U.S. Forest Carbon and Climate Change

Controversies and Win-Win Policy Approaches

Economic Analysis

SCIENCE FROM

THE WILDERNESS SOCIETY

Our Mission

Since 1935, **The Wilderness Society** has worked to preserve America's unparalleled wildland heritage and the vast storehouse of resources these lands provide. From the threatened tupelo and cypress forests of the Southeast to critical grizzly bear and wolf habitat in the Yellowstone-to-Yukon corridor to the incomparable, biologically rich Arctic, The Wilderness Society has forged powerful partnerships with members and friends across the country to conserve interconnected landscapes for our nation. We want to leave a legacy rich in the biological diversity and natural systems that nurture both wildlife and humans alike.

Headquartered in Washington, D.C., the Society also maintains nine regional offices where our staff address on-the-ground conservation issues linked to local communities. Since spearheading passage of the seminal Wilderness Act in 1964, we have been a leading advocate for every major piece of Wilderness legislation enacted by Congress, work that is supported by an active membership of more than 200,000 committed conservationists. Our effectiveness stems from a team approach to conservation, which links our scientists, policy experts, and media specialists to thousands of grassroots activists — creating a potent force to promote change.

Building the case for land preservation with tactical research and sound science is the key to successful environmental advocacy and policy work. Nearly a quarter century ago, The Wilderness Society helped pioneer strategies that incorporated expert economic and ecological analysis into conservation work. Today, through focused studies, state-of-the-art landscape analysis — and diligent legwork by our many partners who provide us with on-site data — our **Ecology and Economics Research Department** is able to serve the needs of the larger conservation community.

Legislators, on-the-ground resource managers, news reporters, our conservation partners, and — most importantly — the American people must have the facts if they are going to make informed decisions about the future of this nation's vanishing wildlands. The answers to the pressing legal, economic, social, and ecological questions now at issue are the stepping stones to that understanding and, ultimately, to achieving lasting protection for the irreplaceable lands and waters that sustain our lives and spirits.

U.S. Forest Carbon and Climate Change

Controversies and Win-Win Policy Approaches

by

Ann Ingerson

THE WILDERNESS SOCIETY

Acknowledgments

The author and The Wilderness Society thank the Johnson and Johnson Family of Companies for making this report possible. Thanks also to the many forestry and carbon policy experts who provided information and interpretation and reviewed earlier drafts, including: Linda Heath and Richard Birdsey of the USDA Forest Service, Laurie Wayburn of Pacific Forest Trust, John Perez-Garcia of the University of Washington, Thomas Peterson of the Center for Climate Strategies, Rob Bryan of the Maine Audubon Society, Bob Perschel of the Forest Guild, and Ellen Hawes of Environment Northeast. Any remaining errors are the author's responsibility alone.

Thanks also to many colleagues at The Wilderness Society who provided guidance, critiques, and encouragement, including: Tom Bancroft, Linda Lance, Greg Aplet, Tom DeLuca, Joe Kerkvliet, Wendy Loya, Stan VanVelsor, and Tom Gilbert. A special appreciation to Katherine Birnie, 2006 Hewlett Environment Fellow at The Wilderness Society, who conducted extensive research into carbon markets that helped inform this report.

And finally, thanks to Sarah DeWeerdt and Mitchelle Stephenson who with infinite patience, attention to detail, and efficiency molded this report into its final form.

Citation

Ingerson, Ann L. 2007. U.S. *Forest Carbon and Climate Change.* Washington, D.C.: The Wilderness Society.

This science report is one of a series that stems from conservation research studies conducted by The Wilderness Society's Ecology and Economics Research Department. Other reports and briefs in the series that focus on issues relevant to this report include:

- **Environmental Benefits and Consequences of Biofuel Development in the United States:** a Science and Policy Brief
- **Fragmenting Our Lands:** The Ecological Footprint from Oil and Gas Development (A Spatial Analysis of a Wyoming Gas Field)
- **Energy & Western Wildlands:** A GIS Analysis of Economically Recoverable Oil and Gas
- **Wildlife at a Crossroads:** Energy Development in Western Wyoming

These and other reports and briefs are available on The Wilderness Society's web site <www.wilderness.org> and from The Wilderness Society, Communications Department, 1615 M Street, NW, Washington, DC 20036 (202-833-2300 or 1-800-THE-WILD).

Editor: Sarah DeWeerdt
Design/format:
Mitchelle Stephenson

Printed in the
United States of America
by The Printing Network
on recycled paper.

1615 M Street, NW
Washington, DC 20036
Tel: 202-833-2300
Fax: 202-454-4337
Web site: www.wilderness.org

Preface

The United States is blessed with a rich tapestry of forested landscapes—from the shade-dappled hardwood stands of New England to the open pinelands of the Southeast and towering firs of the Pacific Northwest coast. Woodland habitats shelter thousands of wildlife species and provide a treasure trove of recreation opportunities for the American people. In addition, our forests store vast amounts of carbon in tree trunks, roots, leaves, dead wood, and soils—a service that is becoming ever more essential as the threat of global climate change mounts due to the buildup of human-generated carbon dioxide and other greenhouse gases in the atmosphere.

Although investments in energy efficiency and clean energy will provide the only permanent solutions to climate change, forest sequestration can buy us time to develop those alternatives. U.S. forests currently capture the equivalent of about one-tenth of the nation's greenhouse gas emissions. They have the potential to contribute even more to climate change mitigation. But this potential will only be realized if we move carefully, with properly designed policies to increase forest carbon stores.

The Wilderness Society's report, *U.S. Forest Carbon and Climate Change*, examines various policy options to promote the role of forests in carbon sequestration. After a thorough review of the available data measuring and accounting for the amount of carbon stored in and moving through forest ecosystems, author Ann Ingerson presents persuasive evidence about the challenges inherent in many current proposals. Some frequently discussed solutions are much more complex than they first appear. Others such as carbon markets, for example, may present risks around the issues of permanence and measurement, which could hamper their effectiveness as tools for meeting the climate challenge long-term. Several strategies, if adopted without careful consideration of their full carbon-cycle effects, could actually *decrease* the amount of carbon stored in our forests.

Fortunately, several simple and broadly supported policy approaches for increasing forest carbon stores also exist. Protecting the forests we have, replanting depleted landscapes, and managing forests for longer rotations and larger volumes of standing timber will all help ensure these critical wildlands play an ongoing role in climate change mitigation. A host of related benefits will accrue from such policies, including habitat for species, recreation opportunities, and key public values such as water filtration. One way to begin to address the global warming issue is to look to these strategies first to increase forest carbon stores. This approach may also provide the vehicle for bringing together some unusual allies—from environmental NGOs to private forestland owners and the wood products industry—ready to find common solutions to the climate problem that threatens us all.

William H. Meadows
President
The Wilderness Society

G. Thomas Bancroft, Ph.D.
Vice President
Ecology and Economics
Research Department

Contents

List of Figures

List of Tables

Acronyms and Abbreviations

CO_2e	Carbon dioxide equivalent
DOE	U.S. Department of Energy
EPA GHG	U.S. Environmental Protection Agency Greenhouse Gas Inventory
FIA	Forest Inventory and Analysis (program of the U.S. Forest Service)
MMT	Million metric tons (teragrams)
NGO	Non-governmental organization
NRI	National Resources Inventory (program of the U.S. Department of Agriculture)
USDA	U.S. Department of Agriculture

Executive Summary

As consensus grows about the serious impacts of global climate change, the role of forests in carbon storage is increasingly recognized. Terrestrial vegetation worldwide currently removes about 24 percent of the greenhouse gases released by industrial processes. Unfortunately, this contribution is approximately cancelled out by carbon released as a result of global deforestation and other ecosystem changes. Slowing or halting the rate of deforestation is thus one of the prime strategies to mitigate global climate change.

The U.S. situation differs from the global one in several ways. Since both forest acres and average biomass per forest acre are currently increasing, as U.S. forests recover from past clearing or heavy harvest, our forest carbon stores are growing larger over time. However, our high rate of industrial emissions means that only about 10 percent of the carbon released from burning fossil fuels in the United States is captured by our forests. Moreover, net U.S. forest carbon sequestration has begun to slow in recent years as reforestation reaches its limits and development sprawls into more rural forested areas. U.S. forests could possibly capture a much higher portion of our industrial emissions, but only if we prevent forest conversion and development and manage our forests to maximize carbon stores.

How can we develop effective policies to protect and enhance forest carbon stores? A first step is to understand the magnitude of carbon emissions and storage. International discussions about global climate change have led governments at national and state levels to document greenhouse gas emissions and stores through economy-wide inventories or voluntary registries, most of which include special provisions for the forest sector. The next step would be to enact policies that encourage increased forest sequestration. Widely publicized carbon markets under the Kyoto Protocol have tended to focus policy discussions rather narrowly on the sale of forest-based carbon offsets to greenhouse gas emitters under a cap-and-trade scheme. But before forest-based offsets can become a tradeable commodity, several issues need to be addressed, including the need for a consistent and verifiable accounting system, the need to prove additionality over some well-defined baseline, and the need to guarantee permanence of carbon storage.

