CORRIM: Phase I Final Report

Module N

TRACKING CARBON FROM SEQUESTRATION IN THE FOREST TO WOOD PRODUCTS AND SUBSTITUTION

July 1, 2004

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EXECUTIVE SUMMARY

Forest management's role in carbon cycling is often viewed as one of expanding the terrestrial pool in forested ecosystems, and many conclude that the removal of timber for storage in product form does not lead to reductions in atmospheric concentrations of carbon dioxide. This study tests the conclusion by analyzing the forest's role in carbon cycling using an accounting system that tracks carbon from sequestration to substitution in forest product end-use markets. Various models are used to convert carbon into comparable units during its forest stage through to its product pool stage. The amount of carbon embodied in wood and competing products in end-use markets are taken from a life cycle inventory and analysis study on housing construction. The study concludes that forest management leads to a significant reduction in atmospheric carbon by displacing more fossil fuel intensive products in housing construction. However, forest management's role in global warming can be recognized only if this displacement is included in carbon accounts. The result has important policy implications since any incentive to manage forest lands more intensively would likely increase the share of lands positively contributing to a reduction of carbon dioxide in the atmosphere, a position that is not supported by the Kyoto Protocol which only recognizes terrestrial pools of carbon.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Many studies conclude that forest management for timber products will lead to lower forest carbon stocks, and hence more emissions of carbon dioxide and higher carbon concentrations in the atmosphere. Cooper (1983) was among the first to demonstrate that converting a forest region of fully stocked mature stands into managed stands decreases the forest carbon stock by about two thirds. Harmon et al. (1990) used simulations to illustrate the reduction and subsequent time path of forest carbon when an old growth forest is converted to younger plantations. These early studies limited their analysis to an examination of only forest carbon. Dewar (1990) introduced forest product carbon. He showed that longer timber rotations sequester more carbon if products decay less quickly than the harvest rotation. While the Dewar (1990) study considered carbon storage in both forests and its timber products, his study did not consider embodied forest products carbon as a substitute for fossil fuel.

Energy embodied in wood products has been recognized to be an important carbon pool (Koch 1991). Yet there has been little or no analysis that tracks the movement of carbon from forest to forest products end uses accounting for embodied energy and their carbon emission implications. A notable exception is the work by Schlamadinger and Marland (1996). They analyze 4 mechanisms by which net flux of carbon to the atmosphere may be influenced through forest management. Glover et al. (2002) presents a life cycle assessment of wood versus concrete and steel in house construction concluding that houses built primarily of wood require lesser amounts of energy in their manufacture, construction and use. The present study analyzes the movement of carbon. It creates a carbon account for three stages of forests and forest products to determine whether forest management leads to more carbon emission to the atmosphere and higher carbon concentrations there. It differs from the recent life cycle assessment by Glover et al. (2002) in that the carbon account considers the forest stock, the product stock and the product market implications of carbon emissions from fossil fuel use.

The findings of this study are important in two respects. First, the study shows that management of forests can positively contribute to reduced carbon concentrations in the atmosphere. Second the study indicates that international protocols to reduce the threat of climatic change, such as the Kyoto Protocol, limit the recognition of forestry activities since such protocols do not explicitly consider the positive contributions of forest management and wood use, but rather view forest management activities as a leakage issue.

This report is organized as follows. The carbon debate and the relevance of this debate to forest management as a mitigation option are summarized in the following section. In section 3 the study approach is outlined. Model assumptions are presented in Section 4. In sections 5 and 6 the results of the analysis and related discussion are presented. The final section of the report examines the question of whether forest management leads to more carbon emissions to the atmosphere.

2.0 THE CARBON DEBATE

The most recent IPCC report (IPCC 2001) concluded that global change is occurring. The report also recommended that a life cycle analysis is needed to describe the fate of stored carbon in industrial applications, including the conversion efficiency from tree growth into wood products. However, debate leading to the Kyoto Protocol ignored stored carbon in industrial wood products as forestry options were developed. Product carbon is not recognized as a valid carbon credit, nor is the substitution effect associated with greater production of wood products from more intensive forest management.

There are three options for mitigating the rate of carbon emissions to the atmosphere associated with forests. They are 1) increasing standing carbon in vegetation, 2) increasing product carbon storage and 3) substituting for fossil fuel use in economic activity. The Kyoto Protocol recognizes only changes in vegetation carbon as legitimate carbon sequestration. A forest landowner cannot claim credit for any reduction in carbon emissions associated with forest management that leads to less steel or concrete use in the housing market for example. Hence many of the forestry-based options that have been analyzed have been limited to preservation and afforestation projects.

In this study we examine mitigation options available through forestry and forest products use in the economy. We show that, while actions on the part of a forest landowner to intensify his or her forestry practices may lead to less carbon stored in the forests, it creates positive carbon leakage through greater use of wood products in the market place. The term leakage is used since most of the impact of intensive management on carbon pools occurs outside of the forest management project boundary. The leakage is positive since it reduces emission to the atmosphere. The effect of producing and using more wood products reduces consumption of more fossil fuel intensive products in home construction. The proper boundary condition for carbon and wood flows extends beyond the perimeter of the forest area whenever wood is harvested for products.

3.0 STUDY APPROACH

The study approaches the problem of evaluating the forest mitigation option by creating an accounting method that tracks carbon from forest to product end use. We follow the approach suggested by Sampson and Sedjo (1997). The method accounts for biomass carbon, product carbon and fossil fuel substitution carbon. The sum of the three components is defined as total carbon and is measured on a per hectare basis. Comparison of the total carbon accounts across alternative management and no management scenarios are made to assess how a forest management mitigation option influences carbon sequestration and emissions. We pay particular attention to how rotation age and management intensity influence the movement of carbon in all three accounts.

The study utilizes several models that track carbon stocks and emissions from reforestation to forest product use. Models at the forest level are combined with models that describe product use and their associated emissions at the product end-use level. We discuss the models and their use in the sections that follow. But first we describe the carbon pools that are relevant to our study. This literature review becomes our basis for calibrating the carbon model.

3.1 CARBON MOVEMENT AT THE FOREST LEVEL

Forest ecosystems have essentially three carbon pools: living biomass, detritus, and soils. Forests represent a huge storage of carbon since they hold about 80 % of the carbon fixed in the living biota. Much interest and effort has been put into their study due to the fact that much of it can be directly altered by human activity. Different studies present a dichotomy on aboveground biomass dynamics, with some suggesting that aboveground components can be a net sink (Delcourt and Harris 1980, Oliver at al. 1990), or a net source (Houghton et al. 1983, Harmon et al. 1990) of carbon.

In the development of a forest, the foliage, litter fall, net wood production, and nutrient accumulation in above ground tree components usually reach a plateau as trees mature during the stem exclusion stage (Tadaki 1966, Gessel and Turner 1976, Oliver 1981, Sprugel 1985). This pattern, for example, characterizes Douglas-fir (Turner and Long 1975) and directly impacts the development of biomass through time in the various components.

