CHAPTER 4 -- FORESTRY SINKS

Wood consists of about half carbon on a dry weight basis. Increased forest growth thus offers the possibility of substantial increases in the total amounts of carbon sequestered. Indeed, the option of sequestering carbon in forests has thus far received more study and attention than other sequestration alternatives. It is the only sequestration alternative specifically addressed in the Kyoto Protocol. As a part of the Kyoto agreement, countries can gain carbon reduction credits for "removals by sinks resulting from direct human-induced land use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990" (Article 3.3).

There are 737 million acres of forested lands in the United States. In total, the carbon stored in vegetation and soils of these lands amounts to 60 billion tons (Sampson, 1996). Efforts to increase forested acreage and to improve management of these forested lands could substantially increase the total volume of carbon sequestered within the boundaries of the United States.

There are a variety of ways in which forests can be used to increase carbon storage:

Increased Total Forest Area -- This can be accomplished through replanting previously timbered lands ("reforestation") and by converting marginal crop and pasturelands to forest cover ("afforestation").

Improved Forest Management -- This involves actions such as thinning, removing unwanted vegetation, reducing grazing, encouraging natural regeneration, and other techniques that increase the ability of the forest to sequester carbon.

Urban Forestry -- There is also an opportunity to increase forest cover through urban tree planting programs.

Table 4.1 shows estimates of the total carbon sequestration potential associated with each of these options. A United States program utilizing all of these opportunities to their full potential could potentially sequester 64 MMTCE per year. Urban forestry also increases energy efficiency by reducing air conditioning and heating use. If reductions in emissions from energy efficiency are included, the potential could be as much as 97 MMTCE per year. This accounts for about 17 percent of the total reductions that would be required for the United States to meet the Kyoto Protocol. Improvements in technology may increase this number.

Table 4.1 Carbon Sequestration Potential of Forestry Options

Activity	**Annual Carbon Reduction**
Increase Total Forest Area	40.2 MMTCE/yr
Improve Forest Management	23 MMTCE/yr
Urban Forestry	1.2 MMTCE/yr

Table 4.2 shows estimates of the likely ranges of costs per ton associated with each of the main forms of carbon sequestration in forests. On the whole, forest sequestration is cost-effective. Compared with carbon taxes of $50 to $100 per ton believed necessary to achieve conventional energy efficiencies, forest sequestration can remove carbon from the atmosphere at costs ranging from one-third to one-half of these levels. To be sure, the costs of forestry sinks

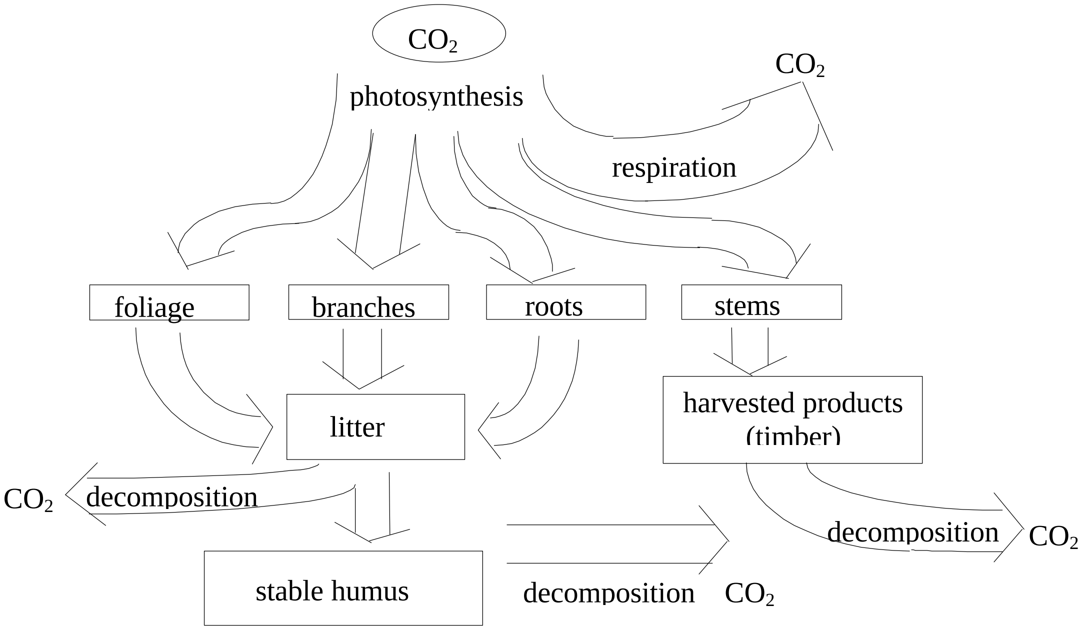
will reflect many individual factors, such as quality of the soil, species of tree, and value of the land. Nonetheless, an approximate value will aid in comparing a forest sequestration program with other greenhouse mitigation alternatives. As shown in Table 4.2, an afforestation or reforestation program on forestland, cropland, and grazing land will cost approximately \$11, \$17, and \$12 per Mg of carbon.

Table 4.2 Costs of Carbon Sequestration for Forestry Options

Activity	Cost per ton of Carbon Sequestered
Increase Total Forest Area	\$9-25
Improved Forest Management	\$5-28
Urban Forestry[1]	\$0.20-2

The Forest Carbon Cycle -- Forest ecosystems contain large amounts of carbon, both in the living biomass and in the dead organic material on the forest floor and in the soil. Through accumulation of biomass, a growing forest absorbs carbon from the atmosphere through photosynthesis and assimilation of CO_2. Plants return stored carbon to the atmosphere through respiration. When leaves and roots die, the organic material decays, adding carbon to the soil. Soil carbon is lost to the atmosphere through decomposition by soil organisms (Figure 4.1). Net removal of CO_2 from the atmosphere occurs when plant photosynthesis exceeds all processes of consumption and respiration, resulting in aboveground plant growth and increased root and microbial biomass in the soil (DOE, 1999).

Figure 4.1: Simplified Diagram of Forest Carbon Stocks and Fluxes



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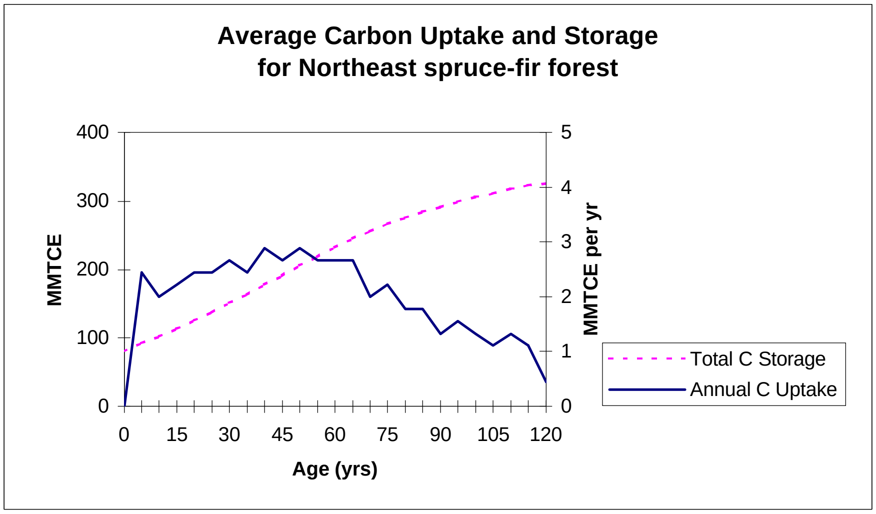
[1] Value based upon seedling cost. However, per-unit cost may rise if an urban program requires management to ensure that the seedlings survive and are healthy.

