CHAPTER 8

Mitigation Activities in the Forest Sector to Reduce Emissions and Enhance Sinks of Greenhouse Gases

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International Negotiations to Stabilize Greenhouse Gases

In June 1992, representatives from 172 countries gathered at the "Earth Summit" in Rio de Janeiro to discuss environmental issues. The United Nations Framework Convention on Climate Change (FCCC) was adopted to achieve ". . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." The nonbinding goal of the Convention was "to return emissions of greenhouse gases to their 1990 levels by the end of the decade." The United States responded to the FCCC in 1993 with the "Climate Change Action Plan," a collection of about 40 individual programs covering emissions reductions, energy efficiency, and productivity enhancements including forestry activities.

At the first Conference of the Parties to the FCCC in 1995, it was concluded that voluntary commitments were inadequate and would not be met by most developed countries. Negotiators then agreed to the need for specific limits on greenhouse gas emissions beyond the year 2000. The U.S. position on mitigation of greenhouse gas concentrations was clearly stated at the second Conference of the Parties in 1996. Three elements were seen as necessary for ratification of a treaty: 1) realistic and binding targets; 2) flexibility in implementation; and 3) the participation of developing countries.

The third Conference of the Parties, held in Kyoto, Japan, in December 1997, produced an agreement known as the "Kyoto Protocol" that contained the first two elements: 1) binding targets, and 2) flexible implementation. The U.S. President promised to negotiate an amendment to the agreement covering the participation of developing countries prior to submitting the agreement to the Senate for ratification. Under the terms of the agreement, the United States is bound to reduce emissions of greenhouse gases 7 percent below 1990 levels by 2008-2012. This is a substantial reduction given that emissions are expected to rise substantially during this period due to population growth and economic expansion. Various countries and groups of countries have different reduction targets (and increases in some cases).

The role of forestry and land use change has been controversial throughout the international negotiation process. There are different opinions around the globe on whether forestry activities should be counted or not. A country's position depends on factors such as whether their forests are currently or prospectively a net source or sink for carbon dioxide (CO_2), whether carbon (C) stock changes in forests can be measured and verified, and the relative emphasis that should be placed on reducing emissions versus increasing sequestration. Some countries expressed concern that forest responses to "natural" factors such as increased atmospheric CO_2 (which may increase growth) would allow a country to claim credit for greenhouse gas reductions that are not associated with specific activities.

The Kyoto Protocol attempted to reconcile the diversity of viewpoints on land use change and forestry. According to article 3.3 of the Protocol, land-use change and forestry activities that can be counted toward the emissions reduction target include afforestation, reforestation, and deforestation since 1990 if the changes in stocks can be verified. According to most interpretations of the Kyoto Protocol, forest management activities alone are not sufficient to allow an area of forest to count toward the emissions reduction target. Article 3.4 provides an opportunity for nations to propose including additional activities such as forest management. The agreement does include sustainable forest management as part of a general statement supporting sustainable development and protection and enhancement of sinks.

The language, terminology, and accounting methods contained in the agreement are somewhat vague, and can be interpreted in different ways. Definitions of key terms such as "reforestation" are not stated, which becomes a problem for implementation because there are many different definitions in use throughout the world. The proposed accounting system is vague. For example, it is not clear whether harvested timber should be counted as a forest sink and if so, under which circumstances it could be counted.

To address these issues, the FCCC asked the Intergovernmental Panel on Climate Change (IPCC) to establish an expert panel to develop a special report on the land use change and forestry provisions of the Kyoto Protocol. That group reviewed definitions, accounting issues, and activities that could potentially be included within the terms of the Protocol, and documented the various options for eventual reconciliation during the ongoing Conferences of Parties.

This chapter addresses options in the United States forestry sector to reduce emissions of greenhouse gases and to increase the rate of carbon sequestration in forest ecosystems. We summarize the various options that have been proposed in the literature, review the methodologies used to analyze options and compute baseline estimates, evaluate the potential for implementing various options and the expected changes in emissions or sequestration, and review costs and other considerations in implementing mitigation policies.

Summary of Forestry Options to Reduce Emissions or Enhance Sinks

Numerous forestry options to mitigate atmospheric buildup of CO_2 have been proposed. These options are categorized below according to whether their primary or direct effect is on emissions reduction, sink enhancement, or a combination of emissions reduction and sink enhancement. Each of the options has indirect effects so that the three categories are not mutually exclusive. For example, forest management activities not only affect C storage in forest ecosystems, but affect the kind of products that may be produced from harvested wood, which in turn impacts energy use in two ways: 1) burning of byproducts to substitute for fossil fuel, and 2) substitution of wood products for similar products that use different amounts of energy in the production process (Marland et al. 1997).

Emissions Reduction

Reducing emissions is the most direct way to stabilize greenhouse gas concentrations in the atmosphere. Activities involving trees and forests may also achieve emission reductions indirectly, for example, by substituting one product for another, or by reducing demand for energy. In this section we identify the various forestry options for reducing emissions and the logic behind their potential inclusion as part of a comprehensive accounting for greenhouse gas sources and sinks.

Substitute Wood Products for More Energy-Intensive Products

Some wood products used in construction can be manufactured with less energy than non-wood substitutes such as aluminum and concrete (Skog et al. 1996). To the extent that such substitution is practical and economic, an increase in these wood products and a corresponding decrease in their substitutes reduces energy demand and associated emissions. The effectiveness of product substitution is based on a number of factors such as relative costs of inputs and elasticity of demand.

Reduce Demand for Energy in Growing Timber, Harvesting, and Wood Processing

Energy is used in establishing plantations, managing forests, harvesting timber, and manufacturing wood products. Efficiency of energy use can be increased through engineering at each step in the manufacturing process. Adoption of more energy-efficient practices depends on economic evaluation (U.S. Congress, Office of Technology Assessment 1991).

Reduce Biomass Burning (Wildfires)

Protecting forests from wildfire maintains standing biomass or allows biomass to increase. In some cases, particularly in the Western United States, fire protection has resulted in overstocked stands and large amounts of biomass in dead and dying trees, posing a substantial risk of catastrophic wildfire or other natural disturbance such as an insect or disease outbreak (Sampson and Clark 1996). Both the long- and short-term consequences of fire protection must be considered in evaluating this option.

Sink Enhancement

Sink enhancement technologies are designed to offset emissions by storing more C in forest ecosystems and wood products. Because much of the forest area in the United States is managed for timber products on recurring cycles of harvest, regeneration, and growth, there are opportunities to increase the average amount of standing biomass while still producing wood products. The harvested C that ends up in wood products and landfills is usually counted as an addition to the total amount of C sequestered. During the manufacturing process, wood waste that is burned for energy is sometimes counted to the extent that wood fuel is substituted for fossil fuel.

Afforest Marginal Cropland and Pasture

Conversion of cropland and pasture to forest, either by tree planting or natural afforestation, usually increases the amount of C stored in biomass and soils relative to the previous land use (Sampson and Hair 1992). If the new forestland is managed for wood products, then the disposition of C in wood products, byproducts, and landfills must also be considered.

Reduce Conversion of Forestland to Nonforest Use (Reduce Deforestation)

Conversion of forestland to nonforest use usually means loss of all or a substantial part of live biomass and reduction of organic matter in soils and the forest floor (Houghton 1996). CO_2 and other greenhouse gases are emitted when the removed biomass and organic matter are burned or decomposed. Some C may be sequestered for a time in wood products if the removed biomass is utilized. When part of a mitigation strategy, controlling deforestation is sometimes referred to as protecting/conserving existing forests (Matthews et al. 1996).

Improve Forest Management

There are opportunities to improve C storage by changing silvicultural practices on certain sites and forest conditions (Sampson and Hair 1996). The magnitude of increased C storage may be difficult to quantify since silvicultural practices are usually developed and applied for another purpose such as increasing timber growth and will not necessarily increase biomass growth. Nevertheless, some forest stands may not be growing at biologically potential rates because of severe overstocking or understocking, and these stands offer the best opportunities for enhanced C storage. Also, silvicultural practices may be designed to maximize the amount of C eventually stored in harvested wood products.

Reduce Harvest

The effectiveness of reducing harvest depends on temporal and spatial considerations. Reducing harvest can cause a short-term increase in the amount of C stored in forests because losses of C to the atmosphere during the removal of biomass and wood processing are avoided (Heath and Birdsey 1993). In contrast, over the long term, a continuous cycle of harvest, efficient utilization of biomass, and regrowth can sequester more C than not harvesting (Sampson and Hair 1996). The analysis should also address imports and exports between regions and countries since reduced harvest in one region may be offset by increased harvest elsewhere (increased imports) or by changes in wood processing technology.

Increase Agroforestry

Agroforestry can add biomass to otherwise low-biomass agro-ecosystems. It can also reduce the need to clear forestland for agriculture (Schroeder 1993). These C benefits can accrue along with increases in crop yields.