The distribution of standing forest biomass in representative stands in the Pacific Northwest region has been previously estimated (Grier and Logan 1977, Keyes 1979, Edmonds 1980, Vogt et al. 1980, Cooper 1983, Keyes and Grier 1981, Santantonio and Herman 1985, Vogt et al. 1986, Edmonds 1987). Total biomass and forest carbon will depend on stand conditions such as age, density, and species composition. However, biomass distribution in coniferous stands of forests of the Pacific Northwest is very similar and is roughly as follows: 65-75% in the stem and bark, 15-20 % in coarse roots, and 5-10 % in the crown (branches and foliage). Biomass in stem and bark on a 40 year old Douglas-fir stand on a high productivity site was about 76 % (Cooper 1983; this proportion was determined to be about 73 % in a low productivity site planted with Douglas-fir (Keyes and Grier 1981). Similar values have been established for old growth Douglas-fir in western Oregon (Grier and Logan 1977).

Soils are believed to be the largest pool of carbon. Soils contain almost twice as much carbon as the aboveground vegetation and the atmosphere combined (Brady 1996). The live biomass, which includes above and below ground pools is composed of coarse roots, understory vegetation and canopy, captures carbon dioxide while releasing oxygen, and also respires, releasing part of the carbon dioxide previously absorbed. Detritus, the debris from dead plants and animals, is a source of storage as well as a source of food for life forms releasing carbon. Detritus forms soils, and soils regulate the carbon cycle through processes of decomposition and the accumulation of organic matter.

The effects of forest management on carbon soil storage are not as clear nor as well understood as our knowledge of carbon in living biomass and detritus. Estimated carbon storage in belowground components is known and has been measured (Brady 1996), but knowledge is lacking as to how harvesting and forest management affect soil carbon.

Soil carbon has been found to be strongly dependent on stand composition and climate (Schlesinger 1977). Organic carbon in the root zone accounts for approximately two-thirds of the carbon in terrestrial ecosystems worldwide (Post et al. 1982). Such carbon is less responsive to harvest than the litter fraction because of its long residence time. Post et al. (1982) estimated a soil carbon turnover rate of 0.00083 per year, although faster turnover rates have also been shown: 0.013 per year (Gardner and Mankin 1981) and 0.025 per year (Schlesinger 1977).

Harvesting can have a significant positive or negative effect on forest floor biomass, mostly based on how much slash is left behind after the harvest operation (Johnson 1992). The majority of studies however, have shown little or no change, with less than 10 % increase or decrease after harvest (Fernandez et al. 1989, Johnson et al. 1991, Aztet et al. 1989, Huntington and Ryan 1990, Alba and Perla 1990, Raich 1983). Exceptions are found in tropical areas. Several researchers suggest a much lower rate of carbon loss following harvest than the commonly held assumption of soil carbon losses of 30-40% (Musselman and Fox 1991).

Fire, be it prescribed or a wild fire, reduces carbon and the overall forest floor biomass. The effect on biomass depends on the intensity of the burn. In the Pacific Northwest, a study found significant losses of forest floor biomass and nitrogen (40%) after a wildfire (Grier 1975). Another study, where a broadcast burning was prescribed, found a decrease in soil carbon of 20 to30 percent, with an equal or higher level of soil carbon almost two years after the prescription (Macadam 1987).

Carbon within soil can be increased with fertilization through its effect on primary productivity. Nitrogen fixation and fertilization may increase soil carbon from 3% to 100% depending on the site and the species mix composition (Binkley 1983, Binkley et al. 1982).

3.2 CARBON MOVEMENT IN PRODUCTS

Harmon et al. (1990) argued that the conversion of old-growth forests to younger forests under current conditions has added and will continue to add carbon to the atmosphere, even when considering long-term products such as lumber. Oliver et al. (1990) found similar results at the forest ecosystem level, but pointed out that the conversion of old growth to managed stands is negligible when compared to the addition of carbon by the burning of fossil fuels. Both studies recognized carbon movement in products as a potentially important consideration but did not give it an adequate deliberation.

Forests store carbon as they accumulate biomass, but forests are also sources of commercial timber and wood fiber products. In most carbon accounting budgets, forest harvesting is usually considered to cause a net release of carbon from the terrestrial biosphere to the atmosphere (Houghton et al. 1983, Harmon et al. 1990). There are at least two implications of drawing the boundary on carbon movements at the edge of the forest. One, no credit is received for the carbon stored in the product pool. Second, and perhaps more importantly, the product pool represents a pool of embodied energy that has been used in its manufacture. This pool of products enters the marketplace and competes with other products that also have embodied energy used in their manufacture. The substitution of fossil fuel-based energy and products by wood biomass can further decrease the emissions of carbon to the atmosphere (Schlamadinger and Marland 1996, Kohlmaier et al. 1998).

4.0 MODELING ASSUMPTIONS

The carbon account is created using a suite of models that can be customized to different site conditions. We use conditions for the west Cascades area of the Pacific Northwest region. Tree list inventory data combined with growth and yield model simulations and the Landscape Management System (LMS) (Oliver et al. 1992) are used to simulate inventory conditions through time and create the forest account. Multipliers based on the literature review then take various biomass components and convert them into carbon on a per unit basis. The forest module calculates the carbon pools accounting for changes in growth, mortality and decomposition of various carbon pools. Products are exported from the forest module to the product module, which then calculates carbon pools in products and manufacturing centers. Each module is described in more detail below.

Use of the forest biomass module requires that a tree list be entered into the LMS, which tracks tree and stand development through time including diameter information. The diameter is used to estimate various biomass components using Ghotz (1982). Biomass is converted into carbon using Birdsey (1992, 1996). Forest components include the canopy, the stem, roots, litter and snags. The module also considers their decay. Canopy biomass is composed of foliage and branches and is 5% to 10% of the total biomass. Stems, composed of the tree trunk and bark, were assumed to make up 65% to 70% of the total biomass. Coarse roots were assumed at 20% to 25% of total biomass and carbon in litter was assumed to be 10% of foliage and branches (Spies and Franklin 1988, Edmonds 1979, Grier and Logan 1977). Assumptions as to the volume in snags were based on mortality predicted by a growth model, adjusted for the density of snag class and is less than 0.5% of total biomass (Canary et al. 1996). Carbon decomposition is modeled following Aber and Melillo (1991).

$$X_t = X_0(1 - k^* t)$$

Where X_t is the biomass at time t, X_0 is the initial biomass, k is a species specific constant describing the biomass loss per year and t is time in years. $k = 0.16$ for litter, 0.5 for snags and coarse roots (Turner et al. 1995, Harmon and Sexton 1996, Canary et al. 2000). More complex nonlinear decay models could easily be incorporated but are not likely to alter any conclusions.

The products module is based on data produced by the Consortium for Research on Renewable Industrial Materials (CORRIM) (Bowyer et al. 2004). The module tracks carbon pools associated with production of forest products from the forest through to end use in the housing sector. Products that are exported from the forest as commercial volume are first converted into biomass and then into carbon using species dependent density factors (Birdsey 1992, 1996). We use the results of sawmill studies (Bowyer et al. 2004) to distribute the commercial volume into long- and short-term products. Roughly fifty percent of the forest carbon in a harvest is exported to lumber, a long-term product. The remaining 50% of carbon is exported to wood chips, sawdust, bark, and shavings, all short-term products or hog fuel used for the production of energy. Short-term products are assumed to decay at 10% per year (Harmon et al. 1996, Winjum et al. 1996). Hog fuel is decomposed in the production of energy. Long term products are assumed to decompose at the end of the useful life of a house, which was set at 80 years, within the range estimated by Bowyer et al. (2004; Module L). Harvested timber volumes per acre are converted into product volumes, then to mass expressed in pounds per thousand board feet. Mass is then converted to carbon units considering moisture content.

