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The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle

Executive Summary

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The Earth's carbon budget is in imbalance. Beginning with the Industrial Revolution in the 18th century, but most dramatically since World War II, the human use of coal, petroleum, and natural gas has released large amounts of carbon from geological deposits to the atmosphere, primarily as the combustion product carbon dioxide (CO_2). Clearing of forests and plowing of grasslands for agriculture has also released carbon from plants and soils to the atmosphere as CO_2. The combined rate of release is far larger than can be balanced by the biological and geological processes that naturally remove CO_2 from the atmosphere and store it in various terrestrial and marine reservoirs as part of the earth's carbon cycle. Although the oceans have taken up a large fraction of the CO_2 released through human activity, much of it has "piled up" in the atmosphere, as demonstrated by the dramatic increase in the atmospheric concentration of CO_2. The concentration has increased by 31% since 1750, and the present concentration is now higher than at any time in the past 420,000 years and perhaps the past 20 million years. Because CO_2 is an important greenhouse gas, this imbalance and buildup in the atmosphere has consequences for climate and climate change.

North America is a major contributor to this imbalance. Among all countries, the United States, Canada, and Mexico ranked, respectively, as the first, eighth, and eleventh largest emitters of CO_2 from fossil fuels in 2002. Combined, these three countries contributed more than a quarter (27%) of the world's entire fossil fuel emissions in 2002 and almost one third (32%) of the cumulative global fossil fuel emissions between 1751 and 2002. Emissions from parts of Asia are increasing at a growing rate and may surpass those of North America in the near future, but North America is incontrovertibly a major source of atmospheric CO_2, historically, at present, and in the immediate future.

North America may also be an important sink for carbon. Many lines of scientific evidence point to the vegetation and soils of the Northern Hemisphere as removing CO_2 from the atmosphere and to some degree mitigating fossil-fuel sources. The contribution of North America to that sink is highly uncertain, however. The mechanisms responsible for the sink are reasonably well known and include forest regrowth and sequestration of carbon in agricultural soils; but the relative contributions, magnitudes, and future fates of these mechanisms are highly uncertain.

Understanding the North American carbon budget, both sources and sinks, is critical to the U.S. Climate Change Science Program goal of providing the best possible scientific information to support public discussion, as well as government and private sector decision making, on key climate-related issues. In response, this Report provides a synthesis, integration and assessment of the current knowledge of the North American carbon budget and its context within the global carbon cycle. The Report is organized as a response to questions relevant to carbon management and to a broad range of stakeholders charged with understanding and managing energy and land use. The questions were identified through early and continuing dialogue with these stakeholders, including scientists, decision makers in the public and private sectors (e.g., Federal government, carbon-related industry, including energy, transportation, agriculture, and forestry sectors; and climate policy and carbon management interest groups).

The questions and the answers provided by this Report are summarized below. The reader is referred to the indicated chapters for further, more detailed, discussion. Unless otherwise referenced, all values, statements of findings and conclusions are taken from the chapters of this Report where the attribution and citation of the primary sources can be found.

What is the carbon cycle and why should we care? (Chapter 1)

The carbon cycle is the combination of many different physical, chemical and biological processes that transfer carbon between the major reservoirs: the atmosphere, plants, soils, freshwater systems, oceans, and geological sediments. Hundreds of millions of years ago, and over millions of years, this carbon cycle was responsible for the formation of coal, petroleum, and natural gas, the fossil fuels that are the primary sources of energy for our modern societies. Today, the cycling of carbon among atmosphere, land, freshwater and marine reservoirs is in a rapid transition—an imbalance. Over tens of years, the combustion of fossil fuels is releasing into the atmosphere quantities of carbon that were accumulated in the earth system over millions of years. Furthermore, forests that once held large quantities of carbon are being converted to agricultural lands, releasing additional carbon to the atmosphere as a result. It is not surprising, then, that the concentration of carbon dioxide (CO_2) is increasing in the atmosphere. Furthermore, these trends in fossil fuel use and deforestation are accelerating. The magnitude of the changes raises concerns about the future behavior of the carbon cycle. Will the carbon cycle continue to function as it has in recent history, or will a CO_2-caused warming cause further emissions of CO_2 and further warming?