Combined Emissions Reduction and Sink Enhancement

Some technologies have potential to both reduce CO_2 emissions directly and enhance C sinks. Both effects must be analyzed to evaluate the potential contribution to greenhouse gas reduction.

Substitute Renewable Biomass for Fossil Fuel Energy

Short-rotation woody biomass crops may be grown specifically for energy reduction. When biomass is grown sustainably and used to displace fossil fuels, net C emissions are avoided since the CO_2 released in converting the biomass to energy is sequestered in the regrowing biomass through photosynthesis (Rinebolt 1996). Biofuels may be substituted for fossil fuels especially in the pulp and paper industry, which has access to waste biomass produced during manufacturing. There is not a one-to-one substitution because of differential conversion efficiencies and unpredictable energy markets.

Increase Proportion and Retention of C in Durable Wood Products

After harvest, forest C passes through a series of conversion processes to yield wood products and byproducts (Row and Phelps 1996). Maximizing the amount of C in products through efficient utilization of raw material, increasing the use of byproducts for energy substitution, and ensuring that unused byproducts are disposed in sealed landfills will minimize the amount of CO_2 emitted (see Skog and Nicholson this volume). Increasing the life of products in use may result in less new timber harvested for replacement products, which would affect C storage in biomass.

Increase Paper and Wood Recycling

Recycling wood fiber and wood products may reduce CO_2 emissions in two ways: 1) by reducing the area harvested to provide virgin fiber, and 2) by using less energy to convert recycled products versus growing, harvesting, and processing virgin fiber (Skog et al. 1996). Paper recycling is already common. Most solid wood products are currently disposed of in landfills and debris dumps and not recycled. Model estimates are used to quantify effects of recycling.

Plant Trees in Urban and Suburban Areas

Trees affect urban climate by shading, reducing wind, and evapotranspiration (McPherson and Rowntree 1993; Nowak 1993). Proper placement of trees and use of the correct tree species reduces the energy needed to heat and cool residential and small commercial buildings, with the magnitude of the energy reduction dependent on the local climate.

The U.S. Climate Change Action Plan

The U.S. Climate Change Action Plan (CCAP—Clinton and Gore 1993) was unveiled in October 1993 following several conferences to suggest and evaluate options. The plan's objective was to reduce greenhouse gases to 1990 levels by the year 2000 using cost-effective domestic actions. The plan consisted of nearly 50 individual actions affecting all significant greenhouse gases and all sectors of the economy. The plan was to be implemented voluntarily with $1.9 billion in new and redirected funding. Although the plan has failed to meet its goal because of strong economic growth, low energy prices, and funding shortfalls, the individual actions proposed in the plan were tried and evaluated, and the plan provides a basis for continuing efforts that are likely to become more important as the greenhouse gas problem worsens.

The plan included two domestic forestry actions to increase sinks (Moulton 1996). "Reduce the depletion of nonindustrial private forests" targeted poorly managed forests to ensure regeneration after harvest and maintain adequate stocking through landowner assistance programs. Cost was estimated at $4 million through 2000 for an expected emissions offset of 4.0 Tg C. "Accelerate tree planting in nonindustrial forests" was designed to increase tree planting by 233 thousand acres per year over the historical average of 2.5 million acres per year. This action was administered under the Forest Service Stewardship Program and was expected to cost $71 million through 2000. The amount of C sequestered by 2000 was expected to be a modest 0.5 Tg. The short time horizon makes tree planting appear to cost much more per Tg than reducing the depletion of forests. The amount sequestered from tree planting will increase substantially after 2000 because newly planted trees do not sequester C at a high rate until they are well established and have reached a fast growth stage.

The plan also included two domestic forestry actions to both increase sinks and directly reduce emissions. "Accelerate source reduction, pollution prevention, and recycling" included increased paper recycling, which both protects forest C by reducing harvest and reduces emissions because less energy is required to use recycled fiber versus virgin fiber. Including the non-forestry components, this action item was expected to cost $86 million through 2000 and reduce greenhouse gas emissions by 5.0 Tg C. "Expand cool communities program in cities and federal facilities" is based on strategic tree planting and lightening surfaces on buildings to reduce air conditioning energy use. The "Cool Communities" pilot program founded by EPA and American Forests would be expanded to 250 cities and communities and to 100 Department of Defense bases and other federal facilities. This activity was expected to cost $12 million through 2000, reduce greenhouse gas emissions by 4.4 Tg C, and sequester 0.5 Tg C in trees.

These four forestry actions continue to be part of the U.S. plan as described in the recent "Climate Action Report" (U.S. Department of State 1997). None of the actions achieved their original goal because the required funding was never made available.

An important international component of the CCAP is "Joint Implementation." Joint implementation allows U.S. and foreign partners to collaborate in meeting their obligation to reduce greenhouse gas emissions or increase sinks. These collaborative projects can sometimes achieve reductions more cost-effectively than if each country acted alone. For example, it may be less expensive to plant trees in a developing country, and the trees may grow faster than in some parts of the United States. There are many additional benefits to joint implementation such as sharing of technology, encouraging private sector development, and methodology evaluation.

Another international component of the CCAP is the U.S. Country Studies Program. This program is designed to: 1) enhance the ability of countries and regions to inventory emissions and sinks, and evaluate mitigation and adaptation responses; 2) enable countries to develop, implement, and monitor policies and measures; and 3) share information (Dixon et al. 1996).

Participation in the CCAP has been voluntary, with level of participation related to government incentives delivered through funded programs. Other incentives such as consumer preference are just beginning to be a factor. The U.S. Department of Energy sponsors a program called "Voluntary Reporting of Greenhouse Gases" that is developing the methodology and technology to collect and process data on the accomplishments of participants. There were 142 reporters in 1996 representing over 900 individual projects. Most participants have been electric utilities, although 20 percent are non-utilities.

The CCAP represents a first step by the United States to implement greenhouse gas mitigation activities. Although the CCAP has not met its goals, its implementation demonstrates that it is feasible to implement a program of emissions reductions or offsets and establishes partnerships to facilitate voluntary participation by consumers, companies, and non-federal government agencies.

Methodology for Estimating Mitigation Potential

Generally, analyses of forestry mitigation options attempt to determine the magnitude of expected gains in C sequestration and emissions reduction. Options help determine whether proposed activities are both biologically feasible and socially acceptable. The analyses must include sufficient detail at the national level so that policies can be evaluated with respect to societal concerns such as long-term trends in forest resources, economics of supply and demand, impacts on traditional and nontraditional forest products, energy tradeoffs, and land use changes.

The approach most often used to evaluate the mitigation potential of forestry activities involves analytical models that estimate the net effects of biological and social responses to implementation of a policy or activity. The expected C gains are estimated as a relative difference from "business as usual" or "baseline" scenarios. Integrating the biological and social components is critical for determining that the net effect of an activity is "additive," that is, a true departure from the expected baseline not including the activity.

In many mitigation studies, the complexities of ecological systems are represented in a highly simplified way based on observed data from inventories and ecosystem studies and from productivity estimates from a variety of forest growth models. Ecological process models that address the carbon cycle at large spatial scales (see Joyce et al. this volume; Bachelet et al. this volume) have not yet been fully integrated into mitigation analyses because they are usually validated for potential or equilibrium vegetation rather than managed or disturbed forest ecosystems, the subject of most proposed mitigation activities.

The complexities of social systems may be represented in several ways. Econometric models reflect past behavior as documented in historical data (see Mills et al. this volume). Past programs that were designed to implement forestry policies are often included as "case studies." Economic behavior can also be modeled by explicit optimization processes in markets (see later discussion of FASOM model).

The accounting system is a critical part of evaluating the various options (see Heath and Smith this volume). The accounting system should be comprehensive and include both positive and negative impacts on C. A comprehensive accounting system will be representative of the true impact of an activity on the concentration of atmospheric CO_2, whereas a partial accounting system may give misleading results. Comprehensive accounting is always difficult because of the many interactions among activities that preclude simple one-to-one estimation of additivity or substitution. The term "leakage" is often used to describe the difference between the direct effect of an activity on expected C, and the direct plus indirect effects that may occur through interactions.

Defining the scope or domain of the analysis is critical for quantifying the potential for mitigation. The critical domains are temporal, geographical, and sectoral. Temporal scale is important because activities that make sense in the short term may not make sense in the long term. For example, a short-term strategy of reducing timber harvest will increase C in forests for a few years but decrease C in wood products over the longer term. Also, there is increasing (cumulative) probability of damage from pests or fire as forests age, such that an event or series of events could result in large releases of C. The geographic scope is critical to addressing leakage because activities in one area (or country) may provoke an opposite (or reinforcing) action in another area. For example, reducing timber harvest on NFS lands in the Pacific Northwest may increase timber harvest from other regions (Adams et al. 1996b; Martin and Darr 1997).