Energy consumption and air emissions associated with the manufacture of products used in the housing sector are used to analyze carbon flows associated with alternative building techniques with different materials. Bowyer et al. (2004) provides an analysis of home construction in two markets with competing materials. The study utilizes a life-cycle inventory produced by CORRIM (2004) to quantify the carbon emissions and convert them to a per hectare basis to be compatible with the forest carbon account.

Bowyer et al. (2004) provides data for a 45 year rotation harvest producing the wood products for one typical wood house in the Minneapolis market. If no wood were harvested, the use of non-wood products would have to increase to support the same housing market. Substituting 4.9 metric tons of steel and additional insulation for 5.3 metric tons of wood in the steel versus wood frame construction tradeoff emits 9.8 metric tons of CO_2, based on CORRIM results. In other words, foregoing the 134 metric tons of wood products that would be produced in a 45 year rotational PNW harvest, is equivalent to emitting 266 metric tons of carbon dioxide per hectare (72.5 tons carbon) by steel frame substitution. Similarly, substituting 2000 concrete blocks, additional mortar and rebar for 1.5 metric tons of wood in the concrete versus wood-frame construction emits 7.7 additional metric tons of CO_2. So foregoing the PNW harvest is equivalent to emitting 701 metric tons of carbon dioxide per hectare (191 metric tons of carbon) by concrete frame substitution. When a harvest occurs, the carbon contained in products is moved from the forest to product account with a corresponding reduction in emissions from substitute products by the above amounts and referred to as avoided emissions. The carbon in co-products is assumed to be short lived and decomposes rapidly (10% per year).

We utilize scenario analysis to quantify the effects of rotation age on carbon accounts. The four scenarios involve 45, 80 and 120-year rotation and a no-harvest scenario. The no-harvest scenario is not equivalent to earlier natural stands since it includes initial stocking and no disturbances but offers some insight for an afforestation-without-harvest scenario.

The study creates a carbon account for each scenario. The account is composed of the carbon in forest stocks, product stocks and the emissions associated with their manufacture and use in construction. We also consider biomass as potential energy in our analysis for co-products that could be used as biofuel. The forest stock includes canopy, tree stems, snags, litter, live roots, dead roots and, when harvesting occurs, emissions of carbon. The product stock includes product carbon (both short and long lived). It includes the transporting and manufacturing emissions associated with the production of the long-lived products that are used in housing construction. The transporting and manufacturing emissions associated with non-biofuel co-products are not tracked so as to be consistent with the assumption that their use would carry their own burden. We illustrate the option of using most low-valued co-products as biofuel, thereby transferring their burdens to the completed long-lived products. The embodied energy account includes emissions associated with the use of substitute long-lived products in the housing market.

5.0 RESULTS

The results are described in four phases. The first phase consists of analyzing the change in carbon over time associated with the forest stock. The study result is consistent with previous results found in Franklin et al. 1997, Burschel et al. 1993, Houghton et al. 1983, Harmon et al. 1990, Oliver et al. 1990, Cooper 1983, Dewar 1991, and Schlamadinger and Marland 1996. Extending the rotation age increases the store of carbon associated with the forest pool. The second phase consists of analyzing the change in carbon over time as carbon is exported from the forests as products. The result suggests again that extending the rotation age increases the store of carbon in forest and product pools as the decomposition of co-products is effectively delayed. The third phase analyzes substitution and the change in emissions associated with the use of substitute products in the housing market. The result indicates that shorter rotations contribute to less carbon emissions since the impact of reducing the use of fossil fuel-intensive, non-wood products more than offsets the effect of the reduced carbon stored in the forest. The fourth phase studies the impact of more intensive management on carbon pools. The result indicates that greater management intensity contributes to less carbon emissions, and is generally more effective in reducing emissions than long rotations especially when economic costs are considered.

5.1. CARBON IN FOREST STOCKS

Figure 5.1 illustrates the change in forest carbon stocks over time under 4 alternative management scenarios. Carbon in metric tons per hectare increases as the forest grows, declines sharply as harvests take place, and responds with renewed growth under all scenarios except with the no action scenario. Under the no action scenario, carbon increases for several hundred years assuming no major disturbance. The assumption of initial stocking followed by no disturbances is not representative of old forests under natural conditions, so it should be interpreted with caution. The no-action scenario demonstrates a hypothetical upper bound to forest growth as an afforestation scenario. Empirical yields for existing old forests in the Northwest contain only slightly more carbon than the 120 year rotation as a consequence of uneven stocking and disturbances, whereas this hypothetical upper bound suggests much more carbon.

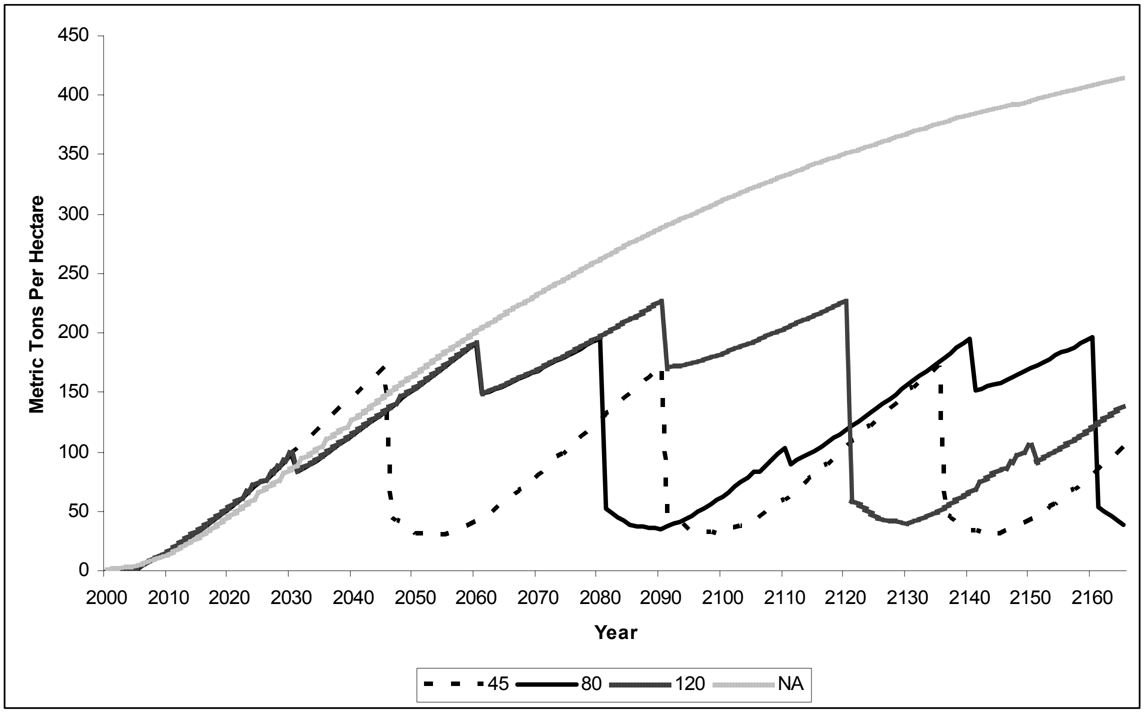

Figure 5.1. Carbon in forest pools for different rotations.