The question is complicated because carbon dioxide is not the only substance in the atmosphere that affects the earth's surface temperature and climate. Other greenhouse gases include methane (CH_4), nitrous oxide, the halocarbons, and ozone, and all of these gases, together with aerosols, solar radiation, and properties of the earth's surface, are involved in the evolution of climate change. Carbon dioxide, alone, is responsible for 55-60% of the greenhouse forcing from gases, and methane, for another 20% (values are for the late 1990s with a relative uncertainty of 10%; IPCC, 2001). These two gases are the primary gases of the carbon cycle, with CO_2 being particularly important. Furthermore, the consequences of increasing atmospheric carbon dioxide extend beyond climate change alone. The accumulation of carbon in the oceans as a result of more than a century of fossil fuel use and deforestation has increased the acidity of the surface waters, with serious consequences for corals and other marine organisms that build their skeletons and shells from calcium carbonate.

Inevitably, any options or actions to prevent, minimize, or forestall future climate change, or to avoid damage to marine ecosystems from ocean acidification, will require management of the carbon cycle so as to influence or control concentrations of carbon dioxide in the atmosphere. That management involves both reducing sources of carbon dioxide to the atmosphere and enhancing sinks for carbon on land or in the oceans. Strategies may involve both short- and long-term solutions, where short-term solutions may help to gain time while longer-term solutions are developed. In any case, formulation of options by decision makers and successful management of the earth's carbon budget will require solid scientific understanding of the carbon cycle.

Understanding the current carbon cycle may not be enough, however. The concept of managing the carbon cycle carries with it the assumption that the carbon cycle will continue to operate as it has in recent centuries. A major concern is that the carbon cycle, itself, is vulnerable to change, and that the change could bring about additional sources of carbon to the atmosphere from either land or the oceans. Over recent decades both terrestrial ecosystems and the oceans have been natural sinks for carbon. If either, or both, of those sinks were to become sources, management of the carbon cycle could become unachievable. Thus, understanding the current global carbon cycle is necessary for managing carbon, but may not be sufficient. The scientific understanding must include confidence in projections of the future behavior of the carbon cycle in response to human activity and to climate and other environmental change.

But just as importantly, effective management of the carbon cycle requires much more than basic understanding of the current or future carbon cycle. It also requires cost-effective, feasible, and politically-palatable options for carbon management. Caring about the carbon cycle, and responding to those concerns, also involves investigation, understanding and evaluation of those options.

How do North American carbon sources and sinks relate to the global carbon cycle? (Chapter 2)

In recent years North America has been responsible for approximately 30% of the carbon dioxide emissions produced globally by fossil fuel combustion (Table ES-1). North America has also contributed approximately 30% to one-third of cumulative carbon dioxide emissions form fossil-fuel combustion (and cement manufacturing) since 1750. In 2002 the United States accounted for 85% of the North American total and approximately one quarter of the global total, ranking first among all nations in carbon dioxide emissions. These emission estimates are accurate, with 95% confidence, to within 5–10% or less, with variation among countries and data sources. Interestingly, despite accounting for 30% of global emissions, North America accounted for only 10% of the global extraction of fossil fuels; that is, North America imported more than 50% of fossil fuels it used.

Table ES-1. North American contribution to the global carbon budget of approximately the 1990s.

The carbon budget of North America is dominated by fossil fuel emissions; however, the vegetation and soils of North America are, in recent years, a net sink, and the surrounding coastal oceans are a small source. The terrestrial sink in the late 1990s and early 21st century of ~600 Mt C yr^{-1}, with a 95% confidence limit of ±300 Mt C yr^{-1}, offsets approximately 30% (15–45%) of the North American fossil fuel emissions. Most of that sink is in relatively young forests in the United States and Canada, growing on lands that were once farmed. The *global* terrestrial sink is quite uncertain, averaging somewhere in the range of 0 to 3800 Mt C yr^{-1} during the 1980s (the land might have even been a small source of 300 Mt C yr^{-1} during that period) (IPCC, 2001) and in the range of 1000 to 3600 Mt C yr^{-1} in the 1990s (IPCC, 2000). As this global sink is predominantly in northern lands [the sink north of 30° N alone is estimated to be 600 to 2300 Mt C yr^{-1} for the 1980s; IPCC (2001)], the sink of ~600 Mt C yr^{-1} in North America is consistent with the fraction of northern land area in North America (37%), as opposed to Eurasia (63%). The uncertainties are very large, but the North American carbon sink reasonably represents approximately 30% of the global terrestrial sink as a most likely estimate (Table ES-1).