Selecting which economic sectors to include and how to analyze outcomes across sectors may be the most complicated problem for addressing leakage. For example, increasing the use of biomass for fuel does not necessarily produce an equivalent reduction in the use of fossil fuels because energy markets are complicated globally and not driven completely by supply and demand economics (see Skog and Nicholson this volume; U.S. Congress, Office of Technology Assessment 1991).

Estimating the gains and losses in C associated with various options is also complicated by lack of data. For example, the impacts of forest management on soil C are poorly understood except in a few specific cases (see Heath and Smith this volume).

Finally, the interactions among various activities should be considered in a policy package. Different options may conflict or produce unintended consequences. For example, harvesting more timber to increase C in wood products is inconsistent with reducing harvest to maintain higher levels of C in forests. Both of these activities would have consequences for the nation's timber supply.

FORCARB and Forest Sector Models

The FORCARB model has several purposes: to estimate past, current, and prospective C storage and changes in C storage in U.S. forests and forest products; to simulate alternative policy options for enhancing the role of forests and forest products as C sinks; and to estimate how environmental change might affect C storage in forests and forest products (Plantinga and Birdsey 1993; Birdsey et al. 1993; Heath et al. 1996). FORCARB is one of a cluster

Table 8.1—Comparison of projected area changes for private timberland in the United States, from the TAMM/ATLAS/AREA CHANGE (T/A/A) and FASOM models, 1990 and 2000 decades (thousand acres). The afforestation, reforestation, and deforestation rates are on an annual basis. The private timberland total is as of the end of the decade.

	Afforestation		Reforestation		Deforestation		Total private timberland	
Decade	T/A/A	FASOM	T/A/A	FASOM	T/A/A	FASOM	T/A/A	FASOM
1990	1441	1674	4825	8022	1960	780	347,100	352,467
2000	558	916	5643	5293	936	710	344,000	354,529

Source: The projections are from baseline runs of two models: the TAMM/ATLAS/AREA CHANGE set is from the 1993 RPA Assessment Update (Haynes et al. 1994) and the FASOM projection is from a December 1997 run.

of integrated models of the forest sector that has been enhanced to evaluate global change effects on forests and wood products and to evaluate mitigation and adaptation strategies (Adams and Haynes 1996; Joyce et al. 1997). This integrated modeling system is used to simulate the effects of environmental changes on productivity, forest type transitions, harvesting, natural disturbance, timber production, and C storage. The system includes socioeconomic models used to conduct national assessments required by the Resources Planning Act (RPA). The socioeconomic models provide estimates and projections of human activities such as land use change and timber harvest that have major impacts on the status of forest vegetation.

The FORCARB model has the strength of national-scale, multi-sectoral analysis with sufficient representation of ecosystems, regions, ownerships, and management intensities to enable detailed analysis of options within a national policy context. A limitation is lack of linkage with the energy sector, so that energy inputs and outputs cannot be directly considered. The temporal domain is limited by the current model configuration that simulates future inventories about 50 years into the future.

FASOM Model

The Forest and Agricultural Sector Optimization Model (FASOM) described by Mills et al. (this volume) has been applied to examine the private forest management, land use, and market implications of terrestrial C sequestration policies (Adams et al. 1996a). The FASOM model uses the same empirically based timber yields from the ATLAS model as does TAMM and other forest sector models to which FORCARB is linked. While the models are similar in other regards, one key difference when examining policy options is that the FASOM model can estimate optimal land use and forest management investment in the context of mitigation strategies. This complements the positivistic approach of the TAMM system of models. A comparison of current and projected land use changes between FASOM and the TAMM system is presented in table 8.1.

When examining mitigation strategies involving forestry, increasing the area of forests and enhancing the productivity of existing forests are typical options to increase sequestration of C in forests and forest products. Many past studies have examined policy impacts of changing land use between forestry and agriculture. These studies typically have either: 1) ignored spillovers between sectors, or 2) simply "added up" impacts across the two sectors, ignoring feedbacks or interactions through the markets for land. To examine forest C sequestration policies while considering intersectoral competition for land, FASOM has both land use and forest management investment as endogenous decisions (Alig et al. 1997).

FASOM lacks linkage with the energy sector, so that energy inputs and outputs cannot be directly considered. The temporal domain is limited by computer resources, available data and assumptions, and policy interest.

Examples of Special Studies

American Forests, a nonprofit institution, organized two extensive studies addressing forests, global change, and mitigation options: increasing the area and growth of forests (Sampson and Hair 1992) and forest management opportunities (Sampson and Hair 1996). These studies brought together experts in many disciplines to evaluate options and provide guidance to public and private landowners for implementing opportunities for mitigation through forestry activities.

The U.S. Environmental Protection Agency has sponsored a series of studies that compared different models of mitigation options for U.S. forest and agricultural land (e.g., U.S. Environmental Protection Agency 1995a, 1997). These studies addressed scenarios of tree planting on marginal crop and pasture land; conservation reserve and wetlands reserve programs; increased use of recycled paper; reduced harvest on National Forest land; increased use of biomass energy; modified agricultural tillage practices; and increased use of winter cover crops.

The U.S. Congress, Office of Technology Assessment (1991) examined a suite of technical and policy measures to reduce greenhouse gases and determined that emissions of CO_2 could be reduced to as much as 35 percent below 1987 levels. Forestry activities comprised 10 percent of the reductions and included tree planting, increasing productivity, urban forestry, and use of trees for biomass energy.

The World Resources Institute studied U.S. forestry strategies to slow global warming (Trexler 1991). A mix of practices similar to the Office of Technology Assessment study was recommended.

The Baseline Carbon Budget for U.S. Forestland

The "baseline" carbon budget refers to long-term trends in forest carbon storage using economic assumptions from the RPA Assessment (Haynes et al. 1995), in the absence of major forestry policy changes or changes in forest productivity or species distributions as a consequence of climate change. Long-term historical timber volume data converted to C estimates show that increases in biomass and organic matter on U.S. forestlands from 1952 to 1992 added 281 Tg C/yr of stored C to forest ecosystems, enough to offset 25 percent of U.S. emissions for the period (Birdsey and Heath 1995). Baseline projections using FORCARB show additional increases of approximately 183 Tg C per year in forest ecosystems through 2040 (fig. 8.1). The projected baseline includes forest policies in effect at the time the projections were made; in particular, reduced harvest levels on National Forest lands, decreases in clearcutting and increases in partial cutting practices, and continuation of federal cost-share programs at recent historical levels. Since that time, funding for cost-share programs was decreased.

The comprehensive baseline estimates are used as the forestry component of the "Inventory of Greenhouse Gases and Sinks" compiled annually by the U.S. Environmental Protection Agency (1995b). The EPA inventory includes forest C in living biomass, wood products, and landfills, and focuses on annual estimates beginning in 1990. The three forest components comprise an estimated annual sink of 125 Tg C for each of the years from 1990 through 1992. If C in the forest floor, coarse woody debris, and soils were added, the average annual estimate for 1990–1992 would be doubled to approximately 250 Tg C. These estimates do not include changes in Alaska, Hawaii, Puerto Rico, or U.S. Territories.

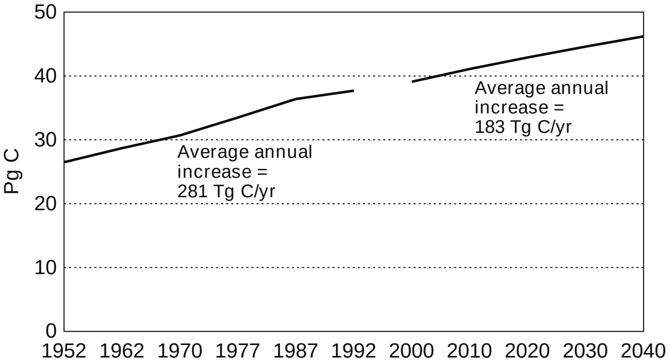

Figure 8.1—Past and prospective C storage for forests in the conterminous U.S. (from Birdsey and Heath 1995).

An earlier study converted 1987 forest area and volume statistics to carbon in standing biomass using simple models. Birdsey (1992a) concluded that U.S. forest trees were accumulating C at an annual rate of 461 Tg C, that removals from timber harvesting and land clearing totaled 355 Tg C, and that the annual net gain of C in live and standing dead trees totaled 106 Tg. Turner et al. (1995) used a similar approach but modeled some ecosystem components differently, particularly woody detritus. They estimated an annual accumulation of C in forest biomass of 331 Tg C, removals of 266 Tg C, and a net annual gain of 79 Tg C.

There are significant regional differences in past and projected C storage (fig. 8.2). These differences reflect variation in species composition and growth, as well as long-term changes in land use, management intensity, and harvesting practices. Millions of acres of forests in the Northeast have regrown on abandoned agricultural land, causing a steep historical increase in C, including a substantial buildup on C-depleted soils. As these regrowing forests mature, the rate of C buildup is expected to slow substantially. The historical pattern is similar in the South Central states, but the more intensive utilization of southern forests for wood products has already leveled past gains in C as growth and removals have come close to balancing. In the Pacific Coast states, C stocks are expected to increase after a recent decline, mainly due to reduced harvest projections as more forestland has been reserved from timber production.

