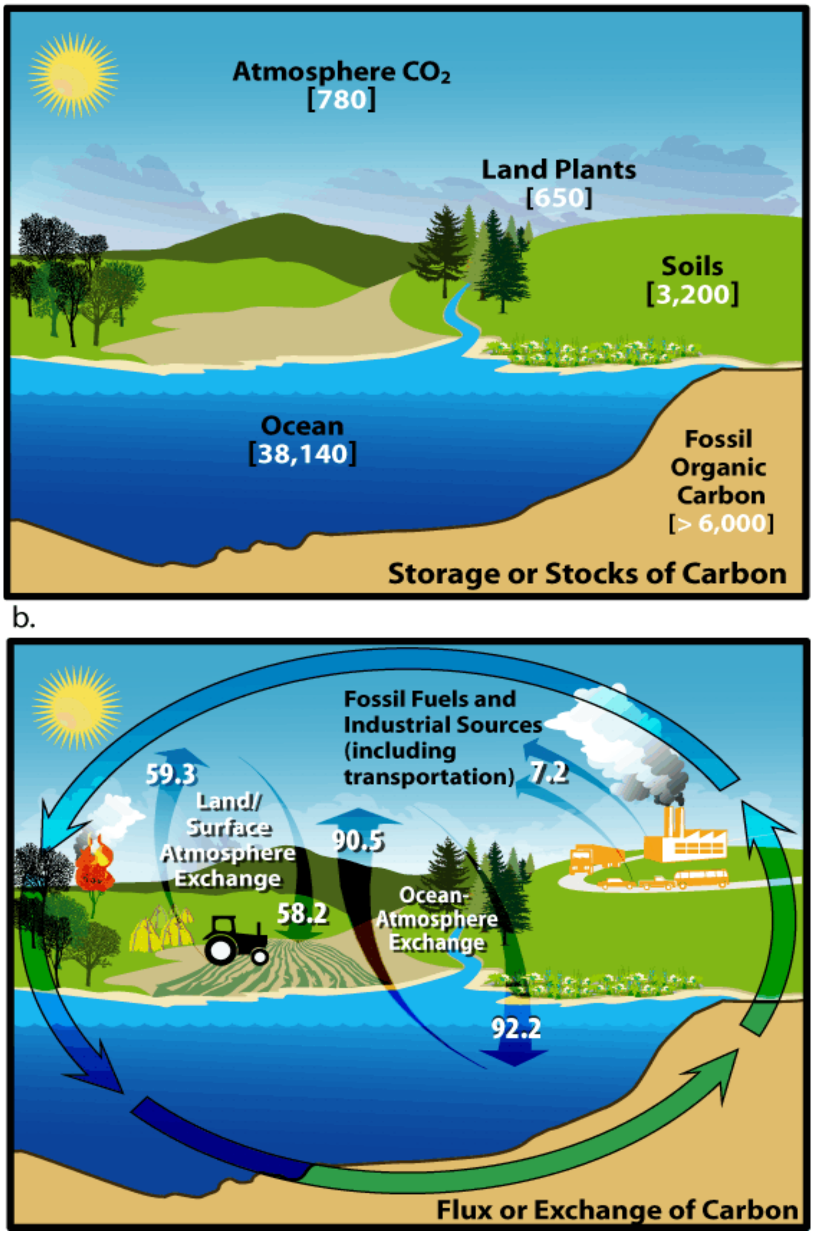
[9] Concentrations of CO_2 are slightly higher in the northern hemisphere compared to the southern hemisphere, by several parts per million, because most of the emissions of CO_2 from human activities are in the north.

[10] An exception to this is the concept of carbon capture and sequestration, whereby the geologic time scale cycle of carbon storage is "short circuited" by capturing CO_2 at its source—a fossil-fueled electricity generating plant for example—and injecting it underground into geologic reservoirs.

Figure 1. (a) Storage or Pools (GtC); and (b) Annual Flux or Exchange of Carbon (GtC per year)

a.

b.