It is clear that the global carbon cycle of the 21st century will continue to be dominated by large fossil fuel emissions from North America. The future trajectory of carbon sinks in North America, and their contribution to the global terrestrial sink is less certain, in part because the role of regrowing forests is likely to decline as the forests mature, and in part because the response of forests and other ecosystems to future climate change and increases in atmospheric CO_2 concentrations is uncertain. The variation among model projections and scenarios of where and how future climate will change contribute to that uncertainty. Additionally, response to a particular future change will likely vary among ecosystems and the response will depend on a variety of incompletely understood environmental factors.

Because North America's carbon budget is such a substantial part of the global carbon budget, management of the North American carbon budget will have important global consequences. North America has many opportunities for decreasing emissions, including changes to the energy system and increasing energy efficiency, as well as for increasing sinks, such as investments in forest planting and agricultural soil management, biomass energy, and geological sequestration. Implementation of policies to deploy these technologies and practices is best achieved by national governments through international cooperation. National programs provide maximum coverage of CO_2 emissions and carbon sinks. They also allow better allocation of resources for technology research and development.

What are the primary carbon sources and sinks in North America, and how are they changing and why? (Chapter 3, Part II Overview, Chapters 6–9, Part III Overview, and Chapters 10–15)

The Sources

The primary source of carbon in North America is the release of CO_2 during the combustion of fossil fuels (Figure ES-1). Fossil fuel carbon emissions in the United States, Canada and Mexico totaled 1856 Mt C in 2003 (with 95% confidence that the actual value lies within 10% of that estimate) and have increased at an average rate of approximately 1% per year for the last 30 years. The United States was responsible for approximately 85% of North America's fossil fuel emissions in 2003, Canada for 9% and Mexico 6%. The 1% growth in U.S. emissions masks faster than 1% growth in some sectors (e.g., transportation) and slower growth in others (e.g., increased manufacturing energy efficiency).

Figure ES-1. North American carbon sources and sinks (Mt C yr^{-1}) circa 2003. Height of a bar indicates a best estimate for net carbon exchange between the atmosphere and the indicated element of the North American carbon budget. Error bars indicate the uncertainty in that estimate, and define the range of values that include the actual value with 95% certainty. See Chapter 3 and Chapters 6-15 of this report for details and discussion of these sources and sinks.

Despite an average growth rate of ~1.0% per year in U.S. emissions, per capita emissions have been roughly constant for the past 30 years, and carbon intensity (carbon emitted/dollar of GDP) has decreased at a rate of ~2% per year. The decrease is in large part caused by the comparatively rapid growth of the service sector (3.6% per year), which now dominates the economy (roughly three-fourths of GDP) and has a carbon intensity only 15% that of manufacturing. Increasing emissions and declining carbon intensity imply that emissions growth is to a large extent decoupled from economic growth. Also, because the service sector is likely to continue to grow more rapidly than other sectors of the economy, carbon intensity may continue to decline.

Electricity generation is the single largest contributor to the North American fossil-fuel source, accounting for approximately 40% of North American fossil emissions. Again, U.S. emissions dominate. In 2003, electricity generation in the United States alone accounted for 35% of total North American fossil fuel emissions.

The transportation sector of North America accounted for 31% of total North American emissions in 2003, most (87%) of it from the United States. The growth in transportation and associated CO_2 emissions has been steady during the past forty years and has been most rapid in Mexico, the country most dependent upon road transport. The growth of transportation is driven by population, per capita income, and economic output and is expected to increase by 46% in North America between 2003 and 2025.

More than half of electricity produced in North America (67% in the United States) is consumed in buildings, making that single use the third largest carbon source in North America (25% of the total). In fact, the CO_2 emissions from U.S. buildings alone were greater than total CO_2 emissions of any country in the world, except China. Energy use in buildings in the United States and Canada (including the use of natural gas, wood, and other fuels as well as electricity) has increased by 30% since 1990, corresponding to an annual growth rate of 2.1%. In the U.S., the major drivers of energy consumption in the buildings sector are growth in commercial floor space and increase in the size of the average home. Carbon emissions from buildings are expected to grow with population and income. Furthermore, the shift from family to single-occupant households means that the number of households will increase faster than population growth—each household with its own heating and cooling systems and electrical appliances. Certain electrical appliances (such as air-conditioning equipment) once considered a luxury are now becoming commonplace. Technology- and market-driven improvements in the efficiency of appliances are expected to continue, but the improvements will probably not be sufficient to curtail emissions growth in the buildings sector without government intervention.