The area under each curve is the cumulative carbon and one can observe that over time, the most carbon is accumulated under the no action scenario, followed by the 120 year rotation scenario, then the 80 year rotation scenario and finally the 45 year rotation scenario. Figure 5.2 shows the sub-accounts leading up to the cumulative carbon pools for the 80 year rotation including two thinning treatments demonstrating that carbon in the stem of the tree is most important, with some offsetting influences over time from decaying litter and roots. For any given repeated treatment scenario forest carbon ultimately reaches a long term steady-state condition. Even the no management scenario will ultimately succumb to disturbances, and so long as the next cycle is similar to the prior cycles, a long-term, steady state condition will be reached.

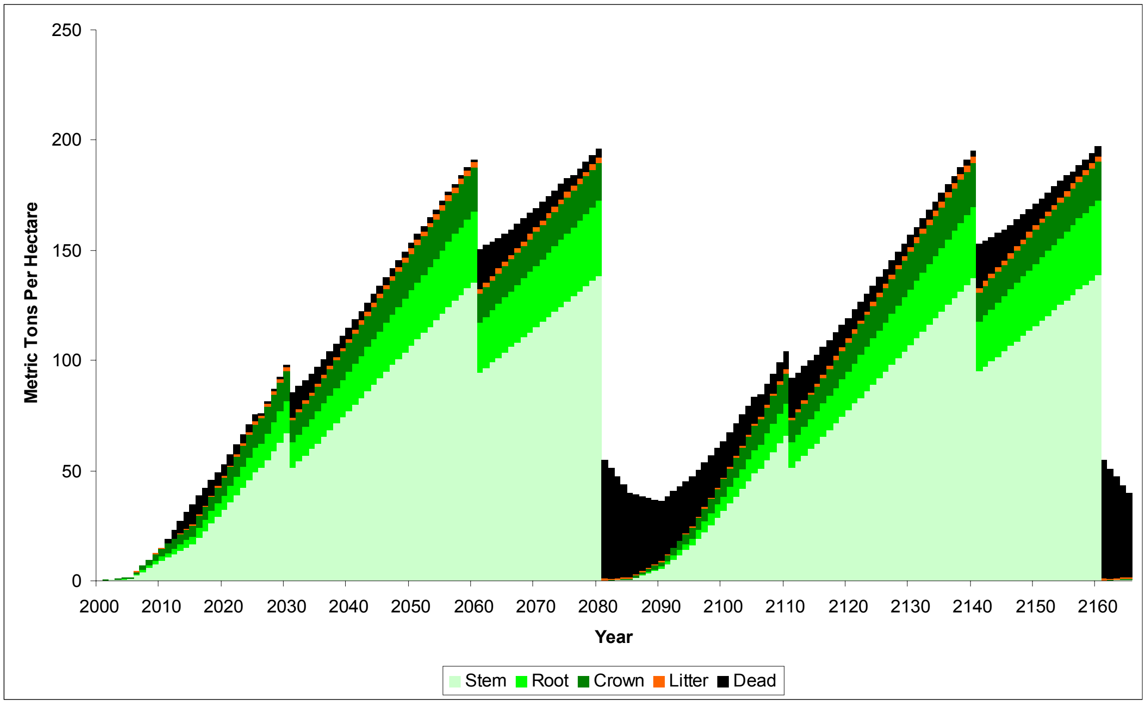

Figure 5.2. **Carbon in the forest pools for an 80 year rotation.**

5.2. EXPORT OF CARBON IN FOREST PRODUCT

The fate of harvested carbon needs to be accounted for however. As forest carbon is exported into products, product carbon pools develop. Figure 5.3 summarizes the carbon in product pools for the 80 year rotation. It shows that product pools more than offset harvesting and manufacture emissions. There is no carbon associated with products under the no-action scenario since this scenario does not export products. For the longer rotation scenarios the product pools develop much later in time than for the short rotation scenarios. The carbon in short-lived products is assumed to decompose completely during the rotation period contributing no long-term increase to the products carbon pool over time.

Alternatively, any portion of these short-lived products can be used for energy production which would reduce purchased energy needs. The effect of such a decision is that the energy produced and the carbon emissions saved by substituting for fossil fuels becomes a permanent carbon pool instead of a short-lived product that is rapidly decomposing. A longer-term pool than even wood products in buildings which eventually decompose is created under such an energy substitution scenario. But in the very short term, there is a loss in the short-lived products pools as the efficiency of the conversion of wood to energy is lower than gas fired boilers (or coal). The net impact is a small displacement of fossil fuel derived carbon in the short term, but accumulating with each harvest. The decomposition of the long-term products is assumed to take place at the end of an 80 year useful life of the house which could more correctly be modeled as a distribution with some houses removed earlier and others later with no material change on long-term comparisons.

