The Role of Forests, Management, and Forest Products on Carbon Mitigation

Some argue that preserving forests stores more carbon than using those same forests to manufacture products. Others maintain that the carbon in the forests would neither increase nor decrease over the long term if we avoided deforestation (land use conversion). Some find that intensive forest management stores more carbon at lower cost than extended rotations. Some claim the carbon stored in products is not important since it deteriorates over time releasing carbon emissions. Others show the buildup of carbon stored in wood products exceeds the carbon stored in the forest. Despite these differences, reducing carbon emissions has become an international commitment with carbon credit markets and pollution taxes on fossil emissions developing at a rapid pace. Placing these different perspectives in the context of current regional variations in forest management and operations helps clarify which options are most likely to reduce atmospheric CO_2.

This updated Fact Sheet summarizes the impacts of forests and forest products, including biofuels, on carbon under several management strategies. The Consortium for Research on Renewable Industrial Materials (CORRIM), a not for profit university lead research group of 16 research institutions developed a research plan in 1998 to study the complete environmental performance of wood. They began by developing a ***life cycle inventory (LCI) database of all inputs and outputs for every stage of processing from forest regeneration, through harvest, processing, transportation, construction, building use and final disposal***. CORRIM completed a thoroughly reviewed Phase I report on forests and their uses for the PNW and SE regions of the USA in 2005 and extended that work with a phase II report on NE/NC and Inland West forests in 2010 (*Wood and Fiber Sci* Special Issues: Vol 37, 2005, and Vol 42, 2010). Most recently they produced a special issue on the potential future impact of a range of biofuels (*Forest Products Journal* Vol 62 No. 4, 2012). Their research details the fundamental differences between wood and fossil fuel impacts on greenhouse gas emissions to the atmosphere and the relative differences in their emissions as a forcing function for climate change.

In summary, the findings show that:

Wood Use Can Reduce Carbon Dioxide In The Atmosphere By:

1. ***Growing trees removes CO2 from the atmosphere and stores it as carbon in the forest.***
2. ***Products made from trees move the stored tree carbon to their point of use.***
3. ***Using Wood Products Creates Opportunities to Avoid the use of Fossil Intensive Products*** (like steel, concrete, aluminum & plastics) that emit far more CO2 than using wood products.
4. ***Wood is both Renewable and Sustainable*** resulting in CO2 initially taken out of the atmosphere and being returned to the atmosphere when decomposed at end of life (a two way flow) whereas using fossil fuels creates a one-way flow of CO2 accumulating in the atmosphere.
5. ***Intensively managing forests increases yields,*** resulting in greater opportunities to avoid using fossil fuels**.**
6. ***Using woody biomass for fuel displaces CO2 emissions from fossil fuels*** although with a lower efficiency of conversion compared to displacement from wood products used in construction.
7. Further CO2 benefits are possible by ***recycling demolition wood*** at the end of first life through reuse or reprocessed products such as panel boards, ***burning the lowest grades of wood for energy, or storing waste wood in landfills*** where it either does not decompose or the gases produced are collected and burned to avoid producing methane a most harmful greenhouse gas, or better yet ***use the energy from burning to displace the use of fossil fuels.***
8. ***Managing forests for best use varies by region with natural disturbance risk playing a key role.***
9. ***Increasing carbon values (taxes or incentives) will affect the cost of sustaining critical habitat.***
10. ***Policies customized for specific interests that ignore life cycle impacts, need revision in order to avoid their unintended consequences.***

Results are provided first for each alternative applicable to a Pacific Northwest forest followed by regional differences.

1. Growing trees removes carbon from the atmosphere and stores that carbon in the forest:

You can store more carbon in the forest without harvesting or using long rotations. Using forest inventory data from stands at different ages shows that extending the rotation age from 50 to 100 years in the PNW will more than double the inventory of wood and carbon stored in the forest (Figure 1).

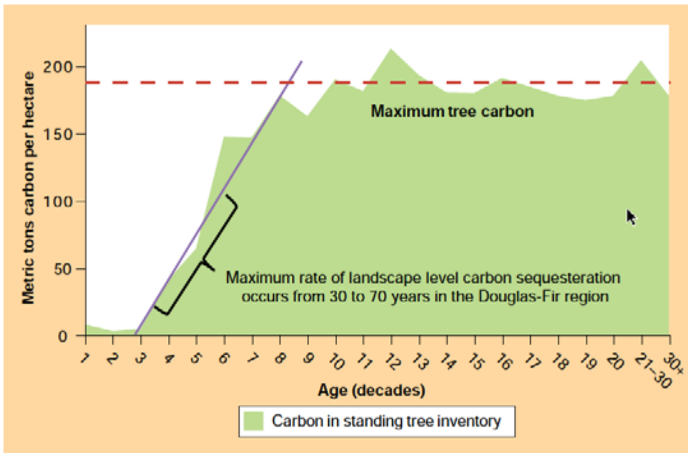
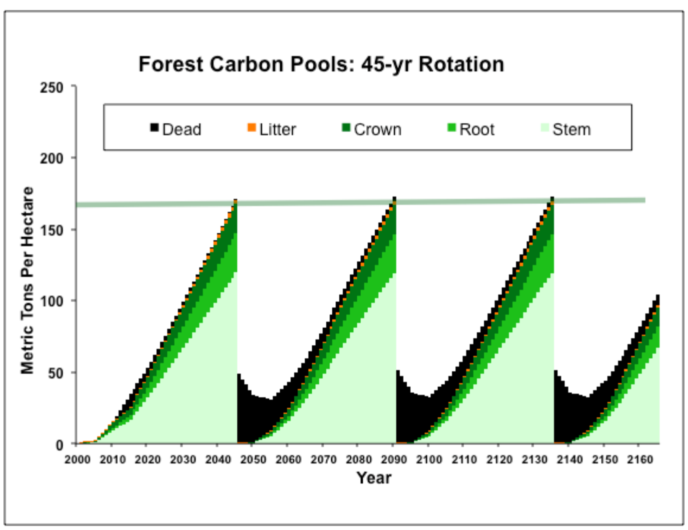