Emissions from North American industry (not including fossil fuel mining and processing or electricity generation) are a relatively small (12%) and declining component of North America's emissions. Emissions decreased nearly 11% between 1990 and 2002, while energy consumption in the U.S. and Canada increased by 8-10% during that period. In both countries, a shift in production toward less energy-intensive industries and dissemination of more energy efficient equipment has kept the rate of growth in energy demand lower than the rate of growth of industrial GDP.

The Sinks

Approximately 30% of North American fossil fuel emissions are offset by a sink of ~600 (±300) Mt C yr^{-1} caused by a variety of factors, including forest regrowth, fire suppression, and agricultural soil conservation (Figure ES-1). The sink is currently ~500 (±250)[1] Mt C yr^{-1} in the U.S. and ~150 (±150) Mt C yr^{-1} in Canada. Mexican ecosystems are a net source of ~50 (±50 or greater) Mt C yr^{-1}, mostly as a consequence of ongoing deforestation. The coastal ocean surrounding North America is also a small net source of carbon to the atmosphere [~20 (±20) Mt C yr^{-1}][2].

The primary carbon sink in North America (approximately 50%) is in the forests of the U.S. and Canada (Figure ES-1). These forests are still growing (accumulating carbon) after their re-colonization of farmland 100 or more years ago. Forest regrowth takes carbon out of the atmosphere and stores most of it in aboveground vegetation (wood), with as much as a third of it in soils. The suppression of forest fires also increases a net accumulation of carbon in forest biomass. As the recovering forests mature, however, the rate of net carbon uptake (the sink) declines. In Canada, the estimated forest sink declined by nearly a third between 1990 and 2004, but with high interannual variability. Over that period, the annual changes in aboveground carbon stored in managed Canadian forests varied from between a sink of approximately 50 Mt C yr^{-1} to a source of approximately 40 Mt C yr^{-1}. Years when the forests were a source were generally years with high forest fire activity.

Woody encroachment, the invasion of woody plants into grasslands or of trees into shrublands, is a potentially large, but highly uncertain carbon sink. It is caused by a combination of fire suppression and grazing. Fire inside the United States has been reduced by more than 95% from the pre-settlement levels, and this reduction favors shrubs and trees in competition with grasses. The sink may be as large as 20% of

[1]With 95% certainty that the actual value is within this range of the estimate.

[2]The variation here is one standard deviation of the measurements used for analysis and represents primarily seasonal variability rather than uncertainty in the estimate of the mean (see Chapter 15).

the North American sink, but it may also be negligible. The uncertainty of this estimate is greater than 100%.

Wood products and wetlands are each thought to account for about 12% of the total North American sink. The uncertainty in this sink is ±50%. Wood products are a sink because they are increasing, both in use (e.g., furniture, house frames, etc.) and in landfills. The wetland sink is in both the peats of Canada's extensive frozen and unfrozen wetlands and the mineral soils of Canadian and U.S. wetlands. Drainage of peatlands in the U.S. has released carbon to the atmosphere, and the very large reservoir of carbon in North American wetlands (the single largest carbon reservoir of any North American ecosystem) is vulnerable to release in response to both climate change and the further drainage of wetlands for development. Either change might shift the current moderate sink to a potentially large source.

The carbon balance of agricultural lands is determined by two processes: management and changes in the environment. The effects of management (e.g., cultivation, conservation tillage) are reasonably well known and have been responsible for historic losses of carbon in Canada and the United States (and current losses in Mexico), albeit with some increased sequestration in recent years. Agricultural lands in North America are nearly neutral with respect to carbon, with mineral soils sequestering carbon and organic soils releasing it. The effects of climate on this balance are not well known.

Conversion of agricultural and wildlands to cities and other human settlements reduces carbon stocks, while the growth of urban and suburban trees increases them. However, the rates of carbon sequestration in the vegetation and soils of settlements, while poorly quantified, are probably relatively small, certainly in comparison to fossil fuel emissions from these areas. Thus, settlements in North America are almost certainly a source of atmospheric carbon, yet the density and development patterns of human settlements are drivers of fossil fuel emissions, especially in the important residential and transportation sectors.