As demonstrated in Figure 4.2, at very early stages, growth is slow, but as the surface area of leaves increases, the rate begins to accelerate. This high rate of growth is maintained for a period of time, but as maturity approaches, growth rates begin to slow until they approach zero. The accumulation of living biomass peaks as growth gradually decreases when the forest ages, and litter loss and decomposition processes increase. Although the physiological processes governing growth are similar across most tree species, growth rates can vary depending on environmental conditions.

Figure 4.2: Example of Average Carbon Uptake for a Specific Forest Type



*source: (Birdsey, 1996b)

When the total system of living biomass, litter, soil stable humus and forest products has reached its equilibrium, the net annual storage rate is zero, but a certain amount of carbon is permanently withdrawn from the atmosphere. The carbon-sequestering potential of forest ecosystems mainly consists of the buildup of this equilibrium biomass after afforestation. When the equilibrium biomass in a mature stand is reached, further carbon assimilation is counterbalanced by equivalent biomass decomposition, and the carbon sequestering potential is used up (Nabuurs, 1993). It might be possible to further increase storage potential by harvesting the forests, converting timber to wood products, and regenerating the forest. Essentially the cycle would be restarted. However, this would require estimates of carbon storage in wood products and consideration of the final destination of those products. These estimates are not readily available at this time and are not figured into the calculations.

It is important to realize that there are a number of uncertainties in predicting carbon storage potential. First of all, there are limitations in performing calculations. Uncertainties in calculations can result from: 1) uncertainties in the input parameters caused by measurement error or lack of sufficiently detailed information, 2) uncertainties in the correctness of the model used to make calculations, and 3) uncertainties associated with predicting forest growth and forest development under future site conditions. One must also consider that if new forestland is being managed for wood products, then the disposition of carbon in wood products, byproducts, and disposal must also be considered. For example, a certain percentage of paper products can end up in landfills where it would most likely remain a carbon store, but if paper is incinerated, carbon can be rereleased to the atmosphere.

I. Reforestation Sink Potential

There are a number of different ways in which forestry projects within the United States could sequester additional carbon. While globally there is still a major challenge to prevent further deforestation, the United States has already taken steps towards improved forest management and reforestation. For example, the cutting of Northeastern forests in the previous century is now being replaced by forest regrowth, and forests across the United States are managed to maintain cover, increase water storage, and retain litter (DOE, 1999). From 1990 to 1995 total forest cover in the United States actually increased by about 3 million hectares. As a result, a limited amount of land remains available for future reforestation or afforestation projects that could increase the United States's carbon sequestering potential.

Studies estimate that of the physically suitable land in the Pacific Northwest and the Southeast United States, there is approximately 300,000 hectares of previously forested land socially and economically suitable for reforestation (Naaburs, 1993). The estimated annual carbon uptake rates for species in this area vary from 3.43 to 7.02 MMTCE per hectare per year for Douglas fir in the Northwest and from 3.21 to 3.49 MMTCE per year for pine species in the Southeast (Appendix 4A & 4B). Based on these available land estimates, the carbon sequestration potential for converting these areas to forest ranges from 985,000 to 1,400,000 MMTCE per year. This potential is a very small percentage of the reductions required by the Kyoto agreement. To increase potential, one must consider other land use changes.

Marginal Cropland and Pastureland -- Large areas of crop and pastureland in the United States—usually forested in the past, but then converted to agriculture—are of marginal value for crop and pasture use due to erodibility, wetness, and other soil characteristics. This land is likely to be unprofitable in its current use, highly erodable, or, due to soil characteristics, more suitable for forest cover. Such a strategy might sequester as much as 39 MMTCE per year (15% of the Kyoto Protocol requirement) at a cost between $10 and $25 per Mg of carbon—resulting in total costs of $390-$975 million per year.[2]

Converting these marginal lands back (or newly) to forests could provide net economic gains and social and environmental benefits. Figure 4.3 shows the forest carbon storage potential associated with increasing the size of U.S. forests by conversion of marginal agricultural lands. If all economically suitable land were converted, carbon storage could be increased by 1000 MMTCE over the first 20 years of forest growth. Over 100 years, carbon storage could be increased by as much as 2500 MMTCE.

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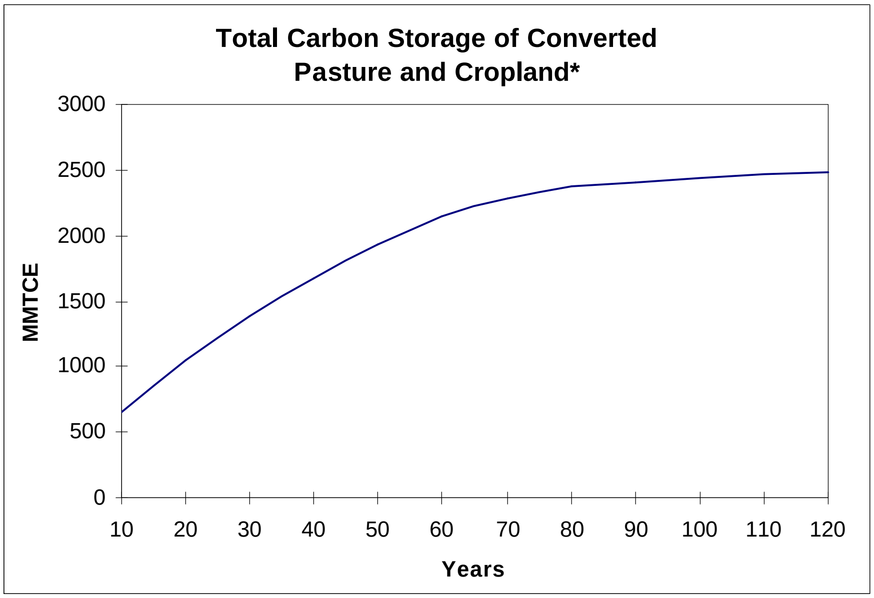
[2] The low end is based upon a per-unit cost of $10 per Mg of C, while the high end is based upon a per-unit cost of $25. The value for the sequestration potential is from Table 4.1.