Given the uncertainties about offsets as a tradeable commodity, other public policies to enhance forest carbon stores may be a better option. One approach might be to maintain a large carbon bank on public forestland; another would be to subsidize private landowners who increase carbon storage on their forestland.

Whether we use marketable offsets or other public policies as tools, managing forest carbon to mitigate climate change is a complex business that requires understanding the entire carbon cycle over long time periods. Three strategies often proposed as forest-based climate change solutions illustrate some of these underlying complexities:

1) **Does replacement of old, slow-growing forests with young, intensively managed plantations speed carbon sequestration?** Since net biomass growth rates slow down in mature forests, keeping forests in a young, fast-growing state through

In this report, we explore:

1. The role of forests in sequestering carbon dioxide—thus mitigating global climate change—and the state of the U.S. forest carbon bank account.
2. The complexities of measuring forest carbon, particularly using such tools as inventories and registries.
3. Some potential pitfalls of cap-and-trade programs, markets for forest-based carbon offsets, and subsidies to boost forest carbon.
4. The complexities of three specific forest-based strategies often proposed for mitigating climate change: managing for fast-growing young forests, increasing carbon stored in wood products, and increasing use of woody biomass fuels.
5. Policy approaches to boosting forest carbon that have many secondary benefits for the public and the environment as well: forest preservation, restoration, and sustainable management.

short-rotation harvests would seem a reasonable strategy for enhancing carbon sequestration. However, only a full accounting will determine whether a regenerating forest fixes more carbon than the mature forest it replaces. Rather than simply comparing live-tree carbon fixed annually by old and young trees, we need to compare *all* carbon flows over time for a mature forest (including accumulations in dead woody biomass and soil) to *all* flows associated with a harvested forest (including harvest-related emissions and wood products carbon losses).

2) **Does converting trees into long-lived wood products increase carbon stores?** Forestland owners would like to claim credit for carbon harvested and stored off-site in long-lived wood products. Though intuitively appealing, this approach presents several unresolved questions, including how to account for emissions related to harvest and processing, the uncertainty of permanent stores not controlled by the landowner, and how to credit emissions reductions due to substituting wood for other building materials. With multiple decision-makers dispersed throughout the national and even global marketplace, tracking the fate of harvested carbon is a challenge.
3) **Is woody biomass a carbon-neutral fuel?** It is often argued that woody biomass sequesters as much carbon while growing as it releases when burned, and hence should be eligible for offset credits when it replaces fossil fuel use. To assure carbon neutrality, however, the source forest must be protected from conversion and managed so as to replace all carbon released by burning. Even with such management, energy conversion losses and emissions from harvest, transport, and chipping will pull the ratio of carbon fixed to carbon released below 1:1.

As we work to better understand the long-term carbon impacts of forest management decisions, it makes good sense to start with strategies for increasing forest carbon that also provide secondary public benefits. Forest preservation and reforestation maintain or increase forested area, and also provide habitat for forest-dependent species, improve water quality, and regulate floodwaters that may become more severe as the climate changes. Lengthening rotations and increasing standing timber volumes enhance scarce late-successional habitat, provide more high-quality timber, and create forest surroundings that are attractive for remote hiking, fishing, and other back-country recreation. Beginning with these low-risk approaches will help achieve consensus about the contributions of forests to moderating climate change and build support for public policies that protect and enhance their role.

Forests and the Global Carbon Cycle

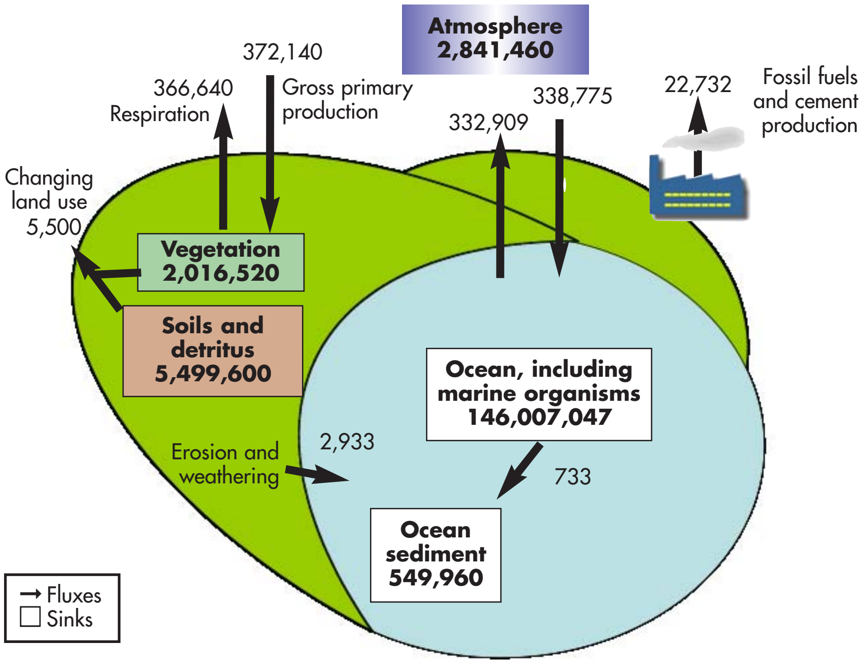
Societies around the globe are beginning to address the threat of severe climate change through policies aimed at reducing the buildup of greenhouse gases. Natural ecosystems, including forests, are a critical link in the global carbon cycle and must play a vital role in the mitigation of global warming. Forests are important both for their large *existing reservoirs* of carbon (often called “pools” or “sinks”) and because of the *ongoing net flow* of carbon from the atmosphere into that forest reservoir (often called “flux”). Figure 1 shows the major global sources, sinks, and annual fluxes of carbon.

Currently, land-based stores of carbon dioxide equivalent[1] are about 7,516,120 million metric tons (MMT) worldwide. This carbon bank account is continuously built up or depleted by photosynthesis, respiration, and erosion, and also through restoration, destruction, or change of various landscape types. For all lands that support plant growth (forests, croplands, wetlands, etc.), the carbon dioxide removed from the atmosphere by photosynthesis—372,140 MMT/year—generally exceeds that released through respiration by plants and decomposer organisms—366,640 MMT/year—meaning that growing plants and associated fungi and bacteria remove a net 5,500 MMT of carbon dioxide from the atmosphere each year (about 24 percent of the carbon released by industrial processes).

Photosynthesis will continue to exceed respiration overall, however, only with proper management of existing landscapes. Clearcutting a forest, for instance, boosts respiration (releasing CO_2) and suppresses photosynthesis (reducing biological fixation of CO_2) for several years or decades—even when land is replanted or allowed to regenerate

FIGURE 1.

Global Carbon Cycle



All figures given in millions of metric tons CO_2e.

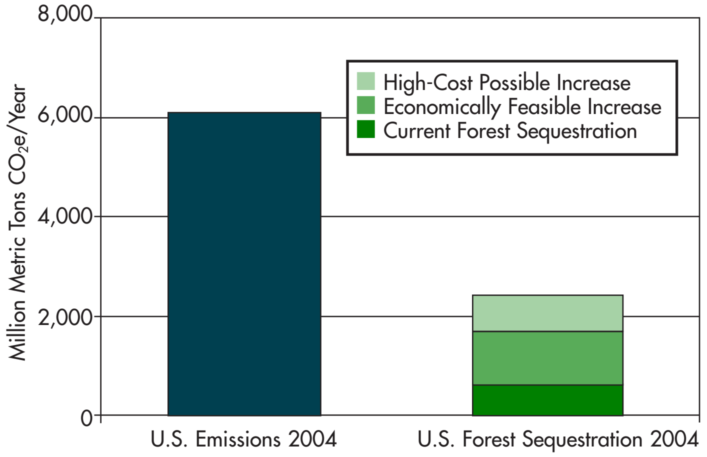
Adapted with permission from Oak Ridge National Laboratory. Source figure available from http://cdiac.ornl.gov/pns/graphics/c_cycle.htm. 1992-1997 data.

---

[1] Carbon budgets can be confusing because of the variety of units utilized. Millions of metric tons (teragrams) is fast becoming the standard unit of measurement, but some sources report the mass of elemental carbon stored, while others use the mass of CO_2 (3.6664 times the mass of C) or include all greenhouse gases as CO_2 equivalents (often abbreviated CO_2e). This last unit is important because, though CO_2 is the main gas responsible for global warming, other gases make an even greater contribution to the greenhouse effect. Methane (CH_4), for instance, is about 21 times as potent as CO_2 pound-for-pound and over time, and N_2O is 310 times as potent. In order to gauge the capacity of forests to offset emissions, we will express carbon quantities in CO_2e (primarily millions of metric tons) through the rest of this paper.

FIGURE 2.

U.S. Industrial Greenhouse Gas Emissions and Current and Potential Forest Sequestration



Emissions and sequestration data from U.S. Environmental Protection Agency 2007. Economically feasible and high-cost possible forest sequestration from Stavins and Richards 2005.

trees. Large existing stores of carbon are released into the atmosphere when land is converted to other uses. Since more land is developed, drained, or otherwise converted annually than is restored to its natural cover, land use changes release about 5,500 MMT of CO_2 each year, essentially negating the entire contribution of plants to the land-based carbon sink.