The Kyoto Protocol (article 3.3) establishes a partial accounting system for forestry and land use change. The comprehensive forestry baseline would be changed to account only for forestlands that have been or will be affected by reforestation, afforestation, and deforestation since 1990. Forestry activities such as management and protection on lands not affected by one of these three activities would not be counted unless added under article 3.4. Since there is not yet agreement on interpreting the language, definitions, and accounting methodology of the Kyoto Protocol, it is impossible to calculate a new forestry baseline. The forestry baseline may change in several ways as illustrated in figure 8.3; however, the eventual baseline will likely be different from any of these as the interpretation of the Protocol evolves and partial accounting methods are implemented.

The alternative baselines in figure 8.3 are compared to the comprehensive baseline that accounts for all forestlands and all activities, as presented in Birdsey and Heath (1995). The first alternative accounts for the effects of reforestation, afforestation, and deforestation since 1990, with the important exception that the disposition of C in wood harvested prior to reforestation is ignored. Reforestation is defined broadly to include clearcut and partial cut harvesting followed by forest regeneration. The second alternative differs from alternative 1 by including the disposition of C in harvested wood. It is therefore a more complete accounting of the true impact of activities since 1990. Harvested wood that is burned for energy is counted as a source of C to the atmosphere and therefore deducted from the C sink estimate. The third alternative includes only afforestation and deforestation.

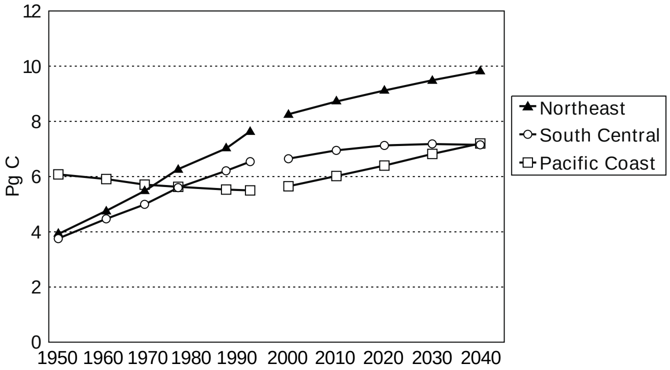

Figure 8.2—Past and prospective C storage for selected regions. Trends reflect land use history: maturing forests on reverted agricultural land in the Northeast; intensified timber utilization on reverted agricultural land in the South; reduced harvesting of old-growth and emergence of reforested areas in the Pacific Coast (from Birdsey and Heath 1995).

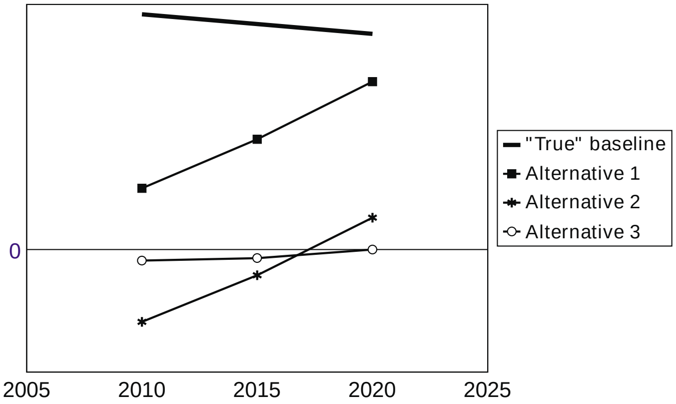

Figure 8.3—Illustrative simulation of several forest baselines from different interpretations of the Kyoto Protocol are compared to the "true" baseline that accounts for all forestlands and all activities. The first alternative accounts for the effects of reforestation (defined as broadly as possible), afforestation, and deforestation since 1990, with the important exception that the disposition of C in wood harvested prior to reforestation is ignored. The second alternative differs from alternative 1 by including the disposition of C in harvested wood and is therefore a more complete accounting of the effects of activities since 1990. Harvested wood that is burned for energy is counted as a source of C to the atmosphere and therefore deducted from the C sink estimate. The third alternative includes only afforestation and deforestation. The scale of the Y-axis is intentionally omitted.

Evaluation of Selected Mitigation Options

In this section we evaluate several mitigation options defined earlier as either sink enhancement or combined sink enhancement and emissions reduction. We do not evaluate options that are primarily intended to reduce emissions.

After a forest C baseline is established, the incremental effect of mitigation options can be evaluated relative to the baseline. The accounting system should include the effect of the activity on all C pools even if outside the forest sector. For example, C changes associated with deforestation should account for C retained in soils and biomass of the new land use. The studies reviewed here have not all used consistent ecological and economic assumptions and C accounting methods, and no attempt has been made to adjust reported estimates to a common basis. Nevertheless, the potential of some elements of a U.S. program to enhance forest C sinks are identified and their approximate costs established.

Afforest Marginal Cropland and Pasture

A large pool of non-forestland in the United States could be converted to forest to sequester additional C (Moulton and Richards 1990). Not all of the land that could support trees would be available, and the infrastructure may not be in place to provide seedlings for all available land. Large afforestation programs must be accompanied by increased nursery capacity. Additional technical assistance must also be provided to deliver

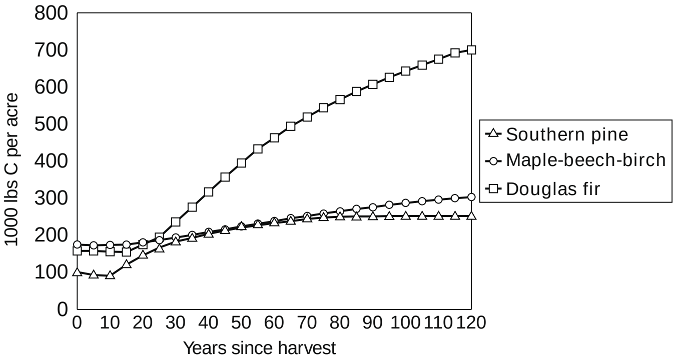

Figure 8.4—Comparison of C yields for several common forest types after a clearcut harvest: southern pine plantation on a good site in the South; maple-beech-birch forest in the Northeast; Douglas fir on a good site in the Pacific Coast (from Birdsey 1996).

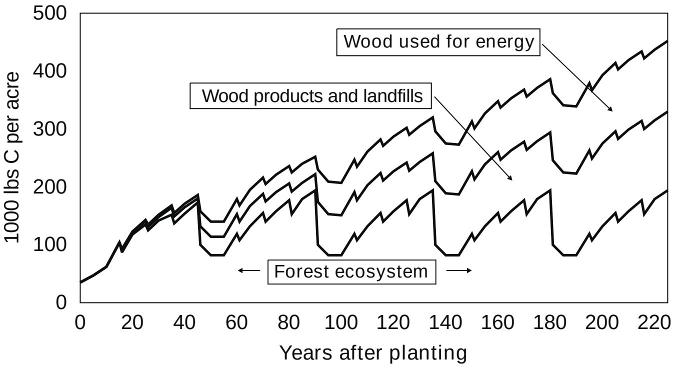

Figure 8.5—Pattern of C storage in a loblolly pine plantation managed for wood products over a long time period, including C in wood products and landfills (from Birdsey 1996).

planting programs effectively to landowners. Baseline projections by forest sector models already include substantial afforestation and reforestation amounts (table 8.1), so capacity and technical assistance issues would need to be addressed if additional afforestation efforts are directed specifically at forest C sequestration.

There is a time lag between tree planting and significant increases in C storage. Seedlings take several years to become established, and accumulation of biomass is low until trees reach sufficient size (leaf area) to fully utilize the "growth potential" of the site. As planted stands age, their growth rises, peaks, and then declines in a predictable pattern. The details of this pattern vary markedly by species, region, management regime, and potential catastrophic events such as fire, insects, and disease (fig. 8.4). For a one-shot afforestation program, aggregate C flux of the plantation would follow the pattern of the selected species. If timber stands are harvested for wood products and regenerated repeatedly over a long period of time, a sustainable pattern of increases and decreases of C in the forest becomes apparent (fig. 8.5). There is an accumulation of C in wood products and landfills over time as long as inputs to these pools exceed losses through decomposition. If wood used for energy is also counted, there is a further gain due to the substitution of wood energy for fossil fuel energy. Figure 8.5 illustrates the effect of a one-to-one substitution of wood energy for fossil fuel energy, an upper bound unlikely to be achieved when conversion efficiency and market effects are considered.