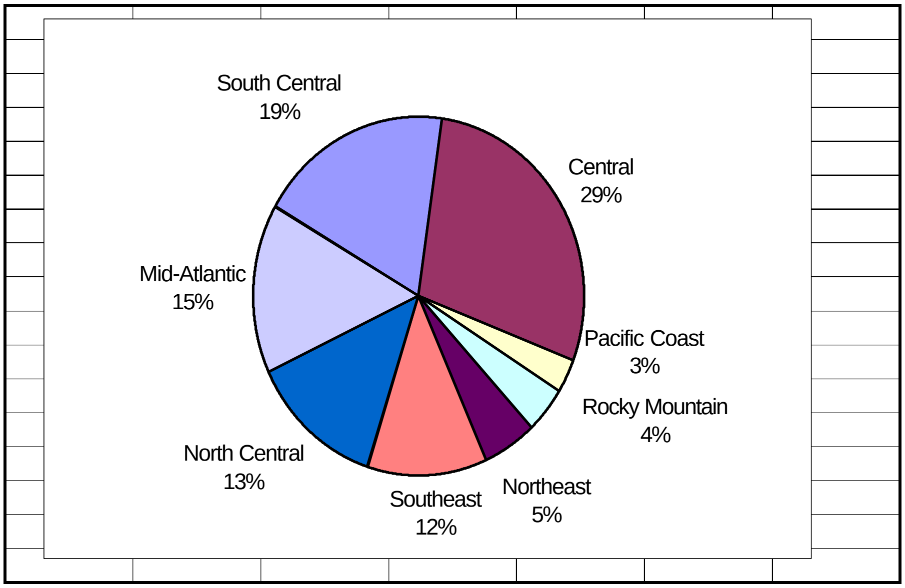
Figure 4.3 Carbon Storage Potential of Converted Marginal Lands



*Source: (Birdsey, 1996), calculations based on economically suitable lands and total carbon storage for highest carbon-storing species in each region.

Figure 4.4 identifies by region where the marginal crop and pastureland suitable for growing hardwood or softwood vegetation is located in the contiguous United States. Most of the convertible cropland is found in the northern regions (16.5 million hectares). The remaining 3.9 million hectares are found in the South Central and Southeast regions.

Figure 4.4 Geographic Distribution of Marginal Crop and Pastureland



The greatest amount of convertible pastureland is found in the South Central (6.8 million hectares) and Central (5.9 million hectares) regions. Another 1.3 million hectares of convertible pastureland are roughly evenly divided between the Rocky Mountains and Pacific Coast regions (Parks et al, 1993). Of the 47 million hectares of marginal land suitable for conversion to forest, about 25.4 million are suited for softwoods and 21.7 million for hardwoods. The ability of lands to support such vegetation was determined by the U.S. Forest Service (Parks et al, 1993).

The carbon sequestration potential in these regions varies due to climate, soil type, native tree species, and other environmental factors. The following tables provide estimates for annual carbon sequestration potential and total carbon storage for cropland and pastureland conversion in various regions. For example, as shown in Table 4.3, a Southeast pine plantation grown on

Table 4.3: Estimates of Forest Carbon after Cropland Reversion to Forest

Region	**Forest Type**	**Avg Annual C uptake during first 50 years (MMTCE/ha/yr)**	**Total Carbon Stored A---------fter 100 years (MMTCE/ha)**
Southeast	pine plantations	4.29	277
South Central	pine plantations	4.53	261
Northeast	white/red pine	4.51	331
	spruce-fir	4.11	306
Lake States	white/red pine	5.98	481
	spruce-fir	3.64	243
Central States	white/red pine	2.78	213
	oak-hickory	3.13	240
Rocky Mountains	Ponderosa pine	2.84	253
Pacific Coast	Douglas fir	8.09	721
	Ponderosa pine	3.11	263

*Source: (Birdsey, 1996)

Table 4.4: Estimates of Forest Carbon after Pasture Reversion to Forest

Region	**Forest Type**	**Avg Annual C Uptake during first 50 years (MMTCE/ha/yr)**	**Total Carbon Stored after 100 years (MMTCE/ha)**
Southeast	pine plantations	3.87	238
South Central	pine plantations	4.02	228
Northeast	white/red pine	4.78	329
	spruce-fir	4.38	303
Lake States	white/red pine	6.20	481
	spruce-fir	3.87	243
Central States	white/red pine	2.91	214
	oak-hickory	3.29	241
Rocky Mountains	Ponderosa pine	3.00	252
Pacific Coast	Douglas fir	6.62	598
	Ponderosa pine	3.27	263

*Source: (Birdsey, 1996)

land that was previously used for crops could annually uptake approximately 4.29 MMTCE per hectare. Over a hundred-year period, the forest would reach a total storage capacity of 277 MMTCE per hectare.

Of the 47 million hectares of marginal crop and pasture land in the contiguous United States that are physically suited for forests, 9.5 million hectares are also economically suited for forests (Parks et al, 1992). In these areas, forest benefits exceed crop or pasture benefits. The largest portion of these marginal lands economically suited for conversion to forests are in the South Central (4.9 million hectares) and Southeast (2.8 million hectares). Another 1.3 million hectares are found in northern regions, and the remaining 0.4 million hectares are in the Pacific Coast region. None of the marginal crop and pastureland in the Rocky Mountains is economically suited for forests.

Based on these estimates of land availability and carbon uptake potential, the maximum total carbon sequestration potential from conversion of marginal lands to forests is approximately 39 MMTCE per year. This calculation assumes that all economically suitable land is converted, and the species with the greatest carbon storing potential for each region is selected. Therefore, this is a “best-case-scenario” estimate. The actual carbon storage could be lower. If this amount of carbon were successfully sequestered, the United States would be able to meet about 7 percent of the reductions required by the Kyoto agreement.

II. Increased Sink Potential of Existing Forests

A program of improved management of currently forested land is estimated to have the potential to sequester between 9 and 23 MMTCE per year (2-4% of the U.S. annual Kyoto commitment) at a cost between $9 and $30 per ton of carbon sequestered—requiring total expenses of $207 and $690 million annually (Moulton and Richards 1990).[3] Combining two different types of management could produce this result. The first type would be through passive management. Under this scenario, the forest land is placed under a formal management agreement that requires owners to reduce or eliminate grazing on their land.

On federal land this could be easily achieved through recalculating grazing permits based upon the sequestering ability of the forest. On private forestland, such a strategy would likely require some type of government incentive (i.e., a tax break or a subsidy). Also, passive management would be achieved through avoiding practices that lead to overharvesting. An education strategy could teach private landowners about the long-term benefits, both for sequestration and for potential timber productivity, which would result from logging practices that avoid overharvesting.

Another type of management, active management, would involve practices that prepare the soil to encourage natural regeneration. While this technique may require an investment of time and money, if done properly it can essentially eliminate the expenditure on replanting.

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[3] Since these management techniques do not require that the land be purchased, the price estimates eliminate the cost of purchasing the land. Overall price is based upon a range of $9 and $30 per Mg of C. At a price of $9 it is estimated that approximately 9 MMTCE could be sequestered annually. At a price of $30, 23 MMTCE could be sequestered per year.

Since landowners could potentially receive credit for sequestration on their land, there would be a stronger incentive to manage the forest properly.

More Intensive Replanting -- Current logging programs on public forestland essentially require that the land be replanted after it is logged; however, no such federal requirement exists for private forest owners and not all states have such a mandate. These landowners could be encouraged to extensively replant their land once logging has occurred. This strategy has been estimated to sequester approximately 47 MMTCE annually (8% of the U.S. annual Kyoto commitment) at a per-unit cost ranging between $5 and 20, resulting in total expenditures between $235 and 940 million annually (Moulton, 1990).[4]

A tax break or subsidy for the cost of the replanting could achieve such results. The tax break or subsidy would be based on a per-unit basis to ensure that the forest land sequesters the largest amount of carbon per dollar. Furthermore, in order to achieve the most cost-effective return, the tax break and subsidy would vary based regional variation in replanting costs. In other words, research would provide further insight into the actual cost of a replanting program in the Pacific Northwest compared with a similar project in the Northeast, allowing the program to be structured differently for each region.