Source: SOCCR; 2007 IPCC Working Group I Report, Table 7.1; and Christopher L. Sabine et al., "Current Status and Past Trends of the Global Carbon Cycle," in C. B. Field and M. R. Raupach, eds., *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World* (Washington, DC: Island Press, 2004), pp. 17-44.

Notes: Figure prepared by CRS. One GtC refers to one billion metric tons of carbon.

Table 1. Carbon Stocks in the Atmosphere, Ocean, and Land Surface, and Annual Carbon Fluxes

Storage pool	GtC	Annual flux (GtC/yr) *from* the atmosphere	Annual flux (GtC/yr) *to* the atmosphere	Net to the atmosphere (GtC/yr)
Atmosphere	780			
Ocean	38,140	92.2	90.5	-1.7[b]
Land Surface[a] (soils plus vegetation)	3,850	59.3	58.2	-1.1[c]
Fossil Carbon (coal, gas oil, other)	>6,000	—	7.2	+7.2

Sources: SOCCR; 2007 IPCC Working Group I Report, Table 7.1; Christopher L. Sabine et al., "Current Status and Past Trends of the Global Carbon Cycle," in C. B. Field and M. R. Raupach, eds., The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World (Washington, DC: Island Press, 2004), pp. 17-44.

a. The soil pool contains about 3,200 GtC, and the vegetation pool contains about 650 GtC.

b. Gross fluxes between the ocean and atmosphere have considerable uncertainty, but the net flux is known to within +/-0.3 GtC per year (SOCCR, p. 2-3).

c. The net flux between the land surface and the atmosphere is known to within +/-0.7 GtC per year (Jonathan A. Foley and Navin Ramankutty, "A Primer on the Terrestrial Carbon Cycle: What We Don't Know But Should," in C. B. Field and M. R. Raupach, eds., *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World* (Washington, DC: Island Press, 2004), p. 281.

How much carbon is stored in the atmospheric pool is important because as more CO_2 is added to the atmosphere, its heat-trapping capacity becomes greater.[11] Each storage pool—oceans, soils, and vegetation—is considered a *sink* for carbon because each pool takes up carbon from the atmosphere. Conversely, each storage pool is also a *source* of carbon for the atmosphere, because of the constant exchange or *flux* between the atmosphere and the storage pools. For example, vegetation in the northern hemisphere is a sink for atmospheric carbon during the spring and summer months due to the process of photosynthesis. In the fall and winter it is a source for atmospheric carbon because the process of respiration returns carbon to the atmosphere from the vegetation pool. In contrast to the oceans, soils, and vegetation, the pool of fossil carbon is only a source, not a sink, except over geologic time scales.

Carbon Flux, or Exchange, with the Atmosphere

How Much Carbon Is Exchanged

Over 90 GtC is exchanged each year between the atmosphere and the oceans, and close to 60 GtC is exchanged between the atmosphere and the land surface annually. (See **Table 1**.)[12] Human

[11] See CRS Report RL33849, *Climate Change: Science and Policy Implications*, by Jane A. Leggett, for an explanation of the heat-trapping properties, or *radiative forcing*, of CO_2 and other greenhouse gases.

[12] These massive exchanges of CO_2 between the atmosphere, oceans, and land surface result mostly from natural processes, such as photosynthesis, respiration, decay, and gas exchange between the ocean surface and the lower atmosphere.

activities—primarily land-use change and fossil fuel combustion—contribute slightly less than 9 GtC to the atmosphere each year.[13] If the human contribution of CO_2 is subtracted from the global carbon cycle, then the average *net flux*—the amount of CO_2 released to the atmosphere versus the amount taken up by the oceans, soils, and vegetation—is close to zero. Most scientists conclude that for 10,000 years prior to 1750, the net flux was less than 0.1 GtC per year when averaged over decades.[14] That small value for net flux is reflected by the relatively stable concentration of CO_2 in the atmosphere—between 260 and 280 ppm—for the 10,000 years prior to 1750.[15]