U.S. Forests as Carbon Sinks

U.S. forests store about 152,236 MMT CO_2e, representing about 2 percent of global terrestrial carbon stores. An additional 8,781 MMT CO_2e are stored in wood products in use and in landfills (U.S. Environmental Protection Agency 2007). Though deforestation is occurring much more rapidly than forest growth globally, forests in the United States currently remove substantially more carbon from the atmosphere than they emit, so our forest-related carbon sink is increasing by about 699 MMT CO_2e annually (a growth rate of 0.4 percent).[2] In the eastern United States, land formerly cleared for farming is growing back naturally to woods or is being replanted through conservation assistance programs like the USDA Conservation Reserve Program. In the Pacific Northwest, forestlands are recovering from intensive harvesting during the mid-to-late 20th century, and are rebuilding large carbon stores in the form of living trees above and below ground, shrubs, snags and coarse woody debris, soil, and forest floor litter.

The United States, with 4 percent of the world's population, is responsible for nearly one-quarter of global carbon emissions. As our nation develops a long-overdue strategy to reduce our climate change impact, we must protect our existing stores of forest carbon and also enhance the capacity of our forests to fix additional carbon in the future. Figure 2 compares estimated annual U.S. industrial emissions of greenhouse gases with net annual carbon sequestration by U.S. forests. Our forests currently sequester about 10 percent of U.S. industrial emissions of CO_2-equivalent gases; given the right policies that proportion could reach as high as 36 percent, though high costs make it unlikely we will ever reach that goal. Although investments in energy efficiency and clean energy will provide the only permanent solutions to climate change, forest sequestration can buy us time to develop those alternatives. Relatively low-cost policies to increase forest carbon stores include protection of existing forestland from development, restoration of deforested or degraded lands, and management to increase carbon stores on existing forestland.

An Uncertain Future for U.S. Forest Carbon Stores

Though U.S. forests currently help offset our industrial carbon emissions and could potentially contribute even more, the ability of our forests to continue providing this important service is in question. Our total stores of forest carbon are still increasing each year, but at an ever-slower rate. Figure 3 shows historic carbon fluxes to and from forests in what is

---

[2] Since the increase in our forest carbon sink is based solely on the difference between starting and ending inventory, it does not reflect the contribution of woody biomass replacement of fossil fuels to reducing greenhouse gas emissions.

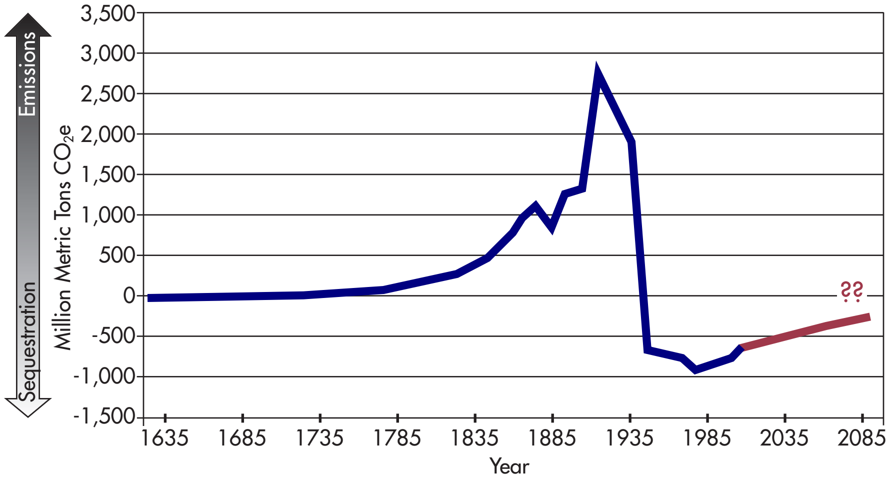
now the United States (including both the forested ecosystem and the carbon derived from it but stored off-site in wood products). Note that positive numbers in the figure represent emissions, and negative numbers represent sequestration. European settlement and accompanying deforestation made our forests net sources of carbon emissions by the mid-1700s, a trend that peaked in the early 1900s. By the mid-1900s, regrowth of forests on abandoned farmland and cut-over timberlands began to replenish our national carbon bank account. In recent years, however, net annual flows of carbon out of the atmosphere and into the forest ecosystem and wood products pools have begun to decline once more. If recent trends continue (red line), our forests may cease to sequester net carbon by the end of this century.

Forest carbon stores are threatened by both reduced forest acreage and reduced carbon density (tons of carbon stored per acre). The U.S. Forest Service's Forest Inventory and Analysis (FIA) Program provides information about trends in forest acreage. Though FIA data show gains in forest acreage for the United States as a whole in recent years, these gains are not uniform and in fact 23 of the 48 coterminous U.S. states lost forest acreage between 1997 and 2002 (Figure 4).

There is much uncertainty regarding the accuracy of these acreage figures, which are derived from periodic sampling and suffer from occasional changes in the definition of forestland. For example, some of the data on which calculations of forestland losses for 1997-2002 are based were collected as far back as the early 1990s, and probably fail to accurately reflect recent changes in forestland acres. Data are also from samples rather than complete land cover analysis, and sampling errors are relatively high. However, these are the best data currently available on a nationwide basis. Efforts are underway to improve estimates of forest area changes.

FIGURE 3.

U.S. Forest Carbon Budget (Ecosystem + Wood Products)



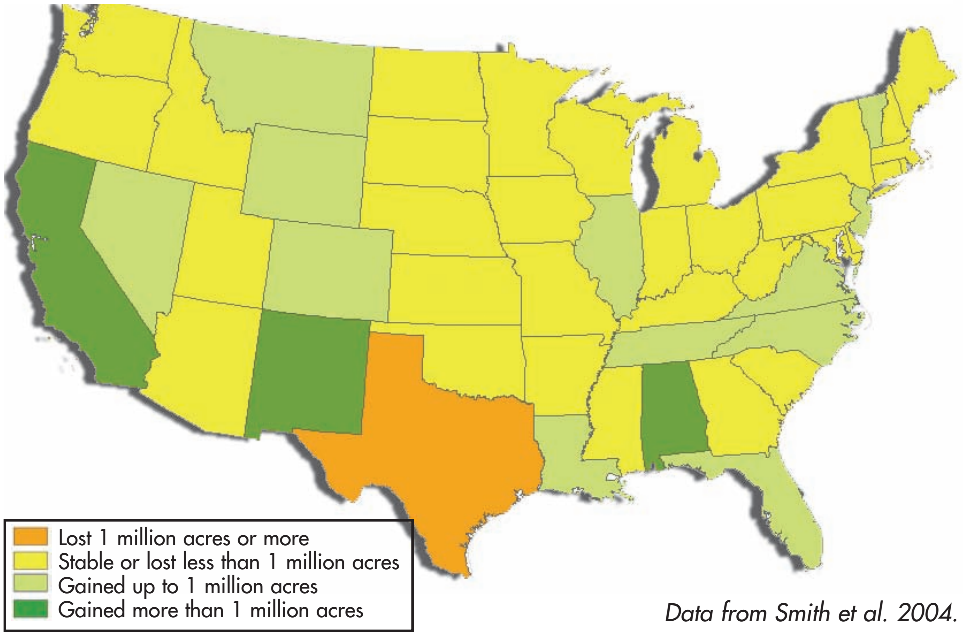
Adapted with permission from Birdsey et al. 2006.

Gross acreage changes also mask the fact that acreage gains often apply to early regrowth of abandoned farmland that is severely depleted in carbon stores, while losses may occur in high-carbon mature forests at the suburban sprawl frontier. The U.S. Department of Agriculture's National Resources Inventory (NRI) allows us to track conversion between specific land cover types (U.S. Department of Agriculture 2000). Though recent changes cannot yet be assessed due to a change in sampling methods, NRI data indicate a net increase of 3.6 million acres of forestland nationwide from 1982 to 1997. Over this period more than 8 million acres of forest were converted to agricultural uses and 12 million acres were developed or converted to "other rural land," while 23 million acres of new forest began to grow on former farmland. Overall, this exchange of acres would cause a net loss of forest carbon.

Estimates of carbon released through land conversion vary widely, as some kinds of low-density development may keep forests nearly intact. But many sources agree that carbon losses due to forest conversion are significant. The Pacific Forest Trust (Gordon 2006) estimates that "probably, upwards of 25 tons of carbon emission per acre [83 metric tons CO_2e] can be prevented for each acre not converted from forest to another use," and that 1.5 million acres of forest lost every year to development in the United States release 275 million metric tons of CO_2e (Pacific Forest Trust 2007). In the Northeast, roughly 150 tons of CO_2e are released for every forested acre developed.[3] Moreover, when forestland is converted to other uses, not only is CO_2 released but the land's future capacity to continue drawing carbon dioxide out of the air may be diminished or lost.

FIGURE 4.

Estimated Change in Forestland Area, 1997-2002



Data from Smith et al. 2004.