What are the direct, non-climatic effects of increasing atmospheric CO_2 or other changes in the carbon cycle on the land and oceans of North America? (Chapters 2–3, Chapters 10–15)

The potential impacts of increasing concentrations of atmospheric CO_2 (and other greenhouse gases) on the earth's climate are well documented (IPCC, 2001) and are the dominant reason for societal interest in the carbon cycle. However, the consequences of a carbon cycle imbalance and the buildup of CO_2 in the atmosphere extend beyond climate change alone. Ocean acidification and "CO_2 fertilization" of land plants are foremost among these direct, non-climatic effects.

The uptake of carbon by the world's oceans as a result of human activity over the last century has made them more acidic. This acidification negatively impacts corals and other marine organisms that build their skeletons and shells from calcium carbonate. Future changes could dramatically alter the composition of ocean ecosystems of North America and elsewhere, possibly eliminating coral reefs by 2100.

Rates of photosynthesis of many plant species often increase in response to elevated concentrations of carbon dioxide, thus potentially increasing plant growth and even agricultural crop yields in the future. There is, however, continuing scientific debate about whether such "CO_2 fertilization" will continue into the future with prolonged exposure to elevated carbon dioxide, and whether the fertilization of photosynthesis will translate into increased plant growth and net uptake and storage of carbon by terrestrial ecosystems. Recent studies include many examples in which experimental treatment with elevated CO_2 leads to consistent increases in plant growth, but others in which elevated CO_2 has little effect on plant growth, leads to an initial stimulation but limited long-term effects, or increases carbon losses as well as gains. Moreover, it is unclear how plants and ecosystem might respond simultaneously to both "CO_2 fertilization" and climate change. While there is some experimental evidence that plants may use less water when exposed to elevated CO_2, it seems likely that extended deep drought or other unfavorable climatic conditions could mitigate the positive effects of elevated CO_2 on plant growth. Thus, it is far from clear that elevated concentrations of atmospheric CO_2 have led to terrestrial carbon sequestration or will do so over large areas in the future. Moreover, elevated CO_2 is known to increase methane emissions from wetlands, further increasing the uncertainty in how plant response to elevated CO_2 will affect the global atmosphere and climate.

The carbon cycle also intersects with a number of critical earth system processes, including the cycling of both water and nitrogen. Virtually any change in the lands or waters of North America as part of purposeful carbon management will consequently affect these other processes and cycles. Some interactions may be beneficial. For example, an increase in organic carbon in soils is likely to increase the availability of nitrogen for plant growth and enhance the water holding capacity of the soil. Other interactions, such as nutrient limitation, fire, insect attack, increased respiration from warming, may be detrimental. However, very little is known about the complex web of interactions between carbon and other systems at continental scales, and the direct, non-climatic effects of management on the interwoven systems of the earth system is essentially unknown.

What are the options and measures implemented in North American that could significantly affect the North American and global carbon cycles (e.g., North American sinks and global atmospheric CO_2 concentrations)? (Chapter 4)

Addressing imbalances in the North American and global carbon cycles requires options and measures focused on reducing carbon emissions. Measures refer to actions and activities designed to reduce carbon emissions or otherwise manage the carbon budget. Options refer to choices among those possible measures. Options and measures focused on enhancing carbon sinks in soils and biomass can contribute as well, but their potential is far from sufficient to deal with the magnitude of current imbalances. Furthermore, carbon sinks are more vulnerable to disturbances and to changes in climate than reduced emissions because, for example, the carbon buried in fossil fuels is more secure than the carbon stored in forests.

Options for reducing carbon emissions include:

- Reducing emissions from the transportation sector through efficiency improvement, higher prices for carbon-based fuels, liquid fuels derived from biomass, and in the longer run (after 2025), hydrogen generated from non-fossil sources of energy;
- Reducing the carbon emission impact of buildings through efficiency improvements and energy-saving passive design measures;
- Reducing emissions from the industrial sector through efficiency improvement, fuel-switching, and innovative process designs; and
- Reducing emissions from energy extraction and conversion through efficiency improvement, fuel-switching, technological change (including carbon sequestration and capture) and reduced demands due to increased end-use efficiency.