How Fast Carbon Is Exchanged

Currently the atmospheric concentration of CO_2 is approximately 100 ppm higher than it was before 1750 because human activities are adding carbon to the atmosphere faster than the oceans, land vegetation, and soils remove it. The relatively rapid addition of CO_2 to the atmosphere has tipped the balance so that even though the oceans and the land surface take up more CO_2 per year on average than they release, atmospheric concentrations of CO_2 continue to rise. (See **Table 1**.) About 45% of the CO_2 released from fossil fuel combustion and land use activities during the 1990s has remained in the atmosphere, while the remainder has been taken up by the oceans, vegetation, or soils on the land surface.[16]

Carbon dioxide is nonreactive[17] in the atmosphere and has a relatively long residence time, although eventually most of it will return to the ocean and land sinks. About 50% of a single pulse of CO_2 will be removed within 30 years, a further 30% will be removed within a few centuries, and the remaining 20% may persist in the atmosphere for thousands of years.[18] If CO_2 emissions continue or grow, however, atmospheric concentrations of CO_2 will likely also continue to rise, increasing *radiative forcing*—the degree to which the atmosphere traps incoming radiation from the sun. A likely result is continued warming of the planet.

At present, the oceans and land surface are acting as sinks for CO_2 emitted from fossil fuel combustion and deforestation, but as they accumulate more carbon the capacity of the sinks—and the rate at which they accumulate carbon—may change. It is also likely that climate change itself (e.g., higher temperatures, a more intense hydrologic cycle) may alter the balance between sources and sinks, due to changes in the complicated feedback mechanisms between the atmosphere, oceans, and land surface.[19] How carbon sinks will behave in the future is a prominent question for both scientists and policy makers.

---

[13] About 80% of human-related CO_2 emissions results from fossil fuel combustion, and 20% from land use change (primarily deforestation). Fossil fuel burning and industrial activities release approximately 7.2 GtC per year, land use change releases about 1.6 GtC per year (2007 IPCC Working Group I Report, pp. 501, 514-515).

[14] 2007 IPCC Working Group I Report, p. 514.

[15] Ice core data indicate that CO_2 concentrations ranged between 180 and 300 ppm over the past 650,000 years, and between 275 and 285 ppm from AD 1000 to AD 1750 (2007 IPCC Working Group I Report, p. 137 and p. 435). See also E.T. Sundquist and K. Visser, "The Geologic History of the Carbon Cycle," in Heinrich D. Holland and Karl K. Turekian (eds.), *Treatise on Geochemistry* (Amsterdam, Netherlands: Elsevier Ltd., 2004), p. 443.

[16] 2007 IPCC Working Group I Report, pp. 514-515.

[17] That is, it does not react with other chemicals in the atmosphere. This contrasts with other greenhouse gases, such as methane (CH_4), which reacts with the hydroxl ion (OH^-) to produce water and a methyl group (CH_3); and nitrous oxide (N_2O), which is decomposed to nitric oxide (NO) in the atmosphere by its reaction with ultraviolet light.

[18] 2007 IPCC Working Group I Report, p. 515.

[19] See CRS Report RL34266, *Climate Change: Science Update 2007*, by Jane A. Leggett, for more information on (continued...)

Land Surface-Atmosphere Flux

Most estimates of the carbon cycle indicate that the land surface (vegetation plus soils) accumulates more carbon per year than it emits to the atmosphere.[20] (See **Figure 1b** and **Table 1.**) That means the land surface acts as a net sink for CO_2 at present. Some policy makers advocate strategies for increasing the amount of CO_2 taken up and stored, or *sequestered*, by soils and plants, typically through land use changes, such as agricultural or forestry practices.[21] How effective these land use practices will be for large-scale and long-term carbon sequestration is not clear.