---

[3] According to the North East State Foresters Association (2002), the forests of New York and New England contain, on average, 106 metric tons of total carbon (388 metric tons CO_2e) per acre, with about one-third in live trees. Environment Northeast (Stoddard and Murrow 2006) estimates that 50-67 percent of above-ground carbon and 22-25 percent of soil carbon are released on conversion. Putting these figures together yields 139 to 178 metric tons CO_2e emitted per acre converted in the Northeast.

Measuring Forest Carbon

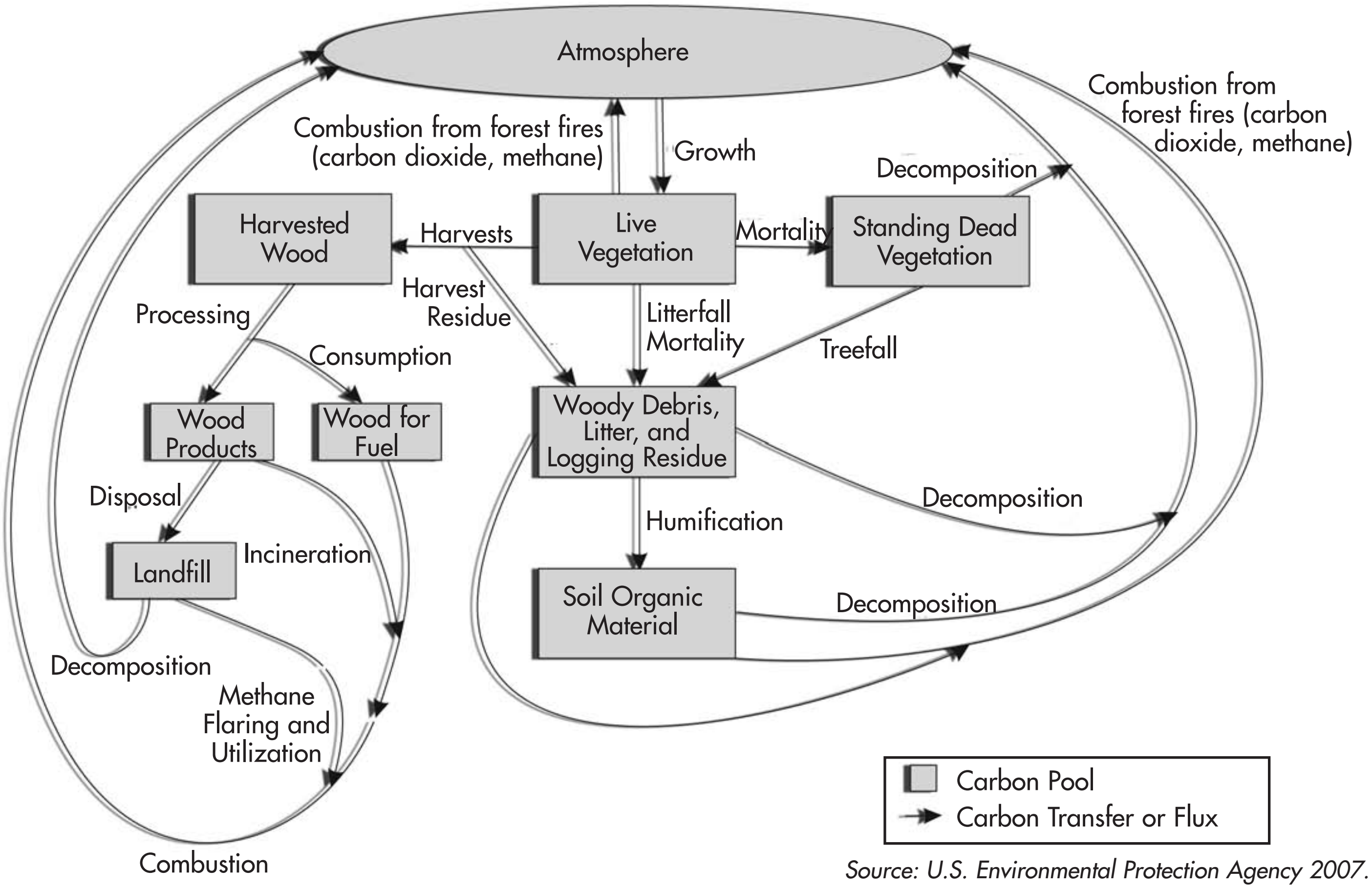
Protecting and enhancing forest carbon is an effective way to reduce greenhouse gases, but its use as a public policy tool will require careful documentation. Official national inventories and voluntary registries at national and state levels are designed to track carbon stores and changes in those stores. A brief look at these tools shows that our capacity to measure all pools of carbon associated with forests is very limited, and we need much better information to manage this resource to its full potential.

The official national inventory of carbon stocks (pools) and average annual changes (fluxes) in greenhouse gases across the entire U.S. economy is the Environmental Protection Agency's annual Greenhouse Gas Inventory (EPA GHG). Policymakers turn to this comprehensive national record to assess U.S. contributions to climate change and will use it in the future to evaluate the effectiveness of mitigation measures. The USDA Forest Service is tasked with developing forest carbon numbers for the Land Use and Land Use Change segment of this inventory. Figure 5, developed by Linda Heath of the USDA Forest Service, illustrates the complexity of tracking forest carbon. Table 1 shows the most recent EPA GHG estimates of changes in forest carbon stores in the United States.

Most of the data in the EPA GHG Inventory comes from the Forest Inventory and Analysis Program. The FIA provides the only nationwide infor-

FIGURE 5.

Forest Sector Carbon Pools and Fluxes



Source: U.S. Environmental Protection Agency 2007.

TABLE 1.

EPA Greenhouse Gas Inventory Estimates of Changes in Forest Carbon Stores

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005
Forest	**(466.5)**	**(602.0)**	**(529.4)**	**(555.5)**	**(595.3)**	**(595.3)**	**(595.3)**	**(595.3)**
Aboveground Biomass	(251.8)	(331.0)	(347.1)	(360.4)	(376.4)	(376.4)	(376.4)	(376.4)
Belowground Biomass	(63.9)	(69.8)	(73.9)	(76.4)	(79.5)	(79.5)	(79.5)	(79.5)
Dead Wood	(36.7)	(60.9)	(48.2)	(50.0)	(52.4)	(52.4)	(52.4)	(52.4)
Litter	(65.6)	(49.5)	(35.8)	(47.1)	(52.2)	(52.2)	(52.2)	(52.2)
Soil Organic Carbon	(48.5)	(90.8)	(24.5)	(21.6)	(34.8)	(34.8)	(34.8)	(34.8)
Harvested Wood	**(132.0)**	**(115.5)**	**(109.3)**	**(90.2)**	**(92.8)**	**(91.7)**	**(102.0)**	**(103.4)**
Wood Products	(63.1)	(53.5)	(46.2)	(31.2)	(34.1)	(33.4)	(43.3)	(44.4)
Landfilled Wood	(68.9)	(62.0)	(63.1)	(59.0)	(58.7)	(58.3)	(58.7)	(59.0)
Total Net Flux	**(598.5)**	**(717.5)**	**(638.7)**	**(645.7)**	**(688.1)**	**(687.0)**	**(697.3)**	**(698.7)**

Note: All figures given in units of MMT CO_2. Forest C stocks do not include forest stocks in Alaska, Hawaii, or U.S. territories, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Source: U.S. Environmental Protection Agency 2007.

mation about forest resources over time, and it was originally designed to track commercial timber resources, not to measure carbon. As a result FIA data suffers from many limitations (though plans are underway to address most of them if funding permits):

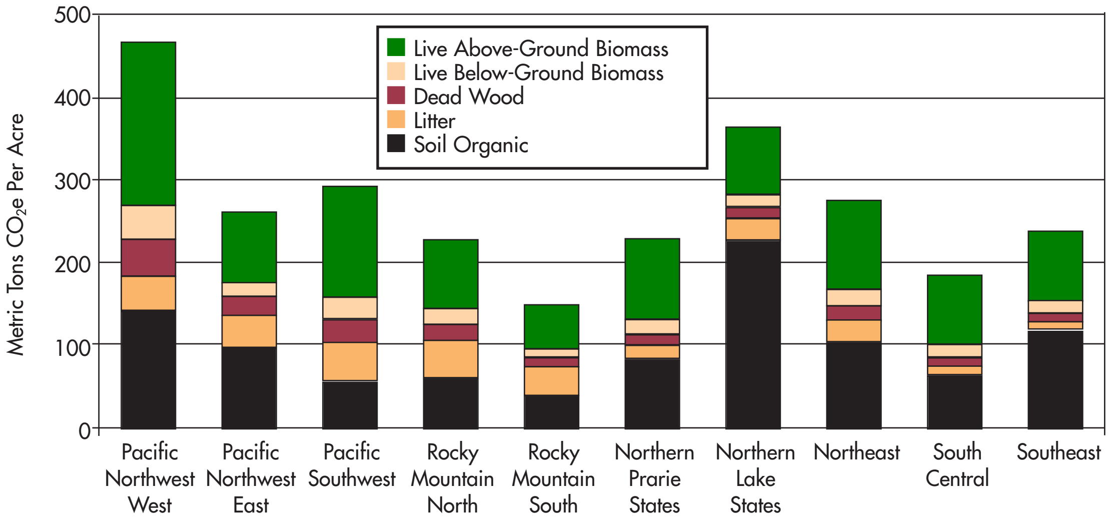
- FIA has only recently begun to measure biomass, forest floor debris, and other variables important for assessing carbon stocks. Soil carbon is not monitored and so estimates are based on broad forest types regardless of land use history.
- FIA inventories for some states are 15 to 20 years old and early sampling protocols varied from state to state. Lack of frequent updates forces researchers to interpolate between sampling dates, resulting in anomalies like the constant forest data for 2002 through 2005 in Table 1.
- Limited inventory data for Alaska means that important state is excluded altogether.
- The EPA GHG Inventory excludes altogether any measures of the impact of development and land use change on forest carbon stores, citing a lack of adequate data on land use changes.