In many cases, significant progress with such options would require a combination of technology research and development, policy interventions, and information and education programs

Opinions differ about the relative mitigation impact of cost-effective emission reduction vs. carbon sequestration at modest cost increases per metric ton of CO_2 emitted. Some economic analyses suggest that the potential mitigation is greater at relatively low prices for agricultural soil carbon sequestration than from fossil fuel use reduction. In addition, analyses suggest that carbon emission cap and trading policies could reduce carbon emissions significantly without a major net economic cost by providing incentives to use the least-cost combination of mitigation/sequestration alternatives.

Many options and measures that reduce emissions and increase sequestration have significant co-benefits in terms of economic efficiency, environmental management, and energy security. At the same time, actions focused on one greenhouse gas or one mitigation pathway can have unintended consequences. For instance, carbon sequestration strategies such as reduced tillage can increase emissions of methane and nitrous oxide, which are also greenhouse gases. Strategies for dealing with climate change will have to consider these other gases as well as other components of the climate systems, such as aerosols and the physical aspects of plant communities, although these components are not considered here.

Options and measures can be implemented in a variety of ways at a variety of scales, not only at international or national levels. For example, a number of municipalities, state governments, and private firms in North America have made commitments to voluntary GHG emission reductions. For cities, one focus has been the Cities for Climate Protection program of International Governments for Local Sustainability (formerly ICLEI). For states, the Regional Greenhouse Gas (Cap and Trade) Initiative is nearing implementation. For industry, one focus has been membership in the Pew Center and in the EPA Climate Leaders Program.

How can we improve the application of scientific information to decision support for carbon management and climate decision making? (Chapter 5)

Effective carbon management requires that relevant, appropriate science be communicated to the wide variety of people whose decisions affect carbon cycling. Because the field is relatively new and the demand for policy-relevant information has been limited, carbon cycle science has rarely been organized or conducted to inform carbon management. To generate information that can systematically inform carbon management decisions, scientists and decision makers need to clarify what information would be most relevant in specific sectors and arenas for carbon management, adjust research priorities as necessary, and develop mechanisms that enhance the credibility and legitimacy of the information being generated.

In the United States, the Federal carbon science enterprise does not yet have many mechanisms to assess emerging demands for carbon information across scales and sectors. Federally funded carbon science has focused predominantly on basic research to reduce uncertainties about the carbon cycle. Initiatives are now underway to promote coordinated, interdisciplinary research that is strategically prioritized to address societal needs. The need for this type of research is increasing. Interest in carbon management across sectors suggests that there may be substantial demand for information in the energy, transportation, agriculture, forestry and industrial sectors, at scales ranging from local to global.

To ensure that carbon science is as useful as possible for decision making, carbon scientists and carbon managers need to create new forums and institutions for communication and coordination. Research suggests that in order to make a significant contribution to management, scientific and technical information intended for decision making must be perceived not only as credible (worth believing), but also as salient (relevant to decision making on high priority issues) and legitimate (conducted in a way that they believe is fair, unbiased and respectful of divergent views and interests). To generate information that meets these tests, carbon stakeholders and scientists need to collaborate to develop research questions, design research strategies, and review, interpret and disseminate results. Transparency and balanced participation are important for guarding against politicization and enhancing usability.

To make carbon cycle science more useful to decision makers in the United States and elsewhere in North America, we suggest that leaders in the carbon science community take the following steps:

- Identify specific categories of decision makers for whom carbon cycle science is likely to be salient, focusing on policy makers and private sector managers in carbon-intensive sectors (energy, transport, manufacturing, agriculture and forestry);
- Identify and evaluate existing information about carbon impacts of decisions and actions in these arenas, and assess the need and demand for additional information. In some cases, demand may need to be nurtured and fostered through a two-way interactive process;
- Encourage scientists and research programs to experiment with new and different ways of making carbon cycle science more salient, credible, and legitimate to carbon managers;
- Involve not just physical or biological disciplines in scientific efforts to produce useable science, but also social scientists, economists, and communication experts; and
- Consider initiating participatory pilot research projects and identifying existing “boundary organizations” (or establishing new ones) to bridge carbon management and carbon science.

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Table ES-1. North American contribution to the global carbon budget of approximately the 1990s. Global values are for the 1990s (IPCC, 2001); the North American terrestrial sink estimate, from this report span the 1990s and first years of the 21st century. Values are in Mt C yr^{-1}, with positive values flues to the atmosphere and negative value are uptake from the atmosphere.