One way to offset part of the cost of a carbon sequestration program for forests is to allow landowners to sell some of the timber on their land. The environmental impact of logging will largely depend upon the structure of the program, i.e., enforcement and monitoring. Despite these factors, a forestry program could yield large annual reductions, as noted above, in a cost-effective manner, especially if the program can successfully invest in those projects that offer a cheaper per-unit cost than alternative mitigation options.

The effects of logging on a carbon sequestration program are uncertain. First of all, does a mature forest sequester more carbon than a newly planted forest? At a certain age, the tree begins to sequester less carbon per year. Therefore, if logging were performed on designated sequestration forestland, then the effects would depend on the wood’s use, since certain uses result in quicker release of the carbon than other uses. For example, trees that are used for firewood immediately release carbon into the atmosphere, whereas wood used in the construction of a home will likely store the carbon for much longer.

Two possible scenarios arise from the impact of logging:

First, in order to eliminate the difficulty in tracking the product uses of the wood, one option would be to plant forest cover and then leave it standing in the forest for perpetuity. This option would likely require some logging in order to maintain the overall health of the forest, through selective harvesting or thinning of the dead and dying trees. However, the logging would be minimal; therefore, very little of the cost would be offset through the sale of timber. The per-unit cost of such a program would likely be similar to those in Table 4.2.

The second scenario would allow logging on the land and then sell the timber to partially offset the cost of the program. Thus, if the profits produced from logging are greater than the

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[4] Costs ranged between $5 and $20 per Mg of C. How much sequestration is sought will largely determine these costs.

cost of the sequestration program, the landowner (either public or private) could generate profits from their participation in the project. Assuming that the wood is developed into a product that slowly releases the carbon, the landowner could sequester carbon at a profit of $67, $77, $54, $38, and $53 per Mg of carbon for loblolly, oak, slash, longleaf, and Douglas-fir, respectively.[5]

These numbers are extremely rough and do not account for the impacts on the timber market. The potential flood of timber placed on the market could dramatically lower the price, thereby sharply cutting into these profits. Therefore, further research will be required to determine if allowing logging will actually produce these types of profits. Yet, these estimates show that there is potential to offset at least part of program's cost through timber sales. However, ensuring that the forest products are not used in a way that quickly releases the stored carbon will likely require that logging on these lands be of a small scale. After all, such a tracking system would likely require a massive amount of information and enforcement to ensure that the replanting program is not a net source of carbon.

Improved Management Practices -- Forest management techniques have often been utilized to increase the productivity of commercial forests. There are four management techniques that will likely affect the outcome of a forest sequestration program. The first factor is the turnover rate of the replanted trees—the quantity of individual trees that will die in each successive year. Survival rates can range between 50 and 100 percent, with seedlings dying in the first five years. The survival rate of the seedlings will affect both the overall sequestration and cost of the program. For example, the rate of survival will potentially affect the cost of replanting. While the actual seedling cost is a minimal portion of the total cost, replanting dead seedlings will require more intensive management and a potentially higher per unit cost.

Secondly, the degree of necessary management will have a great impact on the program's costs. Although pre-commercial thinning, release cuttings, and pruning may increase the output of commercial timber products, these practices may not enhance the ability of stands to sequester carbon (Moulton, 1990). If research proves that both thinning[6] and release treatments[7], for example, are not effective methods to improve the ability of a program to sequester carbon, then such techniques will not be utilized, and the cost will decline.

By eliminating these costs from the data in Appendix 4B, the per-unit cost of carbon declines. For loblolly pine, oak, slash pine, longleaf pine, and Douglas fir, the costs become $2, $3, $4, $2, and $2 per Mg of carbon, respectively. The lowering of the per-unit price is the result of the high cost of managing the forest through these techniques (see Appendix 4B Columns 6 and 7). Therefore, evidence suggesting that such management techniques are not necessary will potentially reduce the per-unit cost of the program by up to 75%. Such a reduction could make afforestation and reforestation an even more economically viable mitigation option.

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[5] See Appendix 4E for the annual profit for these various species. Per-unit profit is based upon annual profit divided by the annual sequestration.

[6] A practice utilized to maintain the overall health of the forest. Usually involves clearing the dead and dying trees form the forest to prevent disease and to protect against forest fires.

[7] A technique to remove competing vegetation. Many states do not allow the use of herbicides, so these costs usually are based upon the use of machinery and labor to remove the weeds.

Third**,** controlling the effects of pests and disease will potentially affect the program. The possibility of losing a project to either a pest or disease will force forest managers to control for such a scenario. Some states do not allow chemical treatments of forest, which requires the development and application of other pest or disease control techniques. Many of these techniques are highly labor intensive, thereby potentially increasing the operation cost of the program. Also, pest and disease control techniques will have side impacts on the program.

Monocultures are heavily prized for their ease of operation and will likely be utilized in a sequestration program. Nonetheless, many monocultures are heavily susceptible to pests and disease, since many inflict their damage on a single species. Replanting programs that utilize multiple species can potentially minimize the risk of losing a whole plantation to a disease or pest. They can further aid in the protection of biodiversity. Yet such multiple species programs are often more expensive because they generally require more intensive management techniques.

Lastly, the threat of forest fire will require a further evaluation of forest management techniques. Forests will require varying amounts of fire management, depending on the susceptibility of the species. An assessment of the potential fire danger will help establish the estimated costs and sequestration ability of a project over its lifetime. Fire management may also play a role in replanting programs.

For the last century, the goal of forest managers was to prevent forest fires. However, in recent years, a variety of fire suppression issues have troubled Americans. Fire plays an integral role in the health of many forests. For example, Ponderosa pine trees depend upon fire for germination, and fire suppression limits the ability of the species to propagate. Furthermore, fire prevention has been blamed for the large forest fires that raged through the West in 1996 and Florida in 1998. By preventing forest fires, many forests have become more susceptible to large-scale fires.[8] Yet the outbreak of fires could put lives and private property at risk.

A fire prevention strategy would likely increase the amount of carbon sequestered, due to the growth of understory. However, such a plan makes the forest more susceptible to a large loss of carbon that would result from a forest fire. In addition, while prescribed burns promote the overall health of the forest, they also emit carbon dioxide into the atmosphere, thereby increasing domestic emissions.

III. Urban Forestry

The trees and undergrowth in our communities constitute an urban forest that can respond to management and treatment in similar ways to ecosystems in rural areas. Few aspects of the urban environment can be readily changed, but a good urban forestry plan could provide significant benefits. There are currently about 76,000 km^2 of urban tree cover in the United States, which is estimated to sequester about 3.3 million tons of carbon per year (DOE, 1999). A plan to increase urban forest cover could reduce the buildup of CO_2 through increased tree planting and improved tree placement for energy conservation. There are an estimated 60-75 million planting opportunities along existing streets and another 75-150 million opportunities in yards. Therefore, the total tree-planting opportunity could run as high as 225 million without

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[8] See Robert H. Nelson, "Ending the Forest Fire Gridlock" (Competitive Enterprise Institute, March 1999).

counting parks, greenways, and other public open spaces (Sampson, 1996). When new developments are considered, there is even greater potential for urban tree planting.