Figure 6 illustrates why the lack of information about soil organic matter, dead wood, and litter might matter. These nonliving components make up a substantial fraction of total forest carbon in all regions—from a low of 45 percent in the Pacific Southwest to a high of 73 percent in the Northern Lake States. These are the ecosystem components that tend to be most depleted under intensive management, particularly in forests regenerating from cleared agricultural lands. Managing forests to restore natural levels of these components could yield substantial carbon sequestration benefits.

In addition to the nationally aggregated EPA GHG *inventory*, another compendium of information on forest carbon stocks is the U.S. Department of Energy's voluntary *registry* that allows individual entities to report their own emissions and sequestration of greenhouse gases. This national registry is often called 1605(b) for the section of the Energy Policy Act of 1992 that required its

FIGURE 6.

Forest Carbon Density by U.S. Region



Regions: PNWW (Western OR and WA); PNWE (Eastern OR and WA); PSW (CA); RMN (ID, MT); RMS (AZ, CO, NM, NV, UT, WY); NPS (IA, IL, IN, KS, MO, ND, NE, SD); NLS (MI, MN, WI); NE (CT, DE, MA, MD, ME, NH, NJ, NY, OH, PA, RI, VT, WV); SC (AL, AR, KY, LA, MS, OK, TN, TX); SE (FL, GA, NC, SC, VA).

Data from Smith and Heath 2006.

establishment. Some states and several private organizations have also developed registries, each with its own system of accounting for carbon stores, emissions, and sequestration. For example, registries may differ in:

- Reporting by entity versus by project (a single tree planting project may be undercut by increased timber cutting by the same company elsewhere).
- Which carbon pools must be measured (increases in wood products carbon might eventually result in depleted soil carbon pools).
- Method of monitoring (models or look-up tables may be less reliable, but also more affordable, than on-the-ground sampling).

Registry standards determine to what extent a forestland owner or a forest sequestration project can claim credit for mitigating climate change. Therefore, establishing a uniform method of accounting is key to making registries work in the future.

Policies to Protect and Enhance Forest Carbon

Mitigating climate change is a classic public good, with benefits that are non-exclusive (if one person benefits, we all do) and non-competitive (one person's enjoyment of a more natural climate regime in no way diminishes others' enjoyment of the same). Policy mechanisms to provide public goods can be either market-based or government-run, or some combination of the two. In the case of greenhouse gas reductions, market solutions in the form of cap-and-trade mechanisms have received much attention, due to their prominent role in the Kyoto Protocol. However, trading of forest-based carbon offsets presents several challenges, and other policy alternatives should also be considered.

Cap-and-Trade Programs and Offsets

Cap-and-trade is a flexible regulatory tool in which a maximum emissions allowance (cap) is set for regulated sources of greenhouse gases. The system then allows those sources to meet their cap either by reducing their own emissions, or by purchasing excess reductions or carbon sequestration offsets from others (trade). Marketed forest-based offsets face all of the same monitoring and measurement issues as voluntary registries described above. But in addition, once a carbon credit carries a market value and is legally equivalent to documented emissions reductions, two further issues rise to the fore—*additionality* and *permanence*.

Additionality refers to the certainty that a forest offset results in new carbon fixation, rather than simply subsidizing business as usual. Demonstrating additionality requires:

- A *baseline* against which new carbon stores can be measured. A projection of what would occur *over time* in the absence of project activities is the only acceptable baseline. Using a single pre-project quantity as a baseline might reward offset providers for sequestration that would have occurred in any case. Natural regeneration of abandoned farmland, for instance, could be used to offset continued fossil-fuel emissions, undercutting greenhouse gas reduction goals.
- Accounting for *leakage*, sometimes referred to as *secondary effects* or *displacement*. Leakage occurs when a project indirectly causes increased emissions outside the defined boundaries of the project itself. If an offset buyer pays to preserve forestland that is in imminent danger of paving over, for instance, but the development merely moves to a neighboring parcel, no net sequestration results. When exact measurements are impractical, leakage is often addressed by discounting, requiring that an offset seller fix more carbon than the quantity purchased in order to compensate for likely losses elsewhere.

Permanence is an issue because reduced emissions from a power plant or vehicle are by definition permanent. If fossil fuel remains unburned, the carbon it contains will never find its way into the atmosphere. If a sequestration project is to be considered fully equivalent to emissions reduction, it must fix carbon just as permanently. For forest offsets, permanence is complicated by the dynamic nature of ecosystems. Carbon stores ebb and flow during forest succession and with normal disturbance regimes, sometimes unpredictably in the case of fire, insect outbreak, or windthrow. However, permanence may be addressed through one of several mechanisms:

- Permanent easements on the land may impose a "lien" obligating the owner to maintain a guaranteed level of carbon stores indefinitely or for a contracted period of time.

- Offsets may be subject to a standard discount based on the risk of catastrophic carbon release.
- Offset contracts may be designed as short-term "leases," with payments made only so long as the carbon remains in place. When the contract expires, the buyer would need to replace this offset with an equivalent one.

In the absence of regulated markets, voluntary carbon trades are already occurring, with at least a dozen entities offering carbon offset services for a fee. Organizations are reducing or offsetting their "carbon footprint," and conferences are offering to offset attendees' air travel. The quality of such unregulated trades varies widely. It is tempting to see these voluntary trading systems as harmless, but they could establish misleading precedents for how a market might operate.

Other Policy Tools

It remains to be seen whether the issues with cap-and-trade systems can be resolved at a reasonable cost, allowing forest-based offsets to become tradeable commodities. In light of these uncertainties, we must also explore alternative policy options for increasing forest carbon stores. One approach to supplying public goods is for government agencies to produce them directly. For example, our national forests and other public lands might add carbon storage to the set of multiple uses they provide as a public service to the nation, through practices that accumulate carbon in old-growth forests, large woody debris, and forest soils.[4]

With 63 percent of our nation's forests privately owned, however, carbon-friendly management of public forestland will not be enough. A second policy approach would be for federal or state agencies to encourage private landowners to maintain or increase carbon stores through conservation payments channeled through the Wildlife Habitat Incentive Program (WHIP), Conservation Reserve Program (CRP), or Environmental Quality Incentives Program (EQIP). Such payments would help counter the tremendous financial incentives that favor forestry practices such as short rotations, high grading, and liquidation harvests, all of which yield maximum present value for timber while damaging long-term forest productivity and depleting carbon stores.

A third policy option is a sort of hybrid between a market and a public subsidy. Along with carbon markets, markets for wetlands, habitat, and water quality are emerging across the United States. Through these mechanisms, private restoration activities help mitigate damage from development activities. In the face of high transaction costs and low trading volume, some states use "in lieu fee" programs as an alternative to market trading, and these programs might offer viable models for forest carbon. In these programs, a state agency collects fees from those who damage wetlands, critical habitat, or water quality and uses the funds to finance restoration by private contractors, often accepting competitive bids. Similarly, a "no-net-loss" forest carbon policy could impose taxes or penalties on those who emit fossil-fuel carbon or release existing forest carbon stores, and use the revenue to subsidize increased forest carbon storage elsewhere. Already, Oregon requires new utilities to offset a portion of their carbon emissions, and many are purchasing offsets from The Climate Trust, a public-private entity that takes competitive bids from offset providers. Vermont's energy efficiency utility,

---

[4] The carbon cycle of naturally fire-prone forests needs more investigation. Forests that naturally burn frequently might accumulate less carbon in the understory and on the forest floor, but more in large fire-resistant trees and long-lived charcoal.

which offers assistance with efficiency investments financed through surcharges on utility bills, offers a similar model for a public-private solution.