	Global[a] (Mt C yr^{-1})	**North America[b] (Mt C yr^{-1})**	**North American fraction of global (percent of means)**
Atmospheric increase	3200 ± 100	NA	NA
Emissions (fossil, fuel, cement)	6300 ± 400	1640 ± 164[c]	26%
Ocean-atmosphere flux	–1700 ± 500	20 ± 20[d]	1%
Emissions from land-use change	1600 ± 800[e]	–37[f]	2%
Terrestrial Sink	–2300 ± 1300[g]	–600 ± 300[h]	26%

NA indicates "Not Applicable"

[a] Global uncertainties are ± 1 standard error (67% confidence intervals) (IPCC, 2001).
[b] North American uncertainties are 95% confidence intervals. See Chapter 3 in this report.
[c] Average emissions for 1990–1999 (Marland *et al*., 2006).
[d] The variation here is one standard deviation of the measurements used for analysis and represents primarily seasonal variability rather than uncertainty in the estimate of the mean (see Chapter 15 in this report).
[e] Estimate for the years 1989–1995 (IPCC, 2000).
[f] United States only; values for the 1980s (Houghton *et al*., 1999).
[g] Residual calculated as the difference between combined fossil-fuel and land-use emissions minus ocean uptake and increase in the atmosphere (IPCC, 2001)
[h] Estimated from changes in inventories of carbon stored in plants and soils (see Chapter 3 in this report).

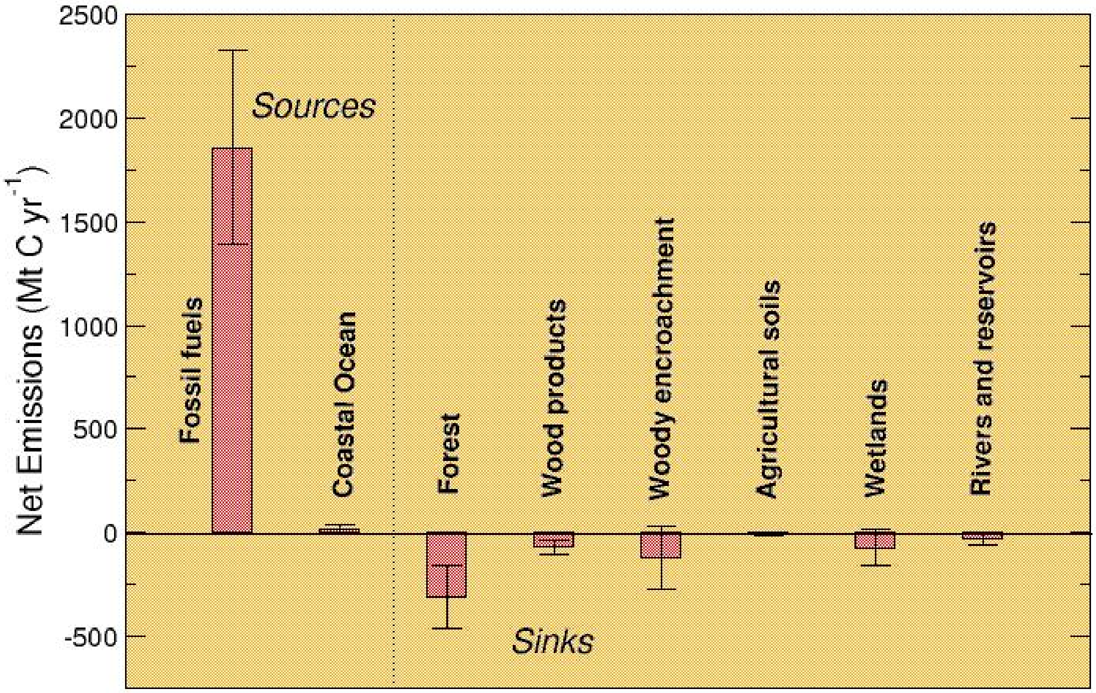

Figure ES-1. North American carbon sources and sinks (Mt C yr^{-1}) circa 2003. Height of a bar indicates a best estimate for net carbon exchange between the atmosphere and the indicated element of the North American carbon budget. Error bars indicate the uncertainty in that estimate, and define the range of values that include the actual value with 95% certainty. See Chapter 3 and Chapters 6-15 of this report for details and discussion of these sources and sinks.