However, in order for an urban tree planting initiative to be effective, it is important to plant the right trees in the right places. Trees in urban areas face a number of stresses not found in rural areas. Cities are hotter and drier, space for growth above ground is often restricted by utility lines and buildings, land use regulations may require that sight lines be retained (at intersections for example), and urban soils often do not have natural subsoil layers or internal drainage (Sampson, 1993). It is important to select tree species that can adapt to these difficult conditions and to insure that they are planted correctly to assure maximum health and longevity. To achieve maximum energy savings and environmental improvement, trees need to be positioned in order to provide maximum shade in the summer, but minimum shade in the winter.

American Forests has estimated that an average tree will remove 1 ton of CO_2 from the atmosphere over a 40-year period. Given the opportunity to plant an additional 135 to 225 million trees in yards and on streets, there could be potential to remove 135 to 225 million tons of CO_2 in 40 years, or an average of 3.4 to 5.6 million tons of CO_2 per year (.9 to 1.5 MMTCE). In addition to sequestering carbon directly, properly placed urban trees can have a significant impact on carbon emissions through energy conservation. Studies have found that properly located trees could lower daily electrical usage for air conditioning by 30 to 50 percent. Heating costs could also be reduced by 4 to 22 percent (Sampson, 1993). Residential emissions currently account for about 19 percent of all CO_2 emissions. Air conditioning demands account for 9 percent of residential emissions. Therefore, a 30 to 50 percent reduction in air conditioning demand could result in an emissions reduction of 7 to 11.6 MMTCE per year. Space heating accounts for 37 percent of residential emissions, so a 4 to 22 percent reduction in heating demand could result in an emissions reduction of 3.8 to 21.1 MMTCE per year. The efficiency increases achievable by planning better tree arrangements could also result in as much as $25 million in savings each year (Sampson, 1993). Increasing urban forests also improves aesthetic quality of urban communities.

Establishing the costs for such a program would depend on a number of assumptions. On the low end, one might assume the only necessary expense would be the cost of the seedlings (Appendix 4A). On the high end, an intensive management program might be needed to ensure that the trees are healthy.[9] One way to implement such a program would be through local tree-planting days in which citizens are encouraged to plant trees on their property or on community property. This day would be organized by the local, state, or federal government with funds provided through private or public sources. Second, the government might provide a tax break or a direct subsidy for those citizens who plant trees. Either of these methods would necessarily require follow-up to ensure that the trees are sequestering their potential.

While such a program might require an investment of government funds, an urban project provides the indirect carbon mitigation potential mentioned earlier. Therefore, landowners properly educated on the potential to reduce their heating and air conditioning bills would likely require a smaller government investment.

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[9] For the costs associated with an urban tree planting program see McPherson et al. 1999. However, these numbers are not per Mg of C.

IV. Total forest potential

Overall, if the United States were to implement the options presented above to their maximum potential, the reduction in carbon could be as much as 97 MMTCE per year (Table 4.5). This accounts for about 17 percent of the reductions the United States needs to meet the Kyoto requirement. Obviously, domestic opportunity is somewhat limited.

Table 4.5: U.S. Potential for Carbon Reduction through Forestry Options

Activity	**Annual Carbon Reduction (**MMTCE/yr)
Forestation of Timbered Lands	1.2
Forestation of Marginal Lands	39
Carbon Storage in Urban Forests	1.2
Forest Management Techniques	23
Sub-Total	**64.4**
Reduction in Air Conditioning Demand	7-11.6
Reduction in Heating Demand	3.8-21.1
Total	**75.2-97.1**

To achieve the offsets calculated above, current U.S. land use patterns must change significantly. Even if all of these actions were carried out to their fullest potential, the offsets would only account for17 percent of the reductions currently required by the targets set at Kyoto. While it may be more economically beneficial for land to be converted to forests, farmers in the central and southern regions may not be willing to convert their land from its current use. Subsidizing these land use changes might assist the United States in increasing the potential for achieving its environmental goals, but the United States may also need to consider the potential for carbon mitigation activities on a global scale.

Nevertheless, a domestic U.S. forestry program can offer a cost-effective strategy for mitigating greenhouse gas emissions. The price of such a project will cost anywhere between \$2 and \$90 per Mg of C. However, a rough estimate would be at a cost of \$25 per Mg of C, which makes it a more inexpensive alternative than several of the other mitigation options. The differences in cost will likely be due to regional variation in land cost, soil type, site preparation, maintenance requirements, fire prevention, and others. Consequently, the actual cost of a forestry program will largely depend on how these factors play out. If land, for example, becomes extremely expensive due to the conversion of more land to forest cover, then the per-unit cost will rise sharply.

V. Cost-effectiveness

Several approaches have been employed (Table 4.6) to estimate the costs of carbon sequestration in U.S. forests. One type of study multiplies the cost of a replanting program by the sequestration potential of forests. Then the cost of the income that is foregone (i.e., opportunity cost) by not putting the land in an alternative use is added on to account for land costs. Based on this method, one researcher found that in the United States sequestration would cost between $5 to $39, $6 to $21, and $13 to $33 per Mg on forestland, pastureland, and cropland, respectively (Moulton, 1990).

Another group of studies accounts for the likelihood that as more land is incorporated into a sequestration program the opportunity cost of land will rise, thus driving up the per-unit cost. These studies yield marginal cost curves in which the cost of the program rises as more sequestration is sought.[10] A study of this type found that an annual sequestration level of 20 Mg of carbon could be achieved at a per-unit marginal cost of $4. At a level of 109 Mg of carbon, the per-unit sequestration cost would be $82 (Parks, 1995). This study shows that at low levels of sequestration a forestry program is relatively cheap, whereas a program that seeks to sequester a large quantity of carbon would dramatically raise the cost.

Yet another group of studies utilizes current land use data to estimate the projected opportunity cost of land for various regions. This type of analysis is useful because landowners do not always act in the way that models predict. Therefore, basing land costs on historical trends will hopefully eliminate some of the errors in prediction. An example of this type of study is shown in Table 4.6 (Stavins, 1996; Mauldin, 1998). The results of these studies show that.