Land use overall has the largest uncertainty of any component in the global carbon cycle.[22] Most scientists agree, however, that in the past two decades *tropical deforestation* has been responsible for the largest share of CO_2 released to the atmosphere from land use changes.[23] Tropical deforestation and other land use changes released approximately 1.6 GtC per year to the atmosphere in the 1990s, and may be contributing similar amounts of carbon to the atmosphere today.[24] Even though deforestation releases more carbon than is captured by forest regrowth within some regions, net forest regrowth in other regions takes up sufficient carbon so the land surface acts as a global net *sink* of approximately 1 GtC per year. By some estimates, even tropical lands, despite widespread deforestation, may be carbon-neutral or even net carbon sinks on a regional basis.[25]

The "Missing Sink"

What used to be known as "the missing sink" component in the global carbon cycle is now understood to be that part of the terrestrial ecosystem responsible for the net uptake of carbon from the atmosphere to the land surface (especially high-latitude, or boreal, forests).[26] Scientists now prefer the term "residual land sink" to "missing sink" as it portrays the residual—or left over—part of the global carbon cycle calculation once the other components are accounted for (fossil fuel emissions, land-use emissions, atmospheric increase, and ocean uptake).[27] Precisely which mechanisms are responsible for the residual land sink is not well understood. One mechanism postulated for many years has been the fertilizing effect of increased atmospheric CO_2

(...continued)

climate feedback mechanisms.

[20]2007 IPCC Working Group I Report, p. 515.

[21]For more information on sequestration in the agricultural and forestry sectors, see CRS Report RL31432, *Carbon Sequestration in Forests*, by Ross W. Gorte, and CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector*, by Renée Johnson.

[22]2007 IPCC Working Group I Report, p. 518.

[23]Ibid, p. 517.

[24]Ibid, Table 7.1.

[25]Ibid, p. 522. Tropical systems take up substantial carbon to offset what is lost through deforestation and fire. However, SOCCR (p. 5) notes that rates of forest clearing in the tropics, including Mexico, exceed rates of recovery and concludes that tropical regions dominated by rainforests or other forest types *are* a net source of carbon to the atmosphere.

[26] However, a recent study indicates that the northern latitude forests take up less carbon than previously estimated, and tropical forests take up more. See Britton B. Stephens, et al., "Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2," *Science*, Vol. 316 (June 22, 2007): pp. 1732-1735.

[27]SOCCR, p. 25.

concentrations on plant growth. Most models predict enhanced growth and carbon sequestration by plants in response to rising CO_2 levels; however, results of experiments have been mixed. Many experiments show enhanced growth from increased CO_2 concentrations—at least initially—but nutrient and water availability and other limitations to growth are common. Long-term observations of biomass change and growth rates suggest that fertilization effects are too small to account for the residual land sink, at least in the United States.[28]

In North America, particularly the United States, the land-atmosphere flux is strongly tilted towards the land, with approximately 0.5 GtC per year accumulating in terrestrial sinks.[29] That amount constitutes a large fraction—possibly 40%—of the global terrestrial carbon sink.[30] According to some estimates, approximately half of the North American terrestrial carbon sink stems from regrowth of forests on abandoned U.S. farmland.[31] Woody encroachment—the increase in woody biomass occurring mainly on former grazing lands—is thought to be another potentially large terrestrial sink, possibly accounting for more than 20% of the net North American sink (although the actual number is highly uncertain).[32] Wood products (e.g., furniture, house frames, etc.), wetlands, and other smaller, poorly understood carbon sinks are likely responsible for accumulating the remaining carbon in North America.

Ocean-Atmosphere Flux

If the land surface and oceans were not acting as net sinks, the CO_2 concentration in the atmosphere would be increasing at a faster rate than observed. Like the land surface, the oceans today accumulate more carbon than they emit to the atmosphere each year, acting as a net sink for about 1.7 GtC per year. (See **Figure 1b** and **Table 1**.) The oceans have a much larger capacity to store carbon than the land surface. Ultimately, the oceans could store more than 90% of all the carbon released to the atmosphere by human activities, but the process takes thousands of years.[33] Policy makers are likely more concerned about CO_2 accumulating in the oceans now and its behavior as a net sink over the next few decades. Also, the additional CO_2 is increasing the acidity of the ocean's surface waters, which may affect marine life.[34]

Carbon dioxide enters the oceans by dissolving into seawater at the ocean surface, at a rate controlled by the difference in CO_2 concentration between the atmosphere and the sea surface.[35] Because the surface waters[36] of the ocean have a relatively small volume—and thus a limited

[28]Sarmiento and Gruber, p. 31.