Forest Carbon Controversies

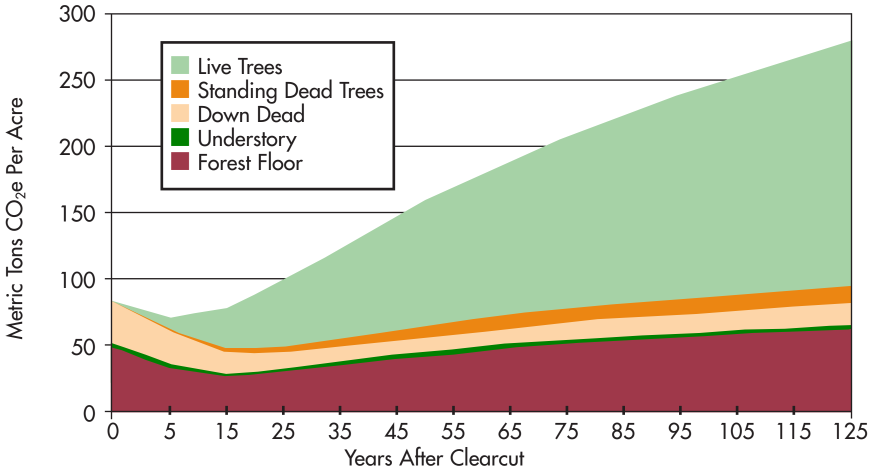
Before we launch into either trading of forest carbon offsets or subsidies to boost forest carbon, we should be certain that the measures we pay for deliver the promised reductions in greenhouse gases. The questions discussed below concern three strategies that are often proposed as forest-based global climate change solutions: managing for fast-growing young forests, increasing carbon stored in wood products, and increasing use of woody biomass fuels. Any of these strategies, if employed without considering their full carbon-cycle impacts, could actually reduce carbon stores instead of increasing them.

1: Does replacement of old, slow-growing forests with young, intensively managed plantations speed carbon sequestration?

Old forests represent large carbon sinks that need to be maintained as part of our nation's common infrastructure, much as we maintain our highways or our wetlands. Figure 7 shows the dynamics of carbon stores in a northeastern spruce-fir forest after an initial clearcut: an undisturbed forest continues to build new carbon stores well past a stand age of 125 years (the end point for this model though far short of the time required to create the complex structural conditions of old growth). Even though the rate of carbon sequestration may be faster in younger stands (the slope of the total carbon curve is steepest between 25 and 35 years post-clearcut), older forests do continue to add substantial carbon stores each year (the total carbon line is still rising rapidly at 125 years) and total carbon stored in the forest will be much higher with extended rotation ages. Under true old-growth conditions, windthrow and other natural disturbances will create patches of younger trees, but more carbon will likely be present in dead and downed material than would be found after commercial harvest. Additional research is needed to help us better understand carbon cycles under different forest types and management regimes.

FIGURE 7.

Non-Soil Forest Carbon, Northeast Spruce-Fir Stand



Data from Smith et al. 2006.

Moving beyond abstract models to practices on the ground, harvesting methods clearly matter. Single-tree or small-group selection—which removes slow-growing trees, releases well-established but suppressed potentially vigorous trees, avoids soil damage, and leaves a high volume of standing trees—may in fact increase both live and dead carbon stores within a few years post-harvest. Conversely, a heavy cut that promotes regeneration-suppressing brambles or ferns, or a harvest that releases soil and litter carbon through erosion or accelerates respiration due to intense exposure, will likely suppress carbon fixation for several years or even decades. For the forest modeled in Figure 7, forest floor carbon declines for 15 years and down dead carbon for 45 years after a clearcut; regrowth of live trees and replacement of standing dead trees is also slow in early decades. Total carbon present in all five pools actually drops below the severely depleted levels present after a clearcut (year 0) for more than 20 years after the harvest.

Conversion of natural forests to intensively managed plantations may likewise release soil carbon as a byproduct of cultivation, burning, and soil drainage, and fertilizers that get new crops of seedlings off to a rapid start may release nitrogen oxides that are greenhouse gases several times more potent than CO_2.

As Figure 5 illustrates, it is important to measure carbon system-wide, and not just in the forest itself. There would be no advantage to rapid carbon uptake by a young plantation if that carbon were quickly released once the trees were cut. Essentially each harvest shifts carbon from in-forest pools ("live vegetation" and "woody debris" pools in Figure 5—which continue to fix more carbon over time, though at a declining rate) to off-forest pools ("wood products" and "landfill" pools—which see slow, steady losses). To assess which strategy is more effective, it is important to track the whole system over time, including soil and dead biomass carbon in the forest and wood products outside the forest, which brings us to a second forest carbon controversy.

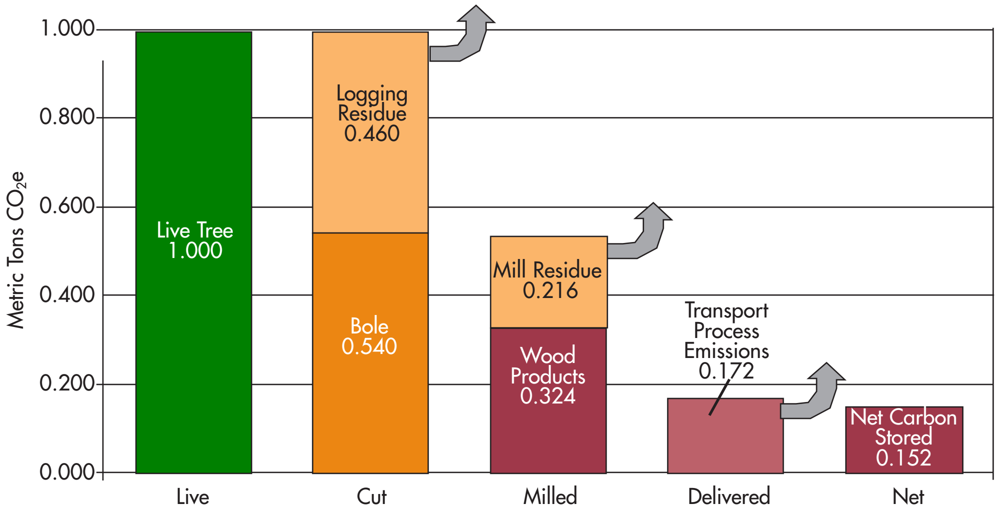
2: Does converting living trees into long-lived wood products increase carbon stores and reduce emissions?

Many forestland owners would like to operate their forests as carbon-fixation assembly lines, allowing trees to convert atmospheric carbon to wood, removing the live-tree carbon and storing it off-site, and releasing other trees from competition so that their growth and carbon storage rates increase. At face value, this claim seems convincing. However, a number of complexities underlie this simple explanation.

First, not all harvested carbon makes it into a finished wood product (Figure 8). Assume that a live tree containing 1 metric ton of CO_2e is cut (such a tree would contain about 0.27 metric tons of pure carbon or about 0.54 metric tons of dry material total). About 0.54 metric tons of CO_2e are in the bole, the portion transported to the mill (the exact proportion varies widely by region, forest type, and even market, and is generally lower in the Northeast). The remaining 0.46 metric tons CO_2e (the "harvest residue" flux in Figure 5 above) are left to rot and will do so fairly rapidly because they are stored in the smaller branches, leaves, and severed roots that now lie resting on or just under the forest floor. After passing through the primary mill and secondary processing facilities, ultimately about 60 percent of the bole, or 0.324 metric tons CO_2e, will be transformed into wood products. Like the logging slash left in the woods, the 0.216 metric tons of CO_2e in the slabs and sawdust will degrade fairly rapidly, likely either burned for fuel at the mill ("consumption" flux shown in Figure 5) or sold as garden mulch or animal bedding (part of the "wood products" pool in

FIGURE 8.

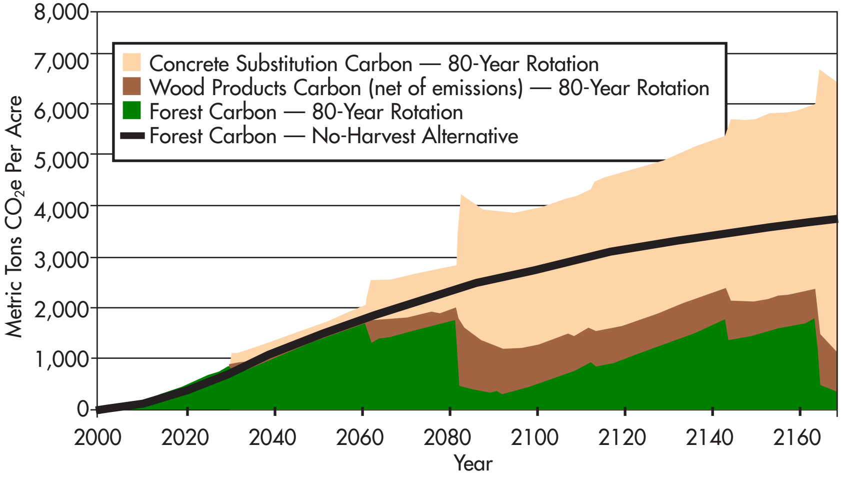
Fate of Carbon from Harvested Wood



Data from Smith et al. 2006 and Gower et al. 2006.

FIGURE 9.

Forest Ecosystem and Wood Products Carbon Under No-Harvest and 80-Year Rotation Alternatives



Adapted from Wilson 2006, data from Perez-Garcia et al. 2005.