Table 4.6: Comparison of Forest Sequestration Studies

Author(s)	**Study Description**	**Per Unit Cost** ($/Mg)
Moulton and Richards 1990	Investigated the potential for forest sequestration on private cropland, pastureland, and forestland. The opportunity cost of the land was included in the cost estimates. Calculated costs prior to logging for a variety of species.	5-33
Adams 1993	Assessed several different scenarios of tree planting on agricultural land. Found that 250 MMTCE could be sequestered.	25
Parks and Hardie 1995	Evaluated costs based on the assumption that, as more land is utilized in a program, the cost of the land will become more expensive, thereby increasing the per-unit cost of sequestering carbon.	4-82
Stavins 1996	Took into account the fact that farmers do not always respond according to economic theory. Derived marginal cost curve for carbon sequestration for the United States based on land use decisions over a 49-year period in Mississippi, Arkansas, Louisiana. Found that 150 MMTCE could be sequestered.	25
Mauldin and Plantinga 1998	Utilized the same method as Stavins (above) except: (1) based on land use in South Carolina, Wisconsin, and Maine (2) included impacts of population growth on land use decisions.	Maine: 31-184 South Carolina: 1-22 Wisconsin: 1-24

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[10] Marginal cost is the price associated with sequestering one additional Mg of carbon.

forestry sequestration of carbon will often be effective. The Mauldin and Plantinga study further illuminates the importance of land costs, since there is limited land available for a sequestration program in Maine, thereby increasing the per-unit cost and likely not making it cost-effective. While there is wide disparity between the exact costs of such a program, regional evaluation will help to develop concrete cost estimates.

The costs associated with forestry sequestration of carbon can vary considerably by region and by tree species. This report offers new estimates of the cost-effectiveness of carbon sequestration for five tree types: loblolly pine, oak, slash pine, longleaf pine, and Douglas fir. The results of the analysis are given in Table 4.7. Appendix 4A provides details of the analytical methods employed. The results obtained in this new analysis are generally consistent with those found by other analysts, as were shown above in Table 4.6.

Table 4.7: Per Unit Cost for Various Land Uses

Species	**Forestland** ($/Mg C)	**Cropland** ($/Mg C)	**Pastureland** ($/Mg C)
Loblolly Pine	10	15	11
Oak	13	25	15
Slash Pine	12	17	13
Longleaf Pine	10	15	12
Douglas Fir	9	14	10

VI. Environmental impacts

Aside from carbon sequestration benefits, forestry initiatives can also provide environmental benefits. First of all, increased forest cover can improve water quality, reduce soil erosion, and prevent flooding. Trees that shelter impervious areas can cut the rate at which water hits the surface, and tree roots can provide protection that slows water flows and reduces soil erosion. Reduced runoff prevents pollutants from flushing into rivers, lakes, and estuaries. Also, trees can improve air quality and reduce urban temperatures. Through photosynthesis, air is purified and temperatures are moderated. Another important benefit from adding forest cover is the increased wildlife habitat. Preventing deforestation preserves the habitat of many species, particularly those that are considered to be endangered or threatened. This is beneficial for species preservation and for the promotion of biodiversity. Increased urban tree cover also provides additional recreational opportunities to urban and suburban residents through managed parks and natural settings.

Converting marginal crop and pastureland to forest cover can also reduce soil erosion and improve water quality. Likewise, it can provide habitat for a number of wildlife species. Regeneration and replanting timbered lands can also provide habitat. Increasing forest cover in urban areas can improve quality of life and provide additional recreational opportunities. It can also reduce heating and cooling costs for households and businesses.

There are some potential negative environmental impacts to consider as well. Many of the forest projects described above may rely on monoculture planting. Single species forests make carbon calculations less complicated and are suitable for plantation forests intended for timber. However, monocultures result in less biodiversity in wildlife and are also more susceptible to many pests and diseases than mixed forests.

VII. Policy options

The government could adopt a number of policies to promote the conversion of marginal agricultural lands to forests. First, subsidies could be offered to encourage current landowners to convert this land to forests. The government would need to provide an amount that would offset both the cost of the land and the initial setup costs. A program of this sort could be structured in a manner similar to the Conservation Reserve Program or Wetlands Reserve Program, except the landowner would be required to put the land to forest cover.

Second, tax breaks could be offered based on the amount of carbon that the given piece of land sequesters. It could be based either upon an annual per-unit tax break (the landowner would be allowed to deduct a set amount based on how much carbon their land sequestered that year) or a one-time deduction when the forest has reached sequestration maturity. A tax program of this sort would be similar to a carbon tax, except it would provide a tax reduction for the landowner instead of an increased payment. It would be necessary to establish a way to measure the sequestration and ensure that landowners are sequestering as much as they claim.

Through direct buyouts the government could also purchase land needed for the sequestration uses described above. Both the costs of the program and the amount of carbon sequestered would likely be the same for such a project as for projects undertaken by private citizens. However, this option would eliminate the possible enforcement and verification difficulties that would arise with private landowners. Essentially this land would be managed in the same way as Forest Service land, and would likely become an additional unit of this agency. Such a program would have to overcome the likelihood that some citizens would not be receptive to more government-owned land.

New development plays an important role in the quantity of forest cover in the United States. Another government option would be to require that all new development plant trees to offset the lost forest cover from the development. To increase forest cover, new developments would be required to plant more trees than were previously on the land. The planting could either be done in the new development or in another location. Planting near the new houses would provide the side benefit of reducing heating and air conditioning demand, thus increasing greenhouse gas reductions, and making the development more aesthetically pleasing. Such a program could be paid for by the developer indirectly through a development tax or by requiring that the landowner manage the replanting program. The expenditures for such a project would likely be small since the cost of a seedling is extremely low. However, ensuring that the seedlings survive will increase the cost of the program. Yet, the cost of an urban tree planting program will likely be lower than other replanting programs, since there will be little need to purchase new land.

VIII. Conclusion

There are a number of opportunities for mitigating the atmospheric buildup of carbon dioxide and other greenhouse gases through forestry initiatives. Efforts to increase forested acreage and improve management of these forested lands could substantially increase carbon storage in the United States and provide offsets for our carbon emission levels. In total, the carbon stored in vegetation and soils of the United States could be increased by as much as 64 MMTCE per year. These offsets could assist the United States in meeting a portion of the reduction levels necessary to meet Kyoto targets. There is also tremendous global potential for the United States to further increase carbon sequestration through joint implementation projects and partnerships with other nations.

However, there is a great deal of variability in estimates for forest carbon sequestration potential, mainly due to uncertainties in calculations. Only limited scientific study has been conducted on the relationships between tree and forest growth and carbon impacts. These estimates may be conservative. They are largely based on current technology, but improvements in technology could greatly increase the potential to mitigate carbon buildup in the atmosphere. Estimates also do not include potential impacts on carbon that would come from substituting wood for other materials, recycling wood products, or improving wood utilization. Harvesting forests for products and replanting could allow for forest sequestration to become a continuous cycle, which would allow a greater amount of carbon to be stored.

Despite the uncertainty, it can be concluded that there are important opportunities to use forests, trees, and wood to mitigate carbon emissions and to ameliorate adverse effects from global warming. In addition, implementation of these forestry opportunities would have many positive effects on the natural environment and the economy, such as reduced soil erosion, improved water quality and wildlife habitat, and increased recreational opportunities. Urban tree planting would improve the quality of life and reduce heating and cooling costs. Implementation would also result in more jobs in tree planting, resource management, and processing of wood products.

While these opportunities offer great potential, forestry programs should not be presented as the sole solution to the climate change problem. Most forestry options offer only a short-term fix for carbon mitigation. Many other actions, such as energy conservation and the development of alternative sources of energy will also be necessary to control carbon emissions. However, with the necessary investments, trees and forests can make substantial contributions and should be included in a comprehensive program designed to mitigate climate changes resulting from the buildup of carbon dioxide in the atmosphere.