Many studies have estimated potential gains in C storage from afforestation. Moulton and Richards (1990) estimated that offsetting U.S. emissions by 10 percent (about 160 Tg C) would require about 71 million acres at an average cost of $12/ton of C or $1.7 billion/year. The U.S. Congress, Office of Technology Assessment (1991) estimated that a tree planting program on 3.5 million acres/year over 20 years would attain a net C flux increase of 30 Tg C/year by the end of the 20-year period. The annualized cost of this program would be about $35/ton C. Using estimates of C storage by age class for different forest types and conditions, Birdsey (1992b) estimated that converting 22 million acres of marginal cropland and pasture in the South to forest would eventually increase C accumulation by about 32 Tg C/year. Parks and Hardie (1995) estimated that converting 22 million acres of land to forest would increase C accumulation by 44 Tg C/year and cost $21/ton C.

These studies did not include effects of increased supply of timber on the forest sector, which may partially offset C gains by reducing prices and increasing quantity demanded. Parks and Hardie (1992) used FORCARB and forest sector models to develop two reforestation scenarios and compared the results with a base run (Heath and Birdsey 1993; U.S. Environmental Protection Agency 1995a). Planting was phased over a 10-year period from 1991–2000, and projections run through 2040. Most planting was expected in the South Central and North Central United States. The average annual increase in C flux (including C in wood products and landfills) over a 50-year period was projected to be 7.5 Tg C for a 0.7 million acres/year program costing $110 million/year, and 14.3 Tg C for a 1.2 million acres/year program costing $220 million/year. These are the direct costs associated with tree planting and payment of subsidies.

Projections using FASOM show that a 28 million-acre program (among other sector adjustments) costing an average $18 per ton C could produce an annual flux increase of 39 Tg C. Costs in this case are estimated as changes in social welfare. FASOM projections suggest that efforts to expand forest C flux should have a rather different geographic and species focus than that proposed in past studies. In contrast to both Moulton and Richards

(1990) and Parks and Hardie (1995), FASOM projections suggest a greater emphasis on hardwood species in minimum cost strategies. Hardwood area increases under all C targets (Adams et al. 1999). Some of this increase involves direct conversion of softwood to hardwood forests after harvest, but most derives from reductions in rates of hardwood-to-softwood conversion relative to the base case.

For some C policy scenarios, FASOM simulations indicate that the bulk of the projected afforestation and management changes should occur in the North, mostly in the Lake States region. This is an area of large concentrations of hardwood forests in which hardwood stands can yield significant rates of C uptake. Although the FASOM model recognizes the rapid growth potential of afforested stands in the South just as in previous studies, broader measures of costs and inclusion of welfare trade-offs across markets and regions act to partially shift the minimum cost solution away from the customary prescription of pine plantations on marginal Southern agricultural lands.

Opportunities for afforestation on nonindustrial private forestland are at least several times higher than recent historical rates. From 1994 to 1996, the U.S. private area planted annually to trees averaged about 2.28 million acres. As discussed earlier, there are tens of millions of acres where tree planting is biologically and financially feasible, especially on non-industrial private forestlands (Alig et al. 1990b; Vasievich and Alig 1996). In the FASOM projections a portion of those eligible acres are targeted for tree planting, particularly over the next two decades. For mitigation policy analysis, a key question is how many of the eligible acres are likely to be planted without any form of government assistance, and how much assistance would be required to induce additional plantings. If these opportunities were pursued, additions to forest C would be substantially higher than under the rates of afforestation projected in line with recent trends by the TAMM system (Haynes et al. 1994).

For large-scale afforestation programs, possible side effects include economic impacts from market dynamics (e.g., compensating land use changes from forestry to agriculture). Such effects can have significant influences on costs of C sequestration (Alig et al. 1997; Adams et al. 1999). Large-scale land use conversion could significantly alter opportunity costs in terms of foregone production from other land use alternatives (Alig et al. 1997). This may act to increase forest sequestration program costs and reduce C sequestration relative to that suggested in static or single sector studies (e.g., Moulton and Richards 1990; Parks and Hardie 1995).

FASOM simulations point to a somewhat different tree planting program than past experience indicates, suggesting more emphasis on hardwood species in the North and less emphasis on softwood species in the South. This finding based on a fuller accounting of opportunity costs highlights the need to carefully plan the implementation of any new C sequestration program by monitoring and re-evaluating economic conditions in the forestry and agricultural sectors.

Reduce Conversion of Forestland to Non-forest Use (Reduce Deforestation)

Approximately six million acres of non-federal forest in the United States (contiguous 48 states) were converted to urban and developed uses between 1982 and 1992 (U.S. Department of Agriculture, Natural Resources Conservation Service 1996). Another 6 million acres of forest were converted to agriculture and other uses. Further deforestation due to growth in urban and developed land is projected over the next several decades (table 8.1), as the United States is expected to add another 100 million people by 2050. Policy options for shifting land from agriculture to forestry for C sequestration must be viewed within the dynamics of land markets and historical trends in land use shifts. A combination of bio-physical, ecological, and socio-economic forces influence the amount of land allocated to major land uses and forest cover types in the United States. Population is the major factor influencing land use dynamics and the conversion of forestland to developed uses (Alig and Healy 1987).

Forest protection or conservation may also be included in this category of activities (Matthews et al. 1996). It may be difficult to determine whether a specific conservation project is truly a C offset activity if it is unclear whether the implementation of the project is due solely to a mitigation strategy, or would have occurred anyway (Brown 1998). Careful attention to identifying the factors included in the baseline calculation is needed to ensure that claims of C changes are truly relative to the baseline conditions.

Improve Forest Management

Timberland in the United States amounts to 490 million acres and includes a diversity of ownership objectives, forest types, site productivities, and stand conditions (Powell et al. 1994). There are opportunities to sequester additional C on some portions of this large area of forest. Of particular interest are opportunities to increase the density of trees on non-stocked or poorly stocked forestland, and to apply silvicultural treatments to stocked forestland so as to increase the average biomass per unit area. The changes in forest management intensity may be relatively small, but by affecting millions of acres of forestland, their aggregate effects may be large (Adams et al. 1999).

Many silvicultural practices are designed to increase the production of growing-stock volume in certain species. Gains in C storage are not necessarily proportional to gains in growing-stock volume because unmerchantable trees will also accumulate C, because stocking will increase naturally in poorly stocked stands, and because some management practices may remove biomass or disturb the site, resulting in loss of stored C. An analysis of broad management practices by major region and forest type in the United States concluded that strategies to maximize C accumulation should include: 1) converting poorly stocked forestland by clearing and regenerating only if current productivity is well below average; 2) applying intermediate stand treatments (thinning or timber stand improvement) only if the current stand is overstocked to the point of stagnation; and 3) managing for longer rotation lengths (Birdsey 1992c).

Including the value of C along with timber value changes the optimal economic rotation (Plantinga and Birdsey 1994; van Kooten et al. 1995). Both theoretically and in several case studies, the optimal rotation length increases if the benefits of C are counted. Harvest age was also found to change in FASOM projections in patterns that vary by species. For softwoods, rotations lengthen over all periods. Hardwood rotation changes are mixed and may, in some cases, involve reductions in both the near and long term.

Hair et al. (1996) summarized management opportunities for U.S. forests based on two comprehensive studies. They noted how timber and C yields varied significantly by management intensity. They concluded that managing plantations by means of timber harvest is the most effective way to achieve substantial and continual increases in C storage. Biological opportunities exist to increase timber growth (regeneration and stocking control) by 8.6 billion cubic feet on 202 million acres of timberland outside National Forests (Alig et al. 1990a; Vasievich and Alig 1996). Rates of return of 4 percent or more were available on almost half of these acres. Translating these potential gains in timber volume into gains in C storage is uncertain because of the variety of practices on many different species and sites, and because C gains are not proportional to timber volume gains. Nevertheless, Vasievich and Alig (1996) made a rough estimate that implementing the economic opportunities on timberland would yield gains in C storage of approximately 140 Tg C/year in vegetation, wood products, and offset fossil fuel C. Comparable gains from the biological opportunities were estimated as 190 Tg C/year.

Reforestation, defined as regeneration of forestland after harvest, may be natural or artificial (planted) in the United States. The definition of reforestation becomes synonymous with forest management for partial harvesting, a practice becoming more common in the United States since clearcutting has been reduced in the face of public opposition. Using U.S. Forest Service forest inventory statistics, W. Brad Smith (personal communication) estimates that between 1980 and 1990, 9.8 million acres/year were harvested, 62 percent by partial cutting methods. On National Forest lands, the area clearcut declined from 243,000 acres in 1984 to 133,000 acres in 1993. The area partially cut increased from 555,000 acres to 600,000 acres during the same period. At present, no studies have estimated how changes in harvesting and reforestation practices would influence C budgets at the national scale.

Conversion of mature or old-growth forest to young forest, which may have a faster growth rate, will reduce C storage until the harvested C remaining in products and landfills, plus additional C in the forest ecosystem from renewed growth, reaches the pre-harvest level. This may take 200 years or more in the case of old growth (Harmon et al. 1990).