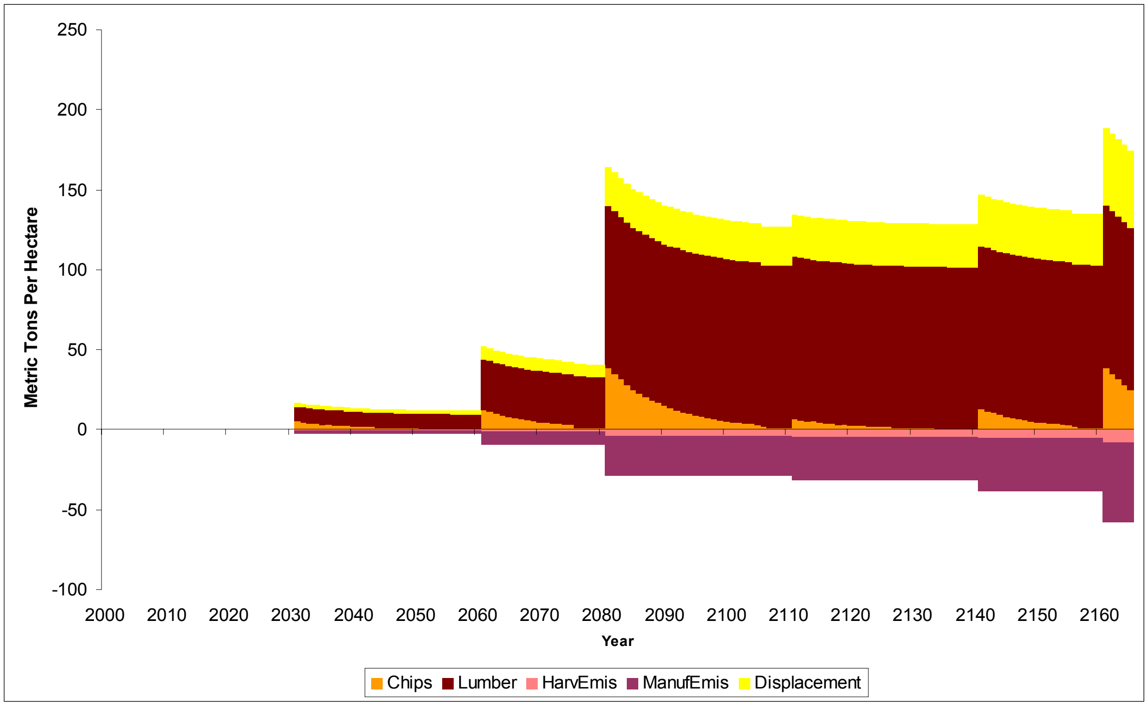

Figure 5.3. **Carbon in the products pools for an 80 year rotation.**

Figure 5.4 combines the forest and product pools over time for the four scenarios. As in Figure 5.1, the no-action scenario contains the most carbon (area under the curve). The 45-year rotation contains the least carbon. Unlike forest carbon which reaches a long term steady state, there is an upward trend in the carbon stored in products as the decomposition is slower than the rate products are produced. The figure includes the impact of using the non-structural co-products other than chips for energy rather than other short lived products, boosting the long-term storage somewhat consistent with mills that produce most of their own energy needs from wood biomass. For the 45 year rotation this displacement for the carbon from purchased energy increases from 13% of the net product pool over the first 80 years to 19% over the first 120 years, and 29% over 165 years demonstrating the accumulative nature of displacement.

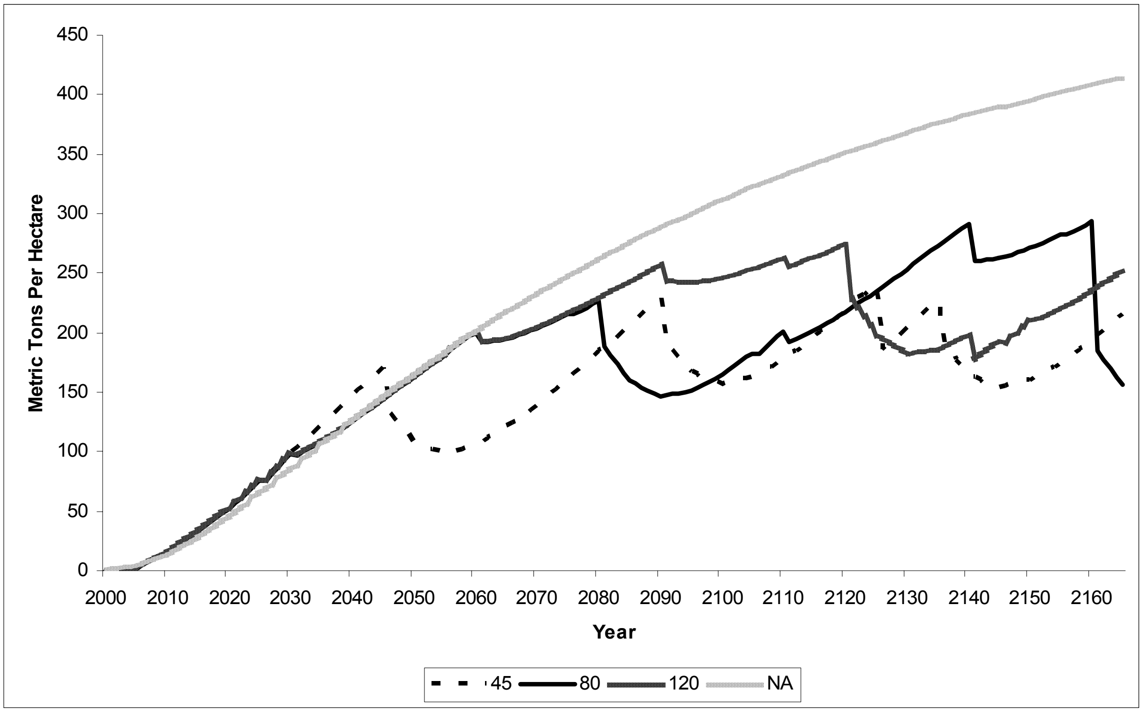

Figure 5.4. **Carbon in forest and products pools in metric tons per hectare.**

5.3. SUBSTITUTION EFFECTS

Wood enters the marketplace and competes with alternative materials in end uses such as housing. Without wood products, less wood houses would be built and more concrete or steel-framed houses would be constructed. The energy burden each product carries has implications for carbon emissions. Figure 5.5 summarizes the carbon pools for the 80 year rotation including the carbon resulting from displacing cement-framed houses as wood products are produced. The increasing trend in carbon pools is substantially greater with the substitution of wood for cement, the second most prevalent framing material in the residential housing market.

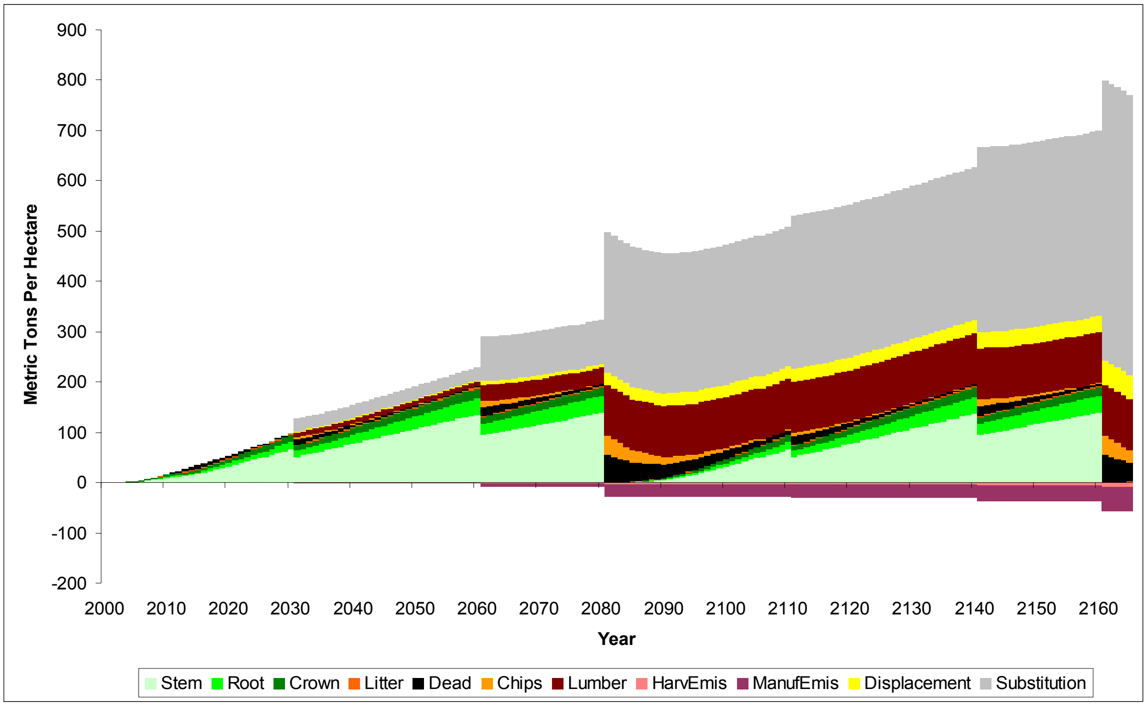

Figure 5.5. **Carbon in the forest and product pools with concrete substitution for the 80 year rotation.**