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APPENDIX 4 -- COST-EFFECTIVENESS OF FORESTRY SINKS BY TYPE OF TREE SPECIES

For the purposes of this report, a separate analysis was undertaken to assess the cost-effectiveness of forestry sinks for specific tree species. Particular species of trees are better suited for specific regions of the United States, but some are suitable in multiple areas. For the purposes of this analysis, the cost-effectiveness of forestry sinks relating to five tree species was examined.

One species assessed was the loblolly pine, the leading commercial timber species in the southern United States. It reaches biological maturity in approximately 150 years and its typical rotation age is 45 years. Its natural range is typically in the southeast; however, due to its ability to grow on a variety of soils, it is utilized in many regions of the United States.

Another important species consists of the oak trees. Due to their sturdy nature and appearance, the oaks are well known for their historic and ornamental role. Their prominence in urban settings may make them good candidates for urban sequestration programs. Their average rotation age is 100 years, since they generally grow more slowly than other types of trees. Depending upon the specific oak species, their natural range is in the eastern part of the country, typically east of the Rocky Mountains. However, a few species are native to western forests and may be used in conjunction with other western species.

A third species examined will be the slash pine, which has a range similar to the loblolly pine. While the loblolly and the slash pine are often employed in different projects, many replanting programs utilize a combination of the two. Also like the loblolly pine, it quickly preempts abandoned land and is generally cut after 30 years. Furthermore, it is often highly susceptible to damage from forest fires. Its natural range is in the Southeast, but with a more limited range than the loblolly pine.

A fourth species is the longleaf pine. Of the same family as the longleaf and loblolly, this species has been heavily impacted by land development and little remains of its natural range. However, efforts have been made to restore the species, partly due to its resilience to forest fires. This species average rotation age is 55 years and its range is in the Southeast, typically near the wet coastal sections.

The Douglas fir comprises about 50 percent of the standing timber of forests in the western United States. It is also commonly used as a Christmas tree. There are two varieties, one typically located in the Northwest and the other in the Rocky Mountain region. While the species is often a key component of an old growth forest, it is often used commercially with an average rotation age of 100 years.

Seedling Costs

To gain a rough understanding of the overall costs of a replanting program, one must first determine the costs of a single tree for the above species. The cost of a single tree is based upon the price of an individual seedling raised in a nursery (Burch 1999; Gramling 1999).[11] As noted in Appendix 4A, the cost for a nursery-raised loblolly pine, oak, slash pine, longleaf pine, and Douglas fir is $0.033, $0.185, $0.33, $0.065, and $0.15, respectively. The cost of an individual seedling may rise as a sequestration program becomes more expansive and includes more projects, thus raising the demand. However, the rise in price will likely depend on how extensive the project becomes. A program that incorporates very little new land into forest cover will have relatively little impact on the seedling cost. Another factor in determining the cost of replanting programs is the ability of the different species to sequester carbon.

The cost-effectiveness of a sequestration program will likely be based on the price-per-unit of carbon. Some species, for example, sequester more carbon than others, but are relatively more expensive. The average sequestration values for the lifetime of the project are depicted in Table 4.8 below.[12] While the seedling cost of some species are typically more expensive, the cost-effectiveness will depend on the dollars per Mg of Carbon (Mg C), as shown in Table 4.8. There is some variation between the different species; however, the cost of a program will largely depend on other factors besides seedling cost.

Table 4.8: Unit Sequestration costs for seedling and forest project

Tree Species	**Seedling Sequestration (Mg C/tree)[13]**	**Seedling Sequestration Cost ($/Mg C)**	**Total Forest Sequestration (Mg C/ha)**	**Unit Carbon Cost ($/Mg)**
Loblolly Pine	0.16	0.21	209	8
Oak	0.32	0.58	161	11
Slash Pine	0.16	2.06	209	10
Longleaf Pine	0.12	0.54	209	8
Douglas Fir	0.37	0.41	368	8

Cost per Hectare

The next step in determining the costs of a replanting program involves applying the cost of an individual tree to a replanting program over the life of the project by incorporating several factors into the estimates (Appendix 4A**.** These figures include the costs of the following: the seedling, site preparation, planting, post-planting inspection, release treatments to reduce the effect of competing vegetation, and pre-commercial thinning. These costs do not include commercial entry; therefore, it is assumed that no logging has occurred on the land. Thus, the value of the wood produced is not factored into the cost estimates. The impact of allowing logging as a part of the program will be discussed later. In addition, land costs are not contained in these values, but will be discussed in another section as well. It is important to note that these

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[11]. The cost of planting a seed is not estimated because most programs will utilize seedlings.

[12] Values in this section represent a project lifetime of 50 years. Some variation in the values may occur after that time period (Appendix 4B). The sequestration potential is based upon an average of the values in Appendix 4B.

[13] Carbon sequestration based upon average per region from Appendix 4B.

costs are rough estimates, since many factors depend on the quality of the soil, type of planting required, and terrain of the land. The per-unit costs of sequestering a mega gram (Mg) of carbon for the various species are listed in Table 4.8 above.

While the costs listed above will be altered by important factors, as will be indicated later, these numbers provide some insight into the variation between the different species.[14] This will lead to different costs for an individual program. For example, a planting program that utilizes oak will cost approximately twenty-five percent more (in the seedling cost) per unit of carbon than a program that utilizes Douglas fir. Therefore, the cost variation coupled with the natural range of the various species will be important factors in deciding which species to utilize in a given region. Some species, such as the Douglas fir, will be suitable only in certain climates, while others, such as the loblolly pine, will be viable options in several regions of the United States.

Value of the Land

The cost and availability of land may be major factors in the success of a replanting program. While it is difficult to predict future land values, economists typically use the rental rate[15] to make this estimation. This rate will depend on the availability of the land and value of the next best alternative. For example, agricultural land that could be converted into a housing development will be economically more valuable than property where such an option does not exist. For some landowners the choice will be between continuing to produce crops on marginal land or selling the land to another individual. Therefore, the possible alternative uses of the piece of land will impact the price. The disparity between the cost of different uses of the land is depicted in Appendix 4C. By incorporating the rental costs into the overall cost of the program, the total cost of the program for each species rises (Appendix 4B). Hence, the value of the land is an important contributor to the overall cost-effectiveness of a species.

On average, the cost of the land accounts for approximately 15, 46, and 23 percent of the costs on forestland, cropland, and pastureland, respectively. Therefore, the price of the land will be a major factor in the overall cost of a program. In most instances, it is difficult to predict the potential cost of the land, thus the actual cost of a program will largely be determined on a case-by-case basis. However, approximating land values will help decide which types of land (i.e., forestland, cropland, or pastureland) will be cost-effective in a reforestation or afforestation project. Further research will be needed to determine the exact variation between the different land uses.

However, Table 4.8 shows that in most instances the per-unit cost of cropland will be higher than forestland and pastureland. Therefore, the overall cost of a sequestration program will be determined mostly by the quantity of land available for a sequestration program in the various uses (i.e., forestland, cropland, and pastureland).