Marland et al. (1997) analyzed the effects of forest management on C in forest ecosystems, wood products, energy substitution, and product substitution. Results of their model (GORCAM) suggest that over long time periods, sustainable management for forest products on highly productive sites will yield a larger C offset than simply protecting the forests intact. They note the difficulty of estimating the magnitude of the substitution effects, and of attributing the C offset to particular projects because the indirect effects of any given project are spread widely and are likely to be partly claimed as a credit elsewhere.

Reduce Harvest

Reducing the area harvested can cause an immediate short-term increase in the amount of C stored in forests because losses of C to the atmosphere during the removal of biomass and processing are avoided. On average, only about half of the live biomass is removed from the site, while logging debris (leaves, twigs, branches), stumps, roots, and unmerchantable biomass is left behind to several fates: decompose, transfer to another C pool (e.g., litter or soil), or become part of the new stand of trees (Birdsey 1992a). Of the biomass that is removed, about 35 percent ends up in durable products or landfills (based on removals since 1900 and historical patterns of utilization and disposal), while the remainder is burned for energy or emitted to the atmosphere (Heath et al. 1996; Skog and Nicholson 1998). Combining the estimates of on-site and off-site losses, less than 20 percent of the forest biomass ends up in long-term storage after harvest, and the remainder may be emitted to the atmosphere. Avoiding this loss by reducing harvest can be a short-term strategy to sequester additional C; however, over the long term, a continuous cycle of harvest, efficient utilization of biomass, and regrowth can sequester more C than not harvesting since the accumulation of C in the forest will eventually slow or stop, while it is possible to accumulate C in wood product and landfill pools for a very long time (Row 1996).

The effects of reduced harvest on C storage are evident in the estimated past and prospective C flux for National Forest lands (fig. 8.6, Birdsey and Heath 1995). High rates of harvesting in the 1970–1990 period caused emissions of 50 Tg C/year or more, while the significantly reduced harvest of the 1990s, if sustained, will cause a prolonged addition of C to National Forest lands, more than 80 Tg C/year. In the unlikely event that all harvesting were stopped in the United States, public and private timberlands could sequester an additional 328 Tg C/year over a 50-year projection (Heath et al. 1993).

Reduced harvest in one ownership category or region may be offset by increased harvest elsewhere, by substitution of energy-intensive non-wood products for wood products, or by changes in wood processing technology. Depending on the exact response, apparent gains in overall C storage may be lessened. The U.S. Environmental Protection Agency (1995a) concluded that reducing National Forest harvest by 21 percent would be fully offset by increased harvest from private timberlands and increased imports. Adams et al. (1996b) concluded that reduced harvest on public lands in the West could be largely offset by substantial private forest investment and increased harvest on private lands in the South. Martin and Darr (1997) found evidence for increased imports from Canada as a consequence of reduced National Forest harvest; but they also found inconclusive evidence for substitution of nonwood products or increased harvest on private lands.

Substitute Renewable Biomass for Fossil Fuel Energy

Large quantities of wood are available for fuel from different sources: 1) residues or byproducts of wood product manufacturing; 2) roundwood not normally removed from timberlands during commercial harvest; 3) trees from "nonforest" areas such as fence rows and urban areas; and 4) roundwood (growing stock) customarily used for wood products (Rinebolt 1996). In addition to these existing sources, short-rotation woody crops could be established specifically for biomass production on marginal cropland and pasture (McCarl et al. in press). Current average dry biomass yields are approximately 5 tons/acre/year, with higher rates attainable (Wright and Hughes 1993).

The U.S. Congress, Office of Technology Assessment (1991) estimated that a program to plant about 1.25 million acres of biomass plantations per year for 20 years would eventually produce 30 Tg C/year of harvestable biomass. Estimating the potential C offset from use of this biomass is complicated by the uncertain availability of land, the relative conversion efficiencies of biomass and fossil fuel, and the actual displacement of fossil fuel by biomass. The OTA study estimated that about half of the harvested C would offset fossil fuel C. Wright and Hughes (1993) estimated that the conversion efficiencies of wood and coal to electricity are the same (33 percent), and that the net C offset averages 2.33 tons/ha/year for an average biomass production of 6.3 dry tons/ha/year.

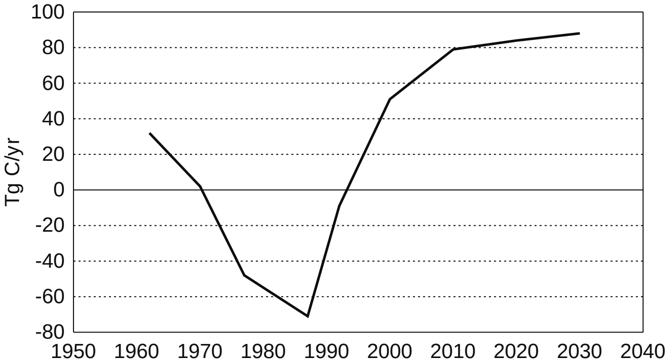

Figure 8.6—Past and prospective C flux on National Forest lands. Trends reflect high levels of harvest in the 1970s and 1980s, then a reduction in harvest in the 1990s resulting from legal and administrative requirements. Harvested C remaining in wood products and landfills is not included (from Birdsey and Heath 1995).

Increase Proportion and Retention of C in Durable Wood Products

Knowledge of the disposition of harvested C is a critical component of evaluating forest carbon sequestration activities (fig. 8.5). The eventual disposition of wood and paper products in landfills should be included along with retention rates for products in use. Micales and Skog (1997) estimated that only 30 percent of the C from paper and almost none of the C from wood is ever emitted as landfill gas.

Heath et al. (1996) estimated that of the 10.7 Pg C harvested in the United States since 1900, 35 percent remained in products and landfills, 35 percent was burned for energy, and 30 percent was emitted to the atmosphere without producing energy for consumption. Heath et al. (1996) estimated that the current average net flux of C into products and landfills is about 37 Tg C/year, with 50 Tg C/year burned for energy or emitted. Skog and Nicholson (1998) estimated that, since 1910, 2.7 Pg C have accumulated and currently reside in wood, paper products, dumps, and landfills. Skog and Nicholson (1998) estimated that the 1990 rate of sequestration in wood and paper products, and dumps and landfills, was 61

Tg C/year. Harmon et al. (1996) estimated that of the 1.7 Pg C harvested from Oregon and Washington from 1900 to 1992, 23 percent is currently stored, primarily in structures and landfills. These estimates vary according to assumptions about historical patterns of harvest and product manufacturing, and disposal and retention rates in landfills and dumps.

Improved utilization of removed biomass could reduce losses of C to the atmosphere. For example, if the percentage of C in wood products were increased by 50 percent, the annual C storage in products would increase by about 10 Tg C, while the other disposition categories (landfills, wood burned for energy, and emissions) would each be reduced by about 3.5 Tg C/year (Heath et al. 1996).

Increase Paper and Wood Recycling

Increased recycling of wood products may have two effects: 1) keeping the C sequestered in usable products longer and 2) reducing the timber harvest. The U.S. EPA sponsored an analysis of recycling that concluded that each ton of recycled paper increased forest C sequestration by 0.73 tons (U.S. Environmental Protection Agency 1997). This estimate was derived from a cluster of U.S. Forest Service models including FORCARB and associated economic models of the pulp and paper industry. Another study estimated that rapidly increasing paper recycling to 45 percent of total fiber used would sequester an average of 10 Tg C/year (Heath and Birdsey 1993).

Plant Trees in Urban and Suburban Areas

Urban and suburban trees store C and can reduce energy use in buildings if the correct species are properly placed. Rowntree and Nowak (1991) estimated that urban areas in the United States have an average tree cover of 28 percent and store an average of 27 tons/ha. McPherson and Rowntree (1993) estimated that a single 25-foot tall tree can reduce annual heating and cooling costs of a typical residence by 8 to 12 percent, which both saves money and avoids the use of energy generated with fossil fuels.

Nowak (1993) concluded that planting an additional 100 million urban trees and maintaining them for 50 years would cumulatively store approximately 75 Tg C in biomass and offset 275 Tg C due to energy conservation. This is an annual average of 7 Tg C over the 50-year period. The rate of sequestration would be very low for the first two decades and higher toward the end of the period as the trees reach maturity (more than 10 Tg C/year). Assuming a cost of planting and initial tree maintenance of $5–25/tree (McPherson 1994), such a program would cost from $50 to $250 per ton of C after several decades.

Verification

Sequestered C may eventually have monetary value, be traded like other commodities, and be counted as an offset to C emissions in international treaties to limit greenhouse gas emissions. Therefore claims of C sequestration as a consequence of an activity must be accurate and verifiable. There must be internationally accepted ways to measure or estimate the gains and losses of C associated with specific activities. Estimates must reflect the true difference from a baseline that has resulted from a specific C sequestration activity.