Table 5.1 summarizes the carbon account averages for intervals of 0-45, 0-80, 0-120 and 0-165 for each of the rotation scenarios and product pools (forest, products, displacement and substitution). Figure 5.6 summarizes these impacts for each rotation and time interval. Unlike the previous charts which show carbon increasing with longer rotations the figure indicates an inverse relationship between rotation age and sequestered carbon with the least amount of carbon stored with the no action alternative. When the fossil fuel burdens in substitute products are included, the shorter rotations gain the benefit of this displacement sooner. While it may be true that over the very long term, the increased volume coming from longer rotations will eventually overtake the early shortfall in products the time frame for this crossover would appear to be in the hundreds of years and beyond any interval of interest for policy.

Table 5.1. Average annual carbon for all rotations at specified intervals in metric tons per hectare.

	averages			
	0-45	0-80	0-120	0-165
45 year rotation BASE				
NET FOREST	70.60	67.30	71.25	74.45
NET PRODUCTS	0.00	24.74	45.38	50.72
NET FOREST & PRODUCTS	70.59	92.03	116.63	126.96
NET FOREST, PROD, DISPLAC.	70.59	95.56	125.46	142.20
NET FOR, PROD, DISPLAC, SUBST.	70.59	165.69	266.18	360.28
80 year rotation				
NET FOREST	60.46	106.90	94.45	110.50
NET PRODUCTS	3.63	11.22	36.92	46.96
NET FOREST & PRODUCTS	64.10	118.12	131.37	157.46
NET FOREST, PROD, DISPLAC.	64.24	119.58	138.27	169.75
NET FOR, PROD, DISPLAC, SUBST.	72.63	150.76	253.16	348.81
120 year rotation				
NET FOREST	60.46	106.95	137.38	121.30
NET PRODUCTS	3.63	11.32	21.08	41.39
NET FOREST & PRODUCTS	64.10	118.27	158.85	163.66
NET FOREST, PROD, DISPLAC.	64.24	119.69	163.14	174.12
NET FOR, PROD, DISPLAC, SUBST.	72.63	150.87	232.20	330.64
No Action				
NET FOREST	60.17	124.03	185.53	238.55
NET PRODUCTS	0.00	0.00	0.00	0.00
NET FOREST & PRODUCTS	60.17	124.03	185.53	238.55
NET FOREST, PROD, DISPLAC.	60.17	124.03	185.53	238.55
NET FOR, PROD, DISPLAC, SUBST.	60.17	124.03	185.53	238.55

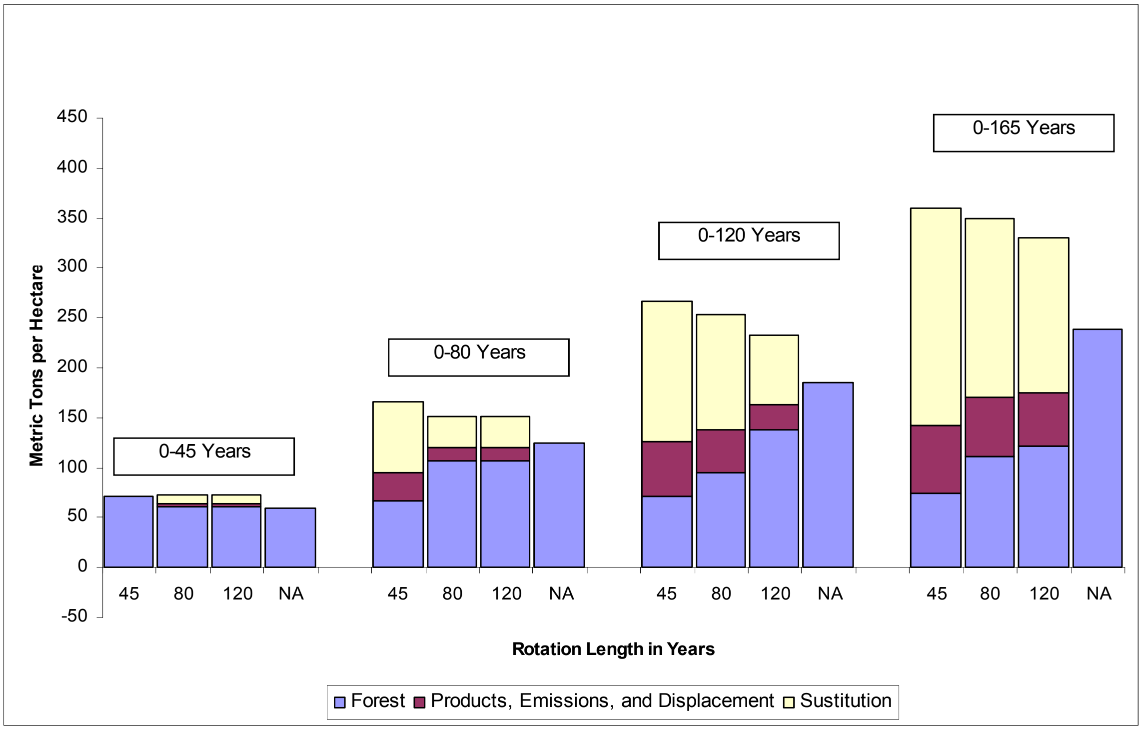

Figure 5.6. **Average annual carbon in forest, product and concrete substitution pools for different rotations and specified intervals.**

5.4 MANAGEMENT INTENSITY

Since the results indicate that forest management leads to more forest products, and that by displacing fossil-fuel intensive products in an end-use market such as housing construction it reduces atmospheric carbon, we explore the implications of intensively managing the forest. The objective of greater forest management is to increase commercial volumes that can be harvested and measure their contribution to the carbon in the products pool. Many acres of industrial forestland are not intensively managed but could be with a small incentive, so such a scenario is relevant to current forest management policies.

The result (Table 5.2 and Figure 5.7) indicates that an increase in management intensity leads to greater carbon pools when we consider the market substitution effects. Under the 45-year rotation age and under greater management intensity, net carbon increases from 72 metric tons per hectare to 89 metric tons per hectare, a 24% increase over the 45 year interval. Net carbon reaches 410 metric tons per hectare over 165 years with intensive management compared to 365 tons, a 12% increase compared to the base case. Extending the rotation just a few years, i.e. 55 years in the illustrated scenario, under intensive management allows the release of increased growth on fewer trees to catch up with the volume removed from the forest. It results in another 2% increase in carbon. But this increase in carbon comes at a substantially greater economic cost and hence would not likely be a cost-effective management option.