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[14] However, it is important to note the relative similarity between the species. This similarity is partially due to the fact that it was assumed that the cost of site preparation and commercial thinning were fairly similar for each species. The greatest variation is in the West where site preparation is likely to be more expensive due to difficulty in accessing the land.

[15] Cost of the land based on the next available option. If land could be put to use in agriculture, for example, the rental rate includes the cost of not putting the land into the production of crops.

Appendix 4A: Individual Seedling Cost and Quantity Per Hectare

Species	**Number of Seedlings** (per ha) **(1)**	**Seedling Cost** ($/tree) **(2)**	**Annualized Seedling Cost** ($/tree) **(3)**
Loblolly Pine	1,343	0.033	0.00066
Oak	494	0.185	0.0037
Slash Pine	1,343	0.33	0.0066
Longleaf Pine	1,730	0.065	0.0013
Douglas Fir	988	0.15	0.003

(1) Based on values from Forest Service nurseries (Burch 1999; Gramling 1999). Values are in dollars per seedling.

(2) Average number of seedlings per hectare (Burch 1999; Gramling 1999). All values converted from acres to hectares: 1 acre = 0.405 hectare (ha).

(3) Seedling cost per year based upon a project length of 50 years. [(Column 2)/50].

Appendix 4B: Discounted Costs over the Lifetime of Project ($/hectare)

Species (1)	**Total Seedling Cost** (2)	**Site Preparation** (3)	**Planting Cost** (4)	**Site Inspection** (5)	**Release Treatment** (6)	**Pre-commercial Thinning** (7)	**Total Cost for Lifetime of Project** (8)
Loblolly Pine	44	185	145	14	1,221	82	1,691
Oak	91	185	145	14	1,221	82	1,738
Slash Pine	443	185	145	14	1,221	82	2,090
Longleaf Pine	112	185	145	14	1,221	82	1,759
Douglas Fir	148	457	296	14	2,034	172	3,121

* These values are discounted at a real rate of 5%.

(2) Value from Appendix 4A column (1) multiplied by column (2).

(3) For species generally in the West, numbers are based on value of $457 per hectare. However, the costs range between $370 and $741 per hectare. For species generally in the East, costs are based on value of $185 per hectare.

(4) Values for Western species are based on cost of $296 per hectare. However, cost ranges between $198 and $494 per hectare. Eastern species are based on cost of $145 per hectare. This cost ranges between $123 and $185 per hectare.

(5) Inspect the plantation to assess health of forest, i.e., if the seedlings are surviving. Occurs usually in year 1 and year 2. Therefore, value is based on cost of $7.41 per hectare per year.

(6) The cost of controlling for weeds without the use of herbicides. Cost range for this practice is $741 to $1728. Usually occurs in year 3 and 5. Values are for both years together, because if treatment is needed, it is necessary in year 5 as well. Values for loblolly pine, oak, longleaf pine, and slash pine on based on cost of $741 per hectare per year. This cost was chosen since treatment is not always needed in the East where there is enough water to protect against competing vegetation. Cost for Douglas fir is based on $1234 per hectare per year, since the Western landscapes usually lack the necessary water to defend against competing vegetation.

(7) Thinning the forest to maximize growth of the trees. Usually done when tree is between the ages of 10 and 15 years. For the values in the table thinning was assumed to occur in year 12. The range for Western projects is between $247 and $370 per hectare. The range for eastern programs is between $123 and $185 per hectare.

(8) Columns added together for total cost over the lifetime of the project.

Appendix 4C: Average Annual Rental Rates by Region

Region	Rental Rates for Each Land Use ($/ha/yr)		
	Cropland	Forest land	Grazing land
Northeast	99.3	29.6	47.7
Appalachian	95.3	24.7	43.5
Southeast	75.3	22.2	39.5
Lake States	113.1	17.3	36.3
Corn Belt	172.3	22.2	52.6
Delta States	90.1	14.8	29.1
Northern Plains	71.1	12.3	18.0
Southern Plains	59.3	9.9	16.0
Mountain	44.0	17.3	20.0
Pacific	103.7	9.9	22.2

* Values are based on average regional rental rates for the various regions and are not discounted (Moulton and Richards 1990).

Appendix 4D: Costs with Total Cost of Land Included ($/hectare)

Species	Forestland		Cropland		Pastureland	
(1)	Rental Rate (2)	Total Cost (3)	Rental Rate (4)	Total Cost (5)	Rental Rate (6)	Total Cost (7)
Loblolly Pine	365	2,056	1,534	3,225	639	2,330
Oak	310	2,048	2,227	3,965	639	2,377
Slash Pine	345	2,435	1,515	3,605	621	2,711
Longleaf Pine	401	2,160	1,369	3,128	730	2,489
Douglas Fir	256	3,377	1,899	5,020	383	3,504

(1) Loblolly pine was assumed to grow in the Northeast, Appalachian, Southeast, Delta States, and Southern Plains; oak in the Northern Plains and Corn Belt; slash pine in the southeast and Delta States; longleaf pine in the Southeast; and Douglas fir in the pacific and mountain.

(2) Rental rate is an average of the forestland rental rate (Appendix 4C) for the regions where the species will potentially be utilized.

(3) Rental rate (Column 2 above) is added to Column (8) Appendix 4B.

(4) Rental rate is an average of the cropland rental rate (Appendix 4C) for the regions where the species will potentially be utilized.

(5) Rental rate (Column 4 above) is added to Column (8) Appendix 4B.

(6) Rental rate is an average of the pastureland rental rate (Appendix 4C) for the regions where the species will potentially be utilized.

(7) Rental rate (Column 6 above) is added to Column (8) Appendix 4B.

Appendix 4E: Impacts of Logging

Species	**Average Rotation Age** (years) **(1)**	**Average Cost** (\$ Ha^{-1} yr^{-1}) **(2)**	**Stumpage Price** (\$ cu ft^{-1}) **(3)**	**Average Volume of Merchantable Wood** (cu ft ha^{-1} yr^{-1}) **(4)**	**Total Price of Merchantable Wood** (\$ ha^{-1} yr^{-1}) **(5)**	**Annual Profit** (\$ ha^{-1} yr^{-1}) **(6)**
Loblolly Pine	45	56	2.40	140	336	280
Oak	100	28	3.54	78	276	248
Slash Pine	30	97	2.40	135	324	227
Longleaf Pine	55	47	2.40	86	206	159
Douglas-Fir	100	40	3.12	138	431	391

(1) Rotation age based on typical rotation cycle or maturation period (Moulton and Richards 1990).

(2) Based on average of all land uses (forestland, cropland, and pastureland) from appendix 4. The value is then divided by the average rotation age to achieve the average cost per year.

(3) The price of the raw log prior to being processed. Pine values based on approximation from Beckwith et al. All pine assumed to be the same price since the different species are generally sold for the same use. Oak price based upon Pennsylvania Woodlands: Timber Market Report 1999 using an estimate from the given numbers. Douglas fir price was taken from average of 1996 stumpage prices for the Pacific Northwest (Haynes 1998).

(4) Based on values from Moulton and Richards 1990 (converted from acre to hectare).

(5) Column (3) multiplied by Column (4).

(6) Column (5) minus Column (2).