[29]SOCCR, p. 29. This includes fluxes to and from land vegetation and soils, and excludes emissions from fossil fuel combustion, cement manufacturing, and other industrial processes.

[30]SOCCR, p. 32. However, SOCCR reports that the magnitude of the global terrestrial carbon sink is highly uncertain.

[31]SOCCR, p. VII.

[32]SOCCR, Table 3.1; 2007 IPCC Working Group I Report, p. 527.

[33] CO_2 forms carbonic acid when dissolved in water. Over time, the solid calcium carbonate ($CaCO_3$) on the seafloor will react with, or *neutralize*, much of the carbonic acid that entered the oceans as CO_2 from the atmosphere. See David Archer, et al., "Dynamics of fossil fuel CO_2 neutralization by marine $CaCO_3$," *Global Biogeochemical Cycles*, vol. 12, no. 2 (June 1998): pp. 259-276.

[34] See CRS Report R40143, *Ocean Acidification*, by Eugene H. Buck and Peter Folger.

[35]SOCCR, p. 26. In addition to the relative difference in CO_2 concentration between atmosphere and ocean, the rate of CO_2 dissolution also depends on factors such as wave action, wind, and turbulence.

[36]The surface waters or surface layer of the ocean is commonly characterized as the top layer of the ocean that is well mixed by waves, tides, and weather events, and is separated from the deep ocean by a difference in density. The depth (continued...)

capacity to store CO_2—how much CO_2 is stored in the oceans over the time scale of decades depends on ocean mixing and the transport of CO_2 from the surface to intermediate and deep waters. Vertical mixing between surface waters and deeper portions of the ocean is a sluggish process; for example, the oldest ocean water in the world—found in the North Pacific—has not flowed to the ocean surface for about 1,000 years.[37] The slow rate of ocean mixing and slow transport of CO_2 from the surface to the ocean depths influence the effectiveness of the ocean sink for CO_2.

In addition to the vertical mixing of the ocean, large-scale circulation of the oceans around the globe is a critical component for determining the effectiveness of the ocean sink.[38] Surface waters carrying anthropogenic CO_2 descend into the ocean depths primarily in the North Atlantic and the Southern Ocean, part of the so-called oceanic "conveyor belt."[39] Some model simulations suggest that the Southern Ocean around Antarctica accounts for nearly half of the net air-sea flux of anthropogenic carbon.[40] From that region, a large portion of dissolved CO_2 is transported north towards the subtropics. Despite its importance as a CO_2 sink, the Southern Ocean is poorly understood, and studies suggest that its capacity for absorbing carbon may be weakening.[41]

Policy Implications

Congress is exploring legislative strategies that would alter the human component of the global carbon cycle. Of possible concern is how the ocean and land surface sinks will behave over the coming decades and longer, and whether they will continue to take up more carbon than they release. This is an area of considerable scientific uncertainty. Whether the oceans and land surface will continue to be net sinks for carbon if atmospheric CO_2 concentrations continue to rise is unclear. Alternatively, they may continue to be net sinks, but their capacity for taking up carbon may weaken or slow down.

Very little carbon is sequestered by deliberate action.[42] Most of the North American terrestrial carbon sink, such as the forest regrowth component, is sometimes referred to as the *unmanaged*, or background, carbon cycle. The future behavior of the unmanaged terrestrial carbon sink is another consideration for lawmakers. Whether the United States will continue its trajectory as a major terrestrial carbon sink is highly uncertain, and little evidence suggests that the terrestrial ecosystem sinks will increase in the future; some current terrestrial sinks may even become

(...continued)

of the surface layer varies, but probably averages 100-200 meters deep. See http://www.windows.ucar.edu/tour/link=/earth/Water/ocean_currents.html.

[37] Sarmiento and Gruber, p. 31.

[38] SOCCR, p. 26.

[39] Sarmiento and Gruber, p. 31.