Figure 5, but with a very short storage life). Emissions from both logging and mill residue take place over time, and the rate of release will vary with harvest methods, mill processes, and whether these parts of the tree decompose or are burned, but residence times in these pools are short relative to live trees or long-lived wood products.

Additional emissions of about 0.172 metric tons CO_2e result from harvest, transport, and processing,[5] mostly from burning of fossil fuels to run equipment, but also from less obvious sources like volatilization of finishes (the “processing” flux in Figure 5 should have an associated emissions flux to represent these costs of storing carbon in wood products). If burning of wood byproducts displaces fossil fuels in some processing and transport steps, as it does in many mills that use wood waste as an energy source, then this portion of emissions may be considered “carbon neutral” (see below, however, for some caveats). With losses at each step of the chain, the net gain in carbon stores may be little as 0.152 metric tons CO_2e—15.2 percent of the carbon originally stored in the live tree.

Depending on the type of wood product, carbon stores will continue to decay over time, with product half-lives ranging from 6 to 100 years (California Climate Action Registry 2007). If harvested wood products decay faster than standing or downed dead wood left in the forest (and the larger the tree, the slower the on-site decay), then harvesting wood is unlikely to increase carbon stores over time. Leaving trees to mature and die in place, making space and fertility for faster growth by their live neighbors, may in fact be a better carbon sequestration strategy.

Some of the most thorough research on wood products carbon has been conducted by the Consortium for Research on Renewable Industrial Materials (CORRIM), originally formed to analyze the life-cycle environmental impacts of wood compared to alternative building materials. Figure 9, developed by CORRIM researchers, provides one comparison of the “storage-on-the-stump” strategy with the “storage-in-wood-products” strategy. The figure shows projected carbon stores in a Pacific Northwest forest regenerated in the year 2000 under a no-harvest regime (black line) and an 80-year rotation with two thinnings (solid areas).

The no-harvest alternative (black line) clearly stores more carbon over time in the forest than the 80-year rotation. Under the harvested system, forest carbon (green area) fluctuates with standing timber volume, but never rises above 2,000 metric tons CO_2e per acre. Carbon in wood products (brown area) does accumulate over time, but slowly since many products decay by the end of each 80-year rotation.

---

[5] Gower et al. (2006) found that nearly 1 ton of CO_2e is released for each ton of wood products produced. One ton of wood products contains about 0.5 tons of carbon, or 1.8332 tons CO_2e. So processing of wood emits about 53 percent as much CO_2e as is contained in the end products. Figure 8 reflects these losses, as processing results in emissions of 0.172 metric tons CO_2e in order to produce wood products that store 0.324 metric tons CO_2e.

The storage-in-wood-products strategy appears superior only if benefits include the substitution of wood for concrete in construction (tan area). Concrete manufacturing releases vast amounts of CO_2e, due to both fossil fuel used for heat and carbon released by the chemical transformation of lime to make cement. As Figure 9 illustrates, substituting wood for concrete would reduce CO_2e emissions dramatically; conversely, if management to boost forest carbon stores reduces the availability of wood for construction, it could inadvertently cause more emissions if builders turn to concrete or fossil-fuel-based plastics as substitutes.

However, adding concrete substitution benefits to forest and wood products stores on a single graph implies that one hundred percent of the wood harvested will displace concrete, a highly unlikely scenario since only 17.9 percent of new U.S. homes in 2005 used concrete in above-ground applications where wood substitution would be possible (Portland Cement Association 2006). A forest landowner who reports carbon sequestration benefits due to concrete substitution as part of a registry or who offers an offset sale that includes those benefits would need to prove that substitution actually takes place.

Once processing emissions and verified materials substitution are accounted for, credit for wood products carbon increases may be claimed by only one link in the chain—a chain that extends from the owner of the forestland where carbon was originally removed from the atmosphere, to the wholesaler, retailer, builder, and home-buyer, all of whom can claim they have reduced emissions by choosing wood over cement, steel, or other greenhouse-gas-emitting material. If increases in wood products carbon stores are to receive market payments or public subsidies, ownership of the credits will need to be clarified to avoid double counting.

3: Is woody biomass a carbon-neutral fuel?

Another wood product often promoted for its carbon sequestration benefits is woody biomass fuel. Many argue that woody biomass is by *definition* a carbon-neutral fuel because growing trees once fixed all the carbon that is eventually released by burning. The critical issue for carbon neutrality, though, is not past sequestration of carbon embodied in fuels, but whether releases are offset by *future* carbon stores. After all, fossil fuels too embody previously sequestered carbon in amounts equal to that released through burning. If climate change policy aims to moderate *future* concentrations of greenhouse gases, we should choose our renewable energy technologies for their *future* impacts.

Those who claim that woody biomass is *by definition* a carbon-neutral fuel make an unspoken assumption that the forest/generator system is maintained in a steady state. In a steady state, the amount of CO_2 released by harvesting and burning biomass would equal the amount fixed by the source forest over a period of time sufficient for the harvested trees to regrow. As always, however, the devil is in the details. How much fossil fuel is burned to harvest, chip, and transport the fuel? How severely and for how long is carbon fixation suppressed due to the impact of mechanized harvesting? How quickly do leaves, needles, and small branches left on-site rot and release their carbon stores? How quickly does residual vegetation respond with a spurt of rapid new growth?

Woody biomass can indeed be managed as a relatively carbon-neutral fuel. Just as wood may be a better option than concrete for use in building construction, substituting wood for fossil fuel use can be an important component of a national policy to mitigate climate change. In particular, emerging cellulosic ethanol technologies promise better ratios of energy output to input than conventional ethanol. But acceptance of tradeable carbon offsets based on substituting woody biomass for fossil fuels, or government subsidies for these fuels justified by their climate benefits, must require *continued* management of the source forest to fully replace the carbon removed, burned, and released. Once fixed, that carbon must remain stored (as living and dead forest material or as long-lived wood products) or must continue to offset fossil fuels in energy production. Furthermore, processing emissions must be accounted for. At some point in the future, as fossil fuels cease to be the norm for generating electricity, the business as usual baseline will change and there will be no further justification for trading offsets or offering subsidies for woody biomass.

Aside from complete and long-term accounting, standards for defining carbon neutrality of woody biomass fuel should incorporate common sustainable forestry practices to avoid unintended negative consequences. Vigorous biomass chip markets could provide perverse incentives to manage for the lowest common denominator in wood value. Operators bent on speedy processing of massive volumes of generic biomass are unlikely to use careful crop tree selection or directional felling to avoid residual stand damage. The Forest Stewardship Council and similar third-party certification systems already favor protection of a full suite of forest values, and it would be relatively straightforward to add carbon-neutrality of fuels derived from forests to their standards.

Win-Win Forest Carbon Strategies: Restoration, Preservation, Sustainable Management

Given the difficulties with some proposals for boosting forest carbon, it seems prudent to support approaches that have few environmental drawbacks and many collateral benefits. Preventing forest conversion, replanting or restoring cleared or degraded forests, and lengthening rotations enjoy support from a wide variety of stakeholders, as these strategies also protect biodiversity, open space, water quality, remote recreation, and other increasingly threatened public values.

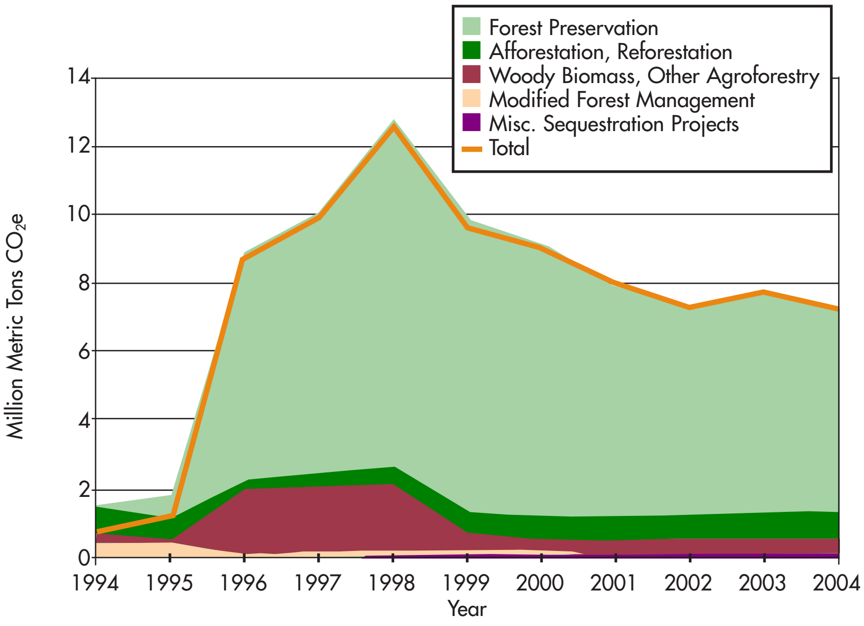
Forest preservation accounts for the great majority of carbon sequestration reported in DOE's 1605(b) registry, as Figure 10 shows. Registry guidelines permit preservation projects to claim 1/100th of the total CO_2e present in all carbon pools at the time of easement or fee purchase, plus report incremental carbon gains each year thereafter, so large quantities of sequestered carbon are registered immediately on project completion. Project sponsors must provide a permanent guarantee of forest cover through easements or other mechanisms, but are not required to prove that these lands would have been converted to other uses as strict additionality would require, so the CO_2 reductions attributed to forest preservation likely far exceed actual emissions reductions compared to a status quo baseline. However, where land conversion trends are well documented, this type of project provides tremendous potential for preventing carbon release due to forest losses.