Verification of attainment in increasing C storage requires an estimation and reporting system. The easiest way to estimate C gains at the national scale or for individual forestry projects is to measure the stocks of C at the beginning and end of a period of time. Unless expensive measuring equipment is used, 5–10 year periods are needed to measure changes in tree biomass. Soil C changes even more slowly, and both pool sizes and changes in pool sizes are more difficult to measure than tree biomass.

The net exchange of C between the ecosystem and the atmosphere can be measured over very short periods (minutes) using CO_2 flux measurement towers, but the equipment is expensive and the towers have been installed only under specific site conditions. Currently, estimates from a limited network of CO_2 flux towers are used to validate the regional and local estimates from forest inventories.

Birdsey (1996) estimated C storage by age class and ecosystem component for the major forest types in the conterminous United States, divided into nine regions. The estimates included the C stored in live trees, understory vegetation, litter and other organic matter on the forest floor, coarse woody debris, soil, and timber removed from the forest. The estimates cover 120 years beginning with the regeneration of clearcut timberland, cropland, or pasture. Carbon yield tables are reported for natural forest types and plantation species that are harvested and regenerated, and for pasture or cropland that is planted with trees or allowed to revert naturally to forest. Different site productivity classes and management intensities are included for some regions. All of the estimates represent expected regional averages for different vegetation classes (e.g., by forest type and past land use).

Carbon yield tables can be used to analyze the expected effects of specific activities outside the context of economic or policy models. The tables provide the basis for estimating changes in C storage in forests that would result from reforesting marginal crop and pasture land and increasing timber growth on timberland. The impacts of two of the action items in the President's plan for

Table 8.2—Estimated costs of forest carbon targets from various studies.

Study	Annual flux increase Tg C/yr	Land shift: agriculture to forests Million acres	Average cost: undiscounted carbon $/MT	Average cost: discounted carbon $/MT
Adams, et al. (1998)[1]	39	28	18	37
Moulton & Richards (1990)	23	9	9	—
	45*	21	10	—
Parks & Hardie (1995)	44*	22	12	—
	88	—	22	—
Richards, et al. (1993)[2]	44*	—	—	25
Adams, et al. (1993)	29	—	3	—
	56	50	7	—

[1] The forest carbon target scenario based on FASOM projections by Adams et al. (1999) involves a gradually rising carbon flux over a 100-year projection period, relative to the FASOM base case. The base case involves an increase in carbon flux of 1.25 gigatonnes per decade between the 1990 and 2000 decades, and a declining (but positive) rate thereafter. Other targets (not shown here) that require large near-term carbon flux increments have sharply higher costs than those that defer increases to later periods.

[2] Values estimated from figures for a 7.8 billion short ton program over 160 years. Costs vary with assumptions on discount rate, agricultural land demand elasticity, and agricultural land availability.

Source: This table is adapted from Adams et al. (1999). Scenarios with roughly equivalent average annual flux increment relative to base indicated by *.

reducing greenhouse emissions were estimated with C yield tables: 1) reducing the depletion of nonindustrial private forests and 2) accelerating tree planting in nonindustrial private forests (Clinton and Gore 1993). On the individual scale, guidelines for voluntary offsets proposed by the U.S. Department of Energy (1994) include tables similar to those that appear in Birdsey (1996).

Costs of Mitigation Policies

Recent national-level economic studies have examined the costs of attaining high rates of C storage to offset emissions (Moulton and Richards 1990; Adams et al.; 1993, Parks and Hardie 1995; Richards et al. 1993; Sedjo et al. 1995; Adams et al. 1999). In most of these studies, the sole vehicle for expanding C flux is the afforestation of agricultural land.

One of the earliest national-level studies that examined opportunities for mitigation activities in forestry was that by Moulton and Richards (1990) of the costs of reforestation and forest management for various levels of investment. They concluded that a maximum program level of $20 billion could offset about 56 percent of 1990 U.S. emissions (about 756 Tg C). The cost/ton of C would be about $10 for a 5 percent offset (67 Tg C) and about $18 for a 30 percent offset (405 Tg C). Cost estimates by Parks and Hardie (1995) are higher than those of Moulton and Richards (1990) in part because the former employ a smaller landbase. However, both studies do not consider interactions with existing forest inventories and markets; Parks and Hardie only consider afforestation options, while Moulton and Richards do include changes in management of existing forest.

Cost estimates with the FASOM model are generally higher than those from Moulton and Richards (1990) and Parks and Hardie (1995). Average costs per ton of C sequestered projected by the FASOM model are as large as twice those in the earlier studies (see table 8.2). This is due to rigid flux targets specified explicitly over time, recognition of intra- and intersectoral reactions to market changes, and inclusion of consumer impacts in welfare accounting (Adams et al. 1999). Costs are estimated as economic welfare losses in markets for forest and agricultural products. An example of the market-based considerations is the case of the C-target scenario projected with FASOM by Adams et al. (1999) that involves a gradually rising C flux over a 100-year projection period, relative to the FASOM base case. The base case involves an increase in C flux of 1,250 Tg C per decade between the 1990 and 2000 decades and declining (but positive) rates thereafter. Other targets that require large near-term C flux increments have sharply higher costs than those that defer increases to later periods.

FASOM-based findings of higher costs reflect, in part, the markedly different nature of the modeling approach. Earlier studies have generally focused on the process of shifting land from agriculture to forestry. The reckoning of costs has been limited to direct government payments to producers (for planting and rent subsidies) using a fixed schedule of agricultural land rental values. FASOM costs are net changes in surpluses in both agricultural and forest markets for consumers as well as landowners/producers, rent schedules are dynamic because of explicit product markets, and land may shift in both directions.

Another major departure from past studies is the inclusion of consumer-side impacts in FASOM cost accounting. Because of the linkage of the two sectors in the FASOM model, imposition of a flux target leads to countervailing land use and management responses in both sectors. From the cost perspective of earlier studies (that is, direct conversion and rent subsidy payments to agricultural land owners to afforest), recognition of these reactions could reduce the C gain for any given subsidy expenditure. For example, if afforested agricultural lands can ultimately be harvested, a land shift would raise agricultural land rents while lowering future forest products prices. This, in turn, would reduce both the incentive to maintain levels of forest management investment and to retain lands in forest cover rather than shifting them to agriculture (see Sedjo et al. 1995 for a similar discussion). Less intensive management or more forest-to-agriculture land movements would reduce the flux effects of the initial response. Ignoring these reactions, as in previous studies, would lower the apparent cost of the strategy.

FASOM cost results may also be higher than past studies because of the strict nature of the flux constraints. Previous work has focused mostly on afforestation or planting, accepting whatever flux time path that might result. While it is generally implied that policy “targets” are increases in average annual flux over some projection period, the length of this period is not always specified. And if the analysis allows harvest, the disposition of plantations after the first rotation is often not clear. The FASOM constraints eliminate this flexibility with attendant increases in costs. The FASOM projections do account for the storage of C in wood products after harvest, in contrast to the earlier studies. Storage in wood products can be substantial and warrants analysis of linked forest growth and harvest options.

Alternative approaches to estimating carbon sequestration costs determine how landowners actually respond to changes in net returns to forestry and agriculture (Plantinga 1997; Stavins 1996). Subregional studies (e.g., multi-county area) indicate that earlier studies may overestimate true costs of a carbon sequestration program due to failure to account for private non-market benefits from forests; however, costs may be underestimated due to failure to account adequately for option values and asymmetric information. Empirical results indicate that factors which tend to increase costs, such as option values, are more important than factors such as consideration of private non-market benefits that decrease program costs (Plantinga 1997).

Other Considerations in Policy Formulation

In addition to impacts on social costs, policy-induced land use changes may have other effects that should be considered in mitigation policy formulation. These include: 1) land use shifts to meet policy targets need not be permanent; 2) implementation of land use and timber management changes in a smooth or regular fashion over time may not be optimal; and 3) primary forms of adjustment to meet C policy targets involve shifting of land from agriculture to forest and more intensive forest management in combinations varying with the C policy target (Alig et al. 1997).

The benefits of sequestering C derive from elimination or reduction of potential damages resulting from future climate changes. Because there are likely to be lags between changes in C emissions, modifications in the climate, and effects on forests, it may be prudent, as part of a comprehensive review of policy options, to consider actions that entail large reductions in net emissions in the near term. In addition to the area drawn into the forest base through afforestation, obtaining these reductions could also involve changes in management practices on existing forests (such as rotation age) and altered intensities of management in future plantations on existing forestland or afforested areas.

Most previous studies have emphasized the physical changes and associated costs of forest C sequestration strategies. The studies have given little attention to the actual policy mechanisms or programs that might be required to implement the mix of actions indicated for a particular C flux target. This is a significant issue in that the costs or complexity of administering an otherwise ideal plan may preclude its use. Further, C cost estimates are frequently based on the normative assumption that landowners will accept the compensation for converting their land to forest (Plantinga 1997). Such compensation rates are assembled from a variety of data sources and often represent averages over broad geographical areas. The compensation rates do not account for some factors that may influence the decisions of landowners, including option values, private non-market benefits, and asymmetric information.