[40] Sarmiento and Gruber, p. 31.

[41] One study, for example, suggests that the efficiency of the ocean sink has been declining at least since 2000; see Josep G. Canadell et al., "Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks," *PNAS*, vol. 47, no. 104 (November 20, 2007), pp. 18866-18870. Another study suggests that most of the weakening of the ocean sink is occurring in the Southern Ocean; see Corinne Le Quere et al., "Saturation of the Southern Ocean CO_2 sink due to recent climate change," *Science*, vol. 316 (June 22, 2007): pp. 1735-1737.

[42] SOCCR, p. 27.

sources for carbon.[43] Sinks may convert to sources, for example, if melting permafrost under warming conditions releases large amounts of methane currently trapped in frozen tundra, or if severe and extended droughts cause more frequent and severe wildfires that release large amounts of CO_2.

Policy makers may also need to evaluate and quantify how management practices, such as afforestation, conservation tillage, and other techniques, would increase the net flux of carbon from the atmosphere to the land surface.[44] For example, some land management practices may be eligible to receive carbon offsets in cap-and-trade legislation that is under consideration.[45] A cap-and-trade system designed to include carbon offsets would likely need an accurate and precise accounting for the tons of carbon sequestered deliberately by land management practices.

Another consideration for policy makers is the future behavior of the ocean sink, particularly the Southern Ocean, given its importance to the net ocean-atmosphere CO_2 flux. In contrast to the terrestrial carbon sink, where management practices such as afforestation and conservation tillage may increase the amount of carbon uptake, it is unclear how the ocean carbon sink can be *managed* in a similar fashion. Some techniques proposed for increasing ocean sequestration of carbon, such as iron fertilization and deep ocean injection of CO_2, are in an experimental phase and have unknown long-term environmental consequences.[46]

The uncertainty in the future behavior of carbon sinks implies that accurately calculating the concentration of atmospheric CO_2 in the future is also uncertain, even if the amount of CO_2 emitted to the atmosphere could be controlled precisely. For example, if global carbon emissions are capped at some agreed-upon level by 2050, such as 80% of the current amount, it would still be difficult to accurately predict atmospheric CO_2 concentrations by that date. A change in the rate of uptake, or release, of carbon from the oceans, soils, or vegetation between now and 2050 would affect any such predictions. Consequently, if Congress seeks policies aimed at keeping atmospheric CO_2 concentrations below a specific threshold, such as 450 or 550 ppm, then Congress may also wish to understand if, how, and why the oceans and land surface are speeding up or slowing down the rate at which they take up or release carbon.

[43] SOCCR, p. 27. See Christopher B. Field et al., “Feedbacks of terrestrial ecosystems to climate change,” *Annual Review of Environment and Resources*, vol. 32 (July 5, 2007): pp. 7.1-7.29.

[44] See also CRS Report RL34042, *Environmental Services Markets in the 2008 Farm Bill*, by Renée Johnson; and CRS Report R40186, *Biochar: Examination of an Emerging Concept to Mitigate Climate Change*, by Kelsi S. Bracmort.

[45] A carbon offset may be defined as measurable avoidance, reduction, or sequestration of CO_2 or other greenhouse gas emissions. For more information on carbon offsets, see CRS Report RL34241, *Voluntary Carbon Offsets: Overview and Assessment*, by Jonathan L. Ramseur.

[46] The deliberate introduction of iron into the surface ocean to stimulate marine phytoplankton growth, which would increase carbon sequestration from the atmosphere via photosynthesis. The Southern Ocean, in particular, is deficient in iron as a nutrient such that the introduction of iron could stimulate phytoplankton growth. Several experiments have been conducted or are underway to further explore this process, for example, Stephane Blain et al., “Effect of natural iron fertilization on carbon sequestration in the Southern Ocean,” *Nature*, vol. 446, no. 7139 (April 26, 2007): pp. 1070-1074.

Author Contact Information

Peter Folger
Specialist in Energy and Natural Resources Policy
pfolger@crs.loc.gov, 7-1517