Table 5.2. Average annual carbon for all management intensities at specified intervals in metric tons per hectare.

	averages			
	0-45	0-80	0-120	0-165
45 year rotation BASE				
NET FOREST	70.60	67.30	71.25	74.45
NET PRODUCTS	0.00	24.74	45.38	50.72
NET FOREST & PRODUCTS	70.59	92.03	116.63	126.96
NET FOREST, PROD, DISPLAC.	70.59	95.56	125.46	142.20
NET FOR, PROD, DISPLAC, SUBST.	70.59	165.69	266.18	360.28
45 year rotation High				
NET FOREST	69.47	68.33	71.95	74.47
NET PRODUCTS	5.07	30.36	51.10	56.68
NET FOREST & PRODUCTS	74.53	98.69	123.60	133.14
NET FOREST, PROD, DISPLAC.	74.81	103.24	134.34	151.14
NET FOR, PROD, DISPLAC, SUBST.	86.93	190.53	300.61	404.98
55 year rotation				
NET FOREST	69.71	77.49	89.77	96.05
NET PRODUCTS	5.25	29.88	50.09	54.46
NET FOREST & PRODUCTS	74.96	107.36	139.86	152.27
NET FOREST, PROD, DISPLAC.	75.16	111.00	149.30	169.56
NET FOR, PROD, DISPLAC, SUBST.	87.28	192.57	305.61	411.52
No Action				
NET FOREST	62.06	125.73	186.90	239.61
NET PRODUCTS	0.00	0.00	0.00	0.00
NET FOREST & PRODUCTS	62.06	125.73	186.90	239.61
NET FOREST, PROD, DISPLAC.	62.06	125.73	186.90	239.61
NET FOR, PROD, DISPLAC, SUBST.	62.06	125.73	186.90	239.61

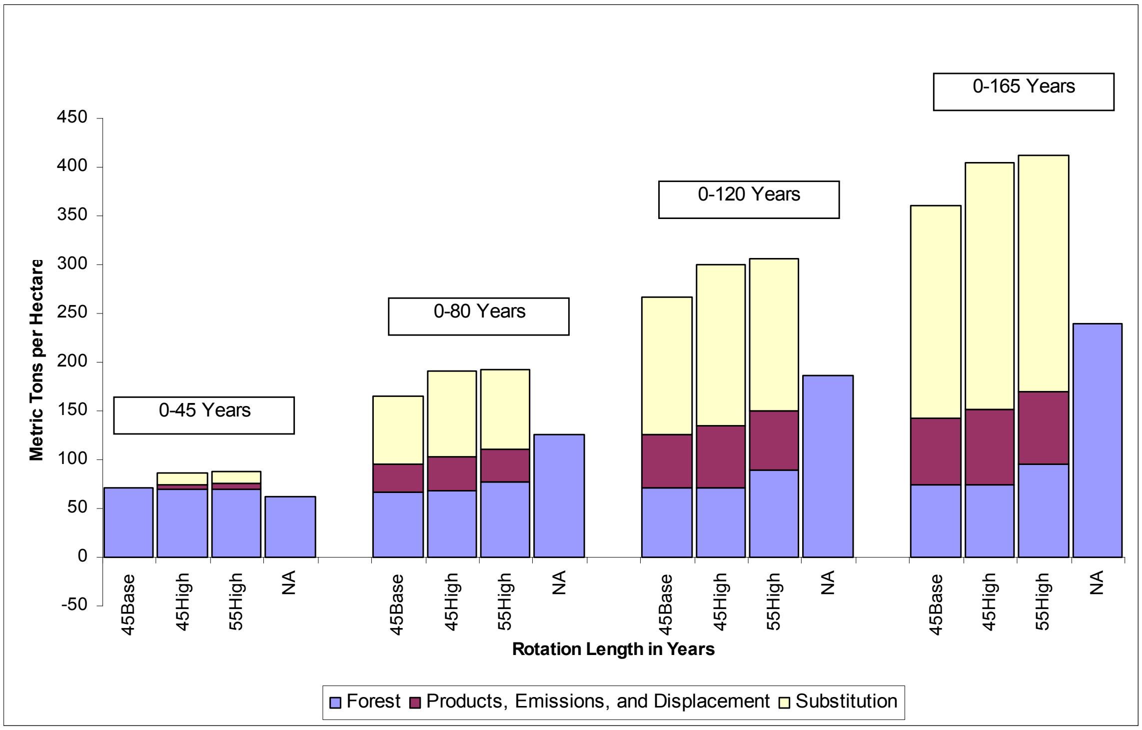

Figure 5.7. **Average annual carbon in forest, product and concrete substitution pools for different management intensities for specified intervals.**

5.5 ECONOMIC TRADEOFFS

The economic cost of long rotations (Stand Expectation Value (i.e. bare land value) at 5% real discount rate) is high as is shown in Figure 5.8. The economic cost of intensive management is sensitive to treatment costs and market returns and may even be positive (as shown for 45 High) unless the treatment extends the rotation length significantly. Our scenarios show a $503 loss for extending the rotation to 55 years producing an insignificant carbon increase in the short term and only 6.5 metric tons over 165 years. This is equivalent to a production cost of $77 per ton of carbon sequestered. However, many land mangers have not taken the risk of the increased investment associated with intensive management over a 45 year rotation so it may take very little in additional compensation from carbon credits to gain 17 metric tons of carbon/hectare in the short term and 45 metric tons over 165 years. The investment could contribute roughly 30 to 80 million tons of additional carbon on private lands for Washington State alone.

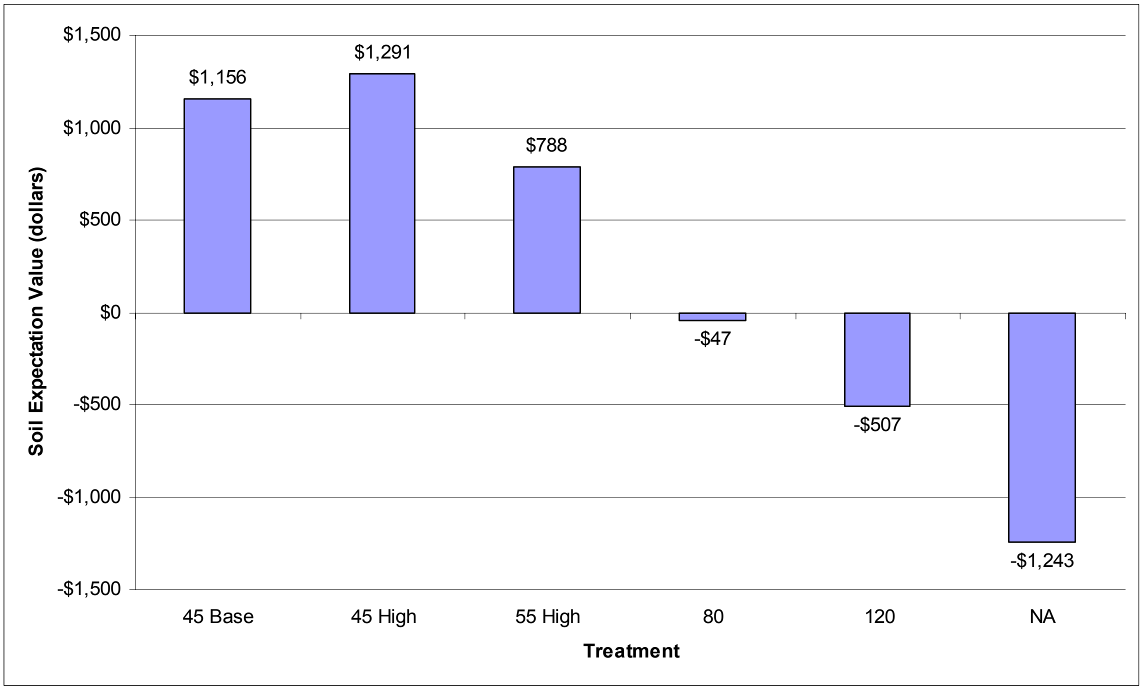

Figure 5.8. **Soil Expectation Value for each rotation length and management intensity.**

6.0 DISCUSSION

The paper constructs an accounting scheme that considers carbon from forests to end-use markets of forest and competing products. The accounting scheme combines three phases of a forest-based mitigation option of potential climate change where forests may play a role. The carbon phases are the forest pool, the product pool and the product substitution pool. This last pool includes the energy-use and carbon-emission implications of competing products.