Analysis of forest C sequestration in the recent past has focused heavily on the impacts of expanded afforestation. Simulations of an array of specific intertemporal C sequestration targets using the FASOM model (Adams et al. 1999) suggest it may be cost-effective to supplement afforestation with other management changes. This is particularly so when policies require large increments in sequestered C in the near term. In these cases, rotation ages of existing softwood stands may be lengthened and new plantations employ a higher level of management input or intensity. Policies seeking more gradual increases in sequestration over the long-term, in contrast, rely more heavily on afforestation and a somewhat lower level of management input to these plantations.

A key long-term aspect of successful programs to shift land from agriculture to forest cover is the retention and condition of afforested areas. Empirical studies suggest that such afforestation plantations are retained at high rates over 10–15 years or longer, often exceeding 80 or 90 percent. These results have been consistent across the Soil Bank Program (Alig et al. 1980), the Agricultural Conservation Program (Kurtz et al. 1980), Forestry Incentives Program (Kurtz et al. 1996), and the Conservation Reserve Program.

Other considerations in policy formulation include infrastructural factors, degree of risk associated with forest investments, and relative difficulty in measuring C sequestration (Richards et al. 1997). An aspect of risk for C sequestration practices is timing of C uptake that results from a practice. For example, retaining a forest that is under imminent threat of clearing provides an immediate benefit—emissions that would have taken place in the near term are avoided. In contrast, the C uptake associated with afforestation can spread over several decades or even a century. If a government adopts a policy instrument that rewards the capture of C or avoidance of C release, the forest retention project will provide more immediate, and therefore less risky, returns (Richards et al. 1997).

Without careful analysis, C sequestration policies may have unintended negative effects. Implementation of forest policy instruments under real world considerations can sometimes lead to outcomes that differ significantly from those intended (Richards et al. 1997). One example from above is that basic market forces may be distorted by government intervention. Unforeseen links occur because we do not understand every possible outcome of a tax, subsidy, or other policy in advance. These types of market forces may in some cases offset, at least partially, land base and forest biomass changes intended by forest C sequestration policies (e.g., countervailing land transfers in response to concentrated large-scale afforestation programs).

Adaptations by humans is another consideration when designing mitigation policies. Policy deliberations should include how to facilitate adoption of appropriate forest production technologies and practices, including the cases where there may be beneficial effects of atmospheric CO_2 on tree growth. The forestry benefits of climate change are not likely to be equally distributed. For example, global warming in some areas, such as arctic and alpine areas, would likely increase the quantity of land suitable for forestry production. However, warming in other areas could reduce soil moisture, thereby shortening growing seasons and decreasing forest production.

Integrating C sequestration goals with those of broader forest policies involves emphasizing complementary benefits and examining values of C sequestration. Baseline projections indicate that U.S. forests and forest products will continue to add C storage (at a declining rate) through at least the year 2040. This baseline is based on optimization of a social welfare function, relying on market forces without any government intervention pertaining to C sequestration (e.g., C policy targets). In addition, integrating C sequestration goals with broader forest policies requires consideration of concerns over endangered species, biodiversity, and other forest-related services or goods. Policy analysts are not as well acquainted with and are less attentive to the unique considerations of forest C sequestration when formulating comprehensive policies. A current example of an opportunity for integrating policies is the Conservation Reserve Program (CRP) (Alig et al. 1997), which has been evolving into a policy with more environmentally-oriented objectives. Integrating C sequestration into the CRP objectives could result in significant afforestation of marginal pastureland and cropland and substantial C sequestration gains.

Conclusions: Potential for Mitigation through Forestry Actions in the U.S.

Forestry activities that directly or indirectly result in emissions reductions may play an important role in the ability of the United States to meet its international commitments to reduce greenhouse gases. The potential for increasing C storage in forests in the United States is quite large. Potential C storage is governed by the biological potential of forestland to maintain biomass, the availability of suitable land for forests, and the costs and tradeoffs associated with increasing and maintaining (protecting) a higher level of C in forests. Although it is practically impossible to maintain all forests at maximum growth and C storage simultaneously, there is a biological and economic potential to increase growth rates and the amount of C stored.

Projections indicate that even without a forest C program, substantial increases in forest C are likely consequences of current timber market activities and forestry policies. There is some uncertainty over time, especially if climate change impacts on ecosystems are substantial and cause catastrophic reductions in biomass as forest ecosystems attempt to adapt. Forest sinks are generally considered a short-term activity because of these limits.

Table 8.3—Summary of selected forestry options to increase carbon storage. Each option would be phased in over a 10-year period.

Option	Size of program	Change in C storage (Tg C/yr)	Annual cost (million $)	Years to achieve target
Afforestation of marginal cropland and pasture	23-45 million ac	50	350–770	20–30
Improve forest management	30-50 million ac	50	40–80	0–10
Reduce harvest	220 million cu ft	50	?	0–10
Increase recycling of fiber	from 40 to 45% of all fiber used	10	?	0–10
Increase C in durable wood products	Increase by 50%	10	?	0–10
Urban forestry	Plant 100 million trees	10	50–250	20–30
Increased use of biomass energy	1.25 million ac of plantations	30	?	10–20

But to the extent that reductions are needed sooner rather than later, forestry actions are an integral part of any comprehensive greenhouse gas reduction strategy.

Increasing the amount of C stored in wood products (in use or permanent disposal) is an important aspect of forestry activities. It is also possible to reduce greenhouse gas emissions from the forest sector by increasing energy efficiency in converting timber to products.

Size of programs, geographic location, and cost estimates vary widely because of differences in how past behavior is considered, differences in C accounting, and differences in model parameters. Carbon accounting rules will eventually become standardized. Models will continue to evolve, but since a model represents a particular view of possible future conditions, maintaining multiple models to allow for comparison of results from different perspectives will continue to be an important analytical activity.

Considering costs and potential impacts, and recognizing that some options have not been analyzed sufficiently, "improved forest management" appears to offer the most cost-effective means to sequester additional C in forest ecosystems in the short term (table 8.3). Verification of C changes attributable to forest management may be difficult because we lack sufficient experimental research that quantifies impacts of specific practices on different C pools.

Afforestation costs are high relative to reforestation, but considering the uncertainty of the estimation process and the fact that costs/ton increase as afforestation programs expand, some program level less than about 20 million acres could be cost-effective. Afforestation may also be needed to offset conversion of forestland to other uses (deforestation). The potential of afforestation is limited primarily by the availability of suitable land (for ecological or economic reasons), nursery capacity, willingness of landowners to participate, and availabilty of technical assistance.

Use of biomass energy will also be important, although we do not have good cost/benefit estimates available at this time. Some simulations have shown that biomass-fueled power is not very competitive with coal without subsidies. Substitution of wood products for other energy-intensive materials may also be effective, but estimating and attributing the benefits are difficult. Urban tree planting and energy efficiency in wood product manufacturing will both be important factors.

Protecting and conserving forests should maintain or increase C pools in the short term, as long as natural disturbance rates do not reach catastrophic levels. For any forestry activity, forest protection must be maintained or enhanced to sustain both the baseline rate of C sequestration and any investment in new programs.

Mitigation options can be analyzed most effectively within the context of the broad array of land use dynamics and forest cover-type changes that are driven by other factors besides forest C considerations. Possible unintended consequences of C sequestration policies warrant close attention by those formulating policies. Important considerations are possible effects on other sectors of the economy for large-scale and concentrated afforestation efforts, timing of C impacts from deforestation versus longer-term afforestation, and uncertainties in climate change projections.

Mitigation policies can not be evaluated independently of behavioral, economic, and institutional adjustments engendered by changing climate (Schimmelpfennig et al. 1996), both in the forestry and agriculture sectors. For example, if some agricultural producers respond to climate change by increasing the amount of land under cultivation, the amount of land available for forest C sequestration could be reduced. Within the forestry sector, producers may attempt to adapt to climate change by adopting appropriate tree planting mixes and practices. Further, increased research and technology transfer could promote technical advances that could help forest growers adjust to soil or other climatic characteristics. Long-run projections indicate that adaptations through forest C programs may not necessarily involve land use and forest management changes in a smooth or regular fashion over time, and that land use shifts to meet policy targets need not be permanent.

A number of policy tools involving forestry actions are available, including slowing deforestation to urban and developed uses and agriculture. Mitigation policies involving increases in forest C should be formulated with an awareness that a substantial increment to the U.S. population is projected to be added over the next several decades. Such population increases are likely to increase pressure to develop additional forestland (Alig and Healy 1987).

In this chapter, we have examined a range of mitigation options independently. Specific mixes of mitigation activities could be analyzed once more concrete policy targets are developed after the post-Kyoto deliberations move further along.

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