Restoration—carbon sequestration through tree planting or regeneration (often called afforestation if land is naturally treeless or reforestation if temporarily cleared)—is the most easily documented means of boosting forest carbon stores, and the most commonly traded in the voluntary offsets marketplace. Eighty-three percent of the sequestration projects reported under the U.S. Department of Energy's 1605(b) program in 2004 involved tree planting (U.S. Department of Energy 2006). Figure 10 shows CO_2e sequestration reported to this registry in 2004; since reforestation project sponsors report the CO_2 sequestered in the reporting year, and tree-planting projects fix very little carbon in the early years, the large number of reforestation projects is not fully reflected in Figure 10.

Many reforestation projects are sponsored by electric utilities, which view forest offsets as a viable low-cost strategy to cope with coming climate change regulation. For example, two large-scale riparian forest restoration efforts sponsored by electric utilities have replanted bottomland hardwoods in the lower Mississippi River Valley. UtiliTree Carbon Company, founded by Edison Electric Institute and 41 utilities in 1995, has replanted 1,000 acres so far (some overseas) with a goal of sequestering 3 million metric tons of CO_2e. PowerTree

FIGURE 10.

Sequestration Projects Reported to U.S. Department of Energy



Data from U.S. Department of Energy 2006.

Carbon Company, formed by 25 power companies and several NGO partners in 2003, has spent $3.4 million to replant 3,600 acres and fix 2 million metric tons of CO_2e. Many of the "retail" carbon sequestration opportunities offered to individuals who want to offset personal carbon emissions also fund tree-planting programs. In the absence of national regulations, the quality of these programs varies tremendously. Valid reforestation offsets must include long-term verification that trees are alive and continue to grow.

Carbon sequestered through changes in forest management is perhaps the most difficult form of forest carbon enhancement to document, but it also holds great promise for secondary benefits to wildlife, water, and recreation. According to the North East State Foresters Association (2002), "management strategies that encourage larger trees, employ harvest methods that reduce waste and damage to residual trees, and minimize soil disturbance during harvest all improve carbon sequestration activities." The Pacific Forest Trust (Gordon 2006) estimates that "if managed over longer rotations [northeastern forests] can accumulate significantly more carbon, perhaps as much as 20 more tons (67 metric tons CO_2e) per acre. Neil Sampson (2004) estimates that improved forest practices such as longer rotations and higher stocking could increase CO_2e by 0.3 to 4.6 metric tons per acre per year in U.S. forests. Longer rotations could temporarily reduce wood supply and promote a shift to carbon-intensive substitutes, and this effect would need to be carefully monitored. But over time, harvest volume from such forests would recover and could even increase.

Potential for New Collaborations

As high fossil fuel use is the ultimate cause of human-induced global climate change, the ultimate solution depends upon reduced use of those fuels through energy efficiency and renewable substitutes. Given our addiction to oil, coal, and natural gas, however, that transition will be costly and time-consuming, and restoring forest carbon stores can help buy time. A national policy to enhance forest carbon stores offers an opportunity for collaboration among unusual allies—regional, national, and international environmental NGOs; small woodlot owners; the National Forest system; forest ecologists; and foresters, logging contractors, and the wood products industry. These groups have a shared interest in moderating climate change, protecting forestland from conversion, understanding the dynamics in natural forest systems, maintaining timber stocks in working forests, and promoting use of long-lived wood products.

Because of this congruence of diverse interests, forest carbon sequestration will likely be an important part of an emerging national climate change policy for the United States. Yet if forests are to make a significant and lasting contribution, and if we are to avoid unintended damage to other natural processes and values, it is critical for both accounting systems and policy measures to be designed with great care. We need improved carbon monitoring techniques, at both national inventory and project levels. Then we should begin to test and study forest sequestration with projects that provide broadly acknowledged secondary public benefits and few possible drawbacks. Overall, we need to keep forests as forests, restore them to a state of health, and manage them to maintain high volumes of above- and belowground carbon. As an added bonus, these measures will help promote a more resilient forested ecosystem, better able to withstand the climate changes that have already begun.

Literature Cited

Birdsey, R., K. Pregitzer, and A. Lucier. 2006. Forest carbon management in the United States: 1600-2100. *Journal of Environmental Quality* 35:1461–1469.

California Climate Action Registry. 2007. *Forest Sector Protocol.* Available from http://www.climateregistry.org/PROTOCOLS/FP/. See Table 5.2.

Gordon, J.C. 2006. *Forests of the Northeast: A Global Opportunity*. Working paper for Northeast forest carbon meeting. Pacific Forest Trust.

Gower, S.T., A. McKeon-Ruediger, A. Reitter, M. Bradley, D. Refkin, T. Tollefson, F.J. Souba, Jr., A. Taup, L. Embury-Williams, S. Schiavone, J. Weinbauer, A.C. Janetos, and R. Jarvis. 2006. *Following the Paper Trail: The Impact of Magazine and Dimensional Lumber Production on Greenhouse Gas Emissions.* Washington, D.C.: The H. John Heinz III Center for Science, Economics and the Environment.

North East State Foresters Association. 2002. *Carbon Sequestration and Its Impacts on Forest Management in the Northeast.* Available from http://www.nefainfo.org/publications/carbonsequestration.pdf.

Oak Ridge National Labratory. *Global Carbon Cycle 1992-1997.* Oak Ridge, TN: Carbon Dioxide Information Analysis Center. Available from http://cdiac.ornl.gov/pns/graphics/c_cycle.htm.

Pacific Forest Trust. 2007. *Setting the Record Straight: Examining the Real Role Forests Play in the Climate Change Equation.* Available from http://www.pacificforest.org/news/index.html#RealRoleofForests.

Perez-Garcia, J., B. Lippke, J. Comnick, and C. Manriquez. 2005. An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. *Wood and Fiber Science 37* (CORRIM Special Issue):140-148.

Portland Cement Association. 2006. Concrete homes increase market share in 2005. Press release, November 13, available from http://www.cement.org/newsroom/market_share110906.asp.

Sampson, N. 2004. *Carbon Offsets–Agriculture and Forestry.* Alexandria, VA: The Sampson Group.

Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2004. *Forest Resources of the United States, 2002.* U. S. Department of Agriculture, Forest Service, General Technical Report NC-241. St. Paul, MN: North Central Research Station.

Smith, J.E., and L.S. Heath. 2006. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004.* USEPA Publication #430-R-06-002. Washington, D.C.: U.S. Environmental Protection Agency. See land use change and forestry and related sections, Chapter 7 and Annex 3.12.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* U.S. Department of Agriculture, Forest Service, General Technical Report NE-343. Newtown Square, PA: Northeastern Research Station.

Stavins, R. N., and K. R. Richards. 2005. *The Cost of U.S. Forest-Based Carbon Sequestration.* Arlington, VA: Pew Center on Global Climate Change.

Stoddard, M. D., and D. K. Murrow, Derek K. 2006. *Climate Change Roadmap for New England and Eastern Canada.* Rockport, ME: Environment Northeast.

U.S. Department of Agriculture. 2000. *Summary Report: 1997 National Resources Inventory (revised December, 2000).* Natural Resources Conservation Service and Iowa State University Statistical Laboratory. Available from http://www.nrcs.usda.gov/TECHNICAL/NRI/1997/index.html. See Table 5.

U.S. Department of Energy. 2006. *Voluntary Reporting of Greenhouse Gases, 2004 Summary*. Washington, D.C.: Energy Information Administration, Office of Integrated Analysis and Forecasting. Available from www.eia.doe.gov/oiaf/1605/vrrpt/summary/index.html.

U.S. Environmental Protection Agency. 2007. *Inventory of Greenhouse Gas Emissions and Sinks, 1990-2005.* Washington, D.C.

Wilson, J. 2006. Using wood products to reduce greenhouse gases. Presentation at Wood Science and Engineering Seminar, Oregon State University, CORRIM and Oregon State University, April 5.

COVER PHOTOS:
Top: Hearts Content Scenic Area, Allegheny National Forest, Pennsylvania. Globally, forest losses account for nearly one-quarter of greenhouse gases released due to human activities. Efforts to reduce our climate impacts need to include protection for forest carbon stores like those in this rare eastern old-growth stand.
Photo by Donald L. Gibbon

Left: Fossil fuel combustion is the primary source of excessive greenhouse gases in the atmosphere, and coal-fired power plants are still on the increase.
Photo: Corbis Images

THE WILDERNESS SOCIETY

Ann Ingerson
ann_ingerson@tws.org
The Wilderness Society
P.O. Box 15
Craftsbury Common, VT 05827
(802) 586-9625

Printed on
recycled paper
using soy inks.