The result indicates that a shorter rotation age does not lead to greater carbon emissions into the atmosphere. Short rotations produce more wood products sooner thereby reducing fossil fuel-intensive substitutes earlier in time. Forests managed under short rotations sequester less carbon than forests managed over longer rotations, but avoid and displace emissions associated with production and use of energy-intensive, competing products. Avoided emissions generally exceed any reductions in sequestration in the forest. The net result is that more carbon is sequestered in the forest and wood products under short rotations when the embodied energy pool is included.

This result also holds with more intensive forest management. Greater management activity in forestry leads to more products and greater amounts of carbon sequestered in the combined forest, forest products and displaced energy pools.

The result depends upon the kind of substitution that takes place in the market. While the market for residential houses is dominated by wood frame housing, followed by concrete, steel-framed housing has gained a 2% share in recent years. Figure 6.1 demonstrates that the impact of substitution between wood and steel frame produces less carbon in the substitution pool than concrete, but still demonstrates the benefits of using wood.

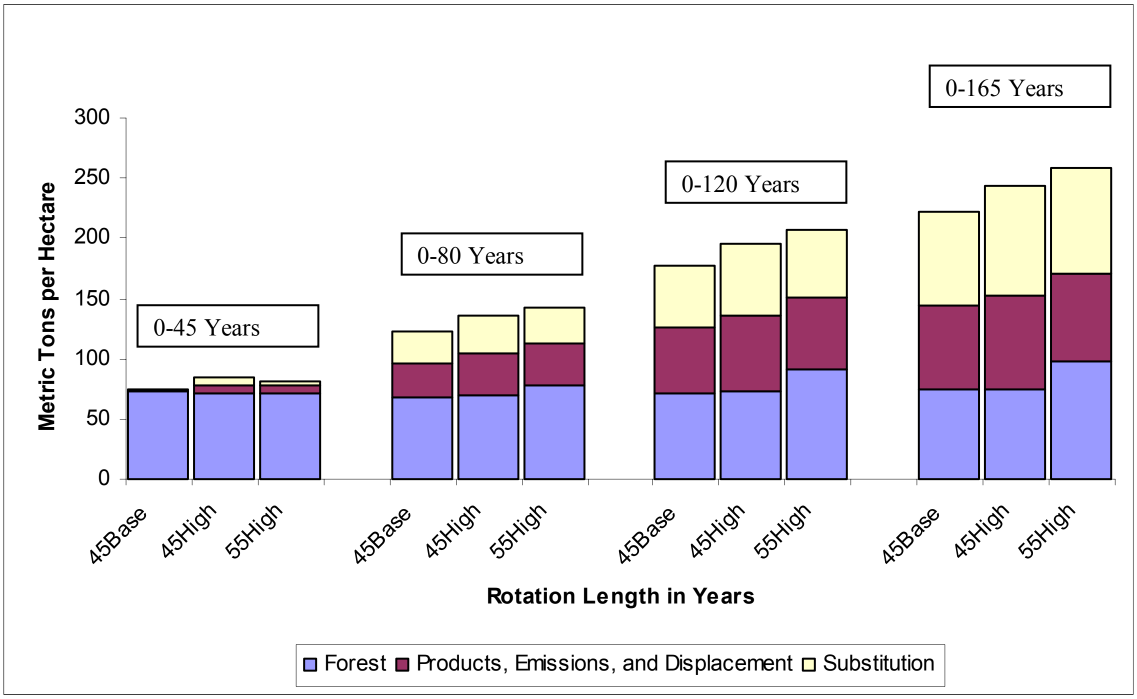

Figure 6.1. **Average annual carbon in forest, product and steel substitution pools for different management intensities for specified intervals.**

A major implication of the study is that forest management contributes in a positive fashion to mitigating potential climate change. Yet this positive contribution is not explicitly recognized in the Kyoto Protocol. The Kyoto Protocol only recognizes the reduction in forest carbon, and does not consider any other contribution to carbon sequestration that products exported from the forest may contribute. It is through market substitution that forest management leads to a net decrease in atmospheric carbon. While less carbon may be stored in the forest (average forest carbon over time is lower for shorter rotations) more carbon is exported from the forest and conserved in products, and less fossil fuels are utilized by economic sectors such as the housing sector. Leaving out the carbon stored in wood products and the impact of non-wood substitute products may be counterproductive to carbon policy objectives.

The implications of recognition for forest management's positive role in sequestering carbon is important since it could be used as an incentive to more actively manage many acres of forestlands. Increasing the productivity of these lands through greater investments in forest management could lead to significant gains in reducing atmospheric carbon.

The CORRIM report of which this is a part (Bowyer et. al 2004) develops life cycle inventory measures of carbon in support of housing. Live cycle analysis does not consider time and hence infers steady state results. This module demonstrates that when the focus is changed to looking at the implications for managing a fixed unit of land over time, carbon pools are not static but increasing so long as the products are serving long-term product markets. This analysis does however assume that the energy used by the housing occupants or the users of short lived products are burdens for those users and not the forest management system. The CORRIM report does consider the energy used in housing as a part of an integrated analysis.

7.0 CONCLUSION

The study analyzes carbon from sequestration in a forest to substitution of fossil fuels emissions from construction materials. When carbon stocks account only for forest sequestration, the longer the rotation the greater the amount of carbon removed from the atmosphere. Even if we are to consider the export of carbon from the forest into product markets, and even if the rate of exported carbon is greater than the rate of tree growth, conversion inefficiencies and eventual decay limits the amount of carbon removed by forests from the atmosphere. Only when product substitution is considered in the analysis do we find that forestry can lead to a significant reduction in atmospheric carbon by displacing more fossil fuel-intensive products. The current structure of the Kyoto Protocol does not recognize this contribution. Only through credit of the positive leakage from forest management projects into products can intensive forestry produce reduced atmospheric carbon within the Kyoto Protocol framework. Recognizing only the carbon stored in forests incorrectly subsidizes doing nothing or lengthening rotations which are counterproductive to the buildup of carbon in the product market pools. Even a small incentive for more intensive management would likely increase the share of lands so managed producing a substantial increase in carbon pools.

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