Figure 1 also shows the dramatic decline in growth rates after about 70 years with no substantial reduction in carbon from the atmosphere after about 100 years, as most stands have reached the carrying capacity of the land. Eventually, due to natural aging and disturbances such as windstorms, fire, and disease the forest may emit rather than store carbon. Looking out over the long term across these disturbances and with no management, the long-term average of carbon stored on a fixed acreage of forestland will not likely change much from its carrying capacity, nor contribute to carbon mitigation.

Figure 1. Carbon in USFS Western Washington Standing Inventory by Age

Forest growth is just the beginning of life cycle carbon storage accounting. As compared to unharvested forests, harvesting on sustained economic rotations reduces the average forest carbon by roughly half depending upon species (more than half for local Douglas-fir) with the removals used for products and the forest replanted to take up new atmospheric carbon during each rotation (Figure 2).



The dead wood (crown, litter, roots) is typically left behind to decompose, as it is too costly to remove for fuel relative to the low price of natural gas (NG). With a financial incentive much like the subsidy received for corn ethanol production, many of these forest residuals could be economically collected and processed into biofuels like cellulosic ethanol, which displaces gasoline and reduces oil imports. While the store of carbon in the forest under a short rotation is reduced below the potential of an older forest, the land is instead being used as a ***pump*** to move the forest carbon to other carbon storage pools at the maximum rate that it can be sustainably grown.

Figure 2. Forest Carbon pools with 45-yr rotation

2. Storing carbon in products:

Figure 3 shows the carbon impact of manufacturing the most common wood products and the comparable impact of substituting a concrete slab floor for a residential wood floor of the same area as measured in CO2 equivalents, which is the normal reporting unit for greenhouse gas (GHG) emissions. Greenhouse gas emissions needed to produce wood products (shown as negative in red) are substantially less than the GHG emissions from a comparable concrete floor area even without considering the carbon stored in the wood.

The net carbon stored in the wood products (shown in blue after deducting the fossil emissions generated from processing) stores enough carbon to offset the emissions from many other fossil intensive products used in construction. The wood products store more net carbon over their useful-life than the emissions from producing a concrete floor. At the end of their useful product life, if the wood products are collected to produce energy that displaces fossil fuel heating sources, the carbon stored becomes permanent.

If the recycled wood is used as the resource for other reprocessed products such as fiberboard, the carbon storage is extended with a future option to collect the material after its second life and use it for energy. If the used products are land filled, they decompose slowly, with most lignin remaining permanently sequestered. Methane emissions from landfills can negate the carbon storage potential in the landfill.

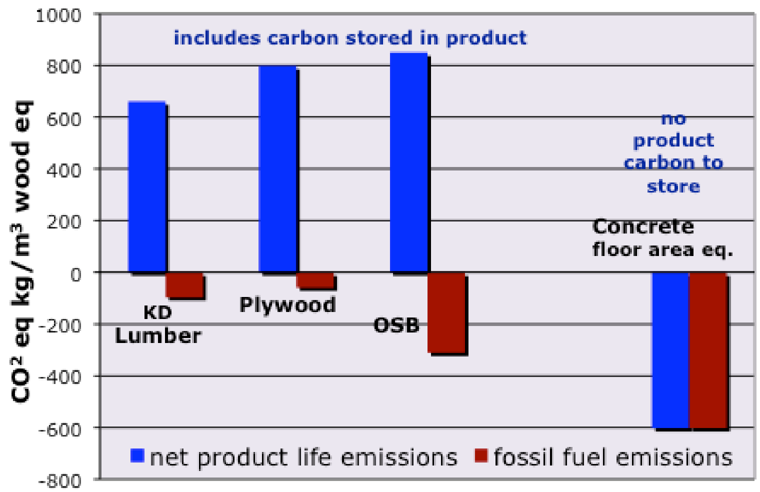


Figure 3. Net Carbon Emissions During Product Life

3. Avoiding the use of fossil intensive products:

Figure 4 shows the carbon stored in the forest (green) and both short (orange) and long-lived product pools (blue) along with the displacement of fossil fuels by using the mill residuals as a biofuel (yellow) which offsets roughly half of the manufacturing energy used in harvesting and processing, a negative pool (maroon). After harvest the carbon left in the forest, plus short and long-lived products net of the processing energy, and the partial offset from using mill residuals decreases for a few years, as decomposition of dead wood in the forest and short-lived products may be greater than new growth. But that is not the end of carbon accounts. The figure also shows a positive carbon pool for substitution as the long-lived products displace the emissions from concrete and other fossil intensive products in buildings. Note that the carbon in the forest is stable across rotations, and by adding the carbon in products there is a modest trend increase in carbon stored. However, when the substitution for more energy intensive products such as steel or concrete is included there is a large positive sustainable trend in stored and offset carbon. The long-lived product pool declines at the end of product life, which is set at 80 years as the half-life of residential housing stocks. The loss of products in service varies over a wider range and can be extended by recycling or even storage in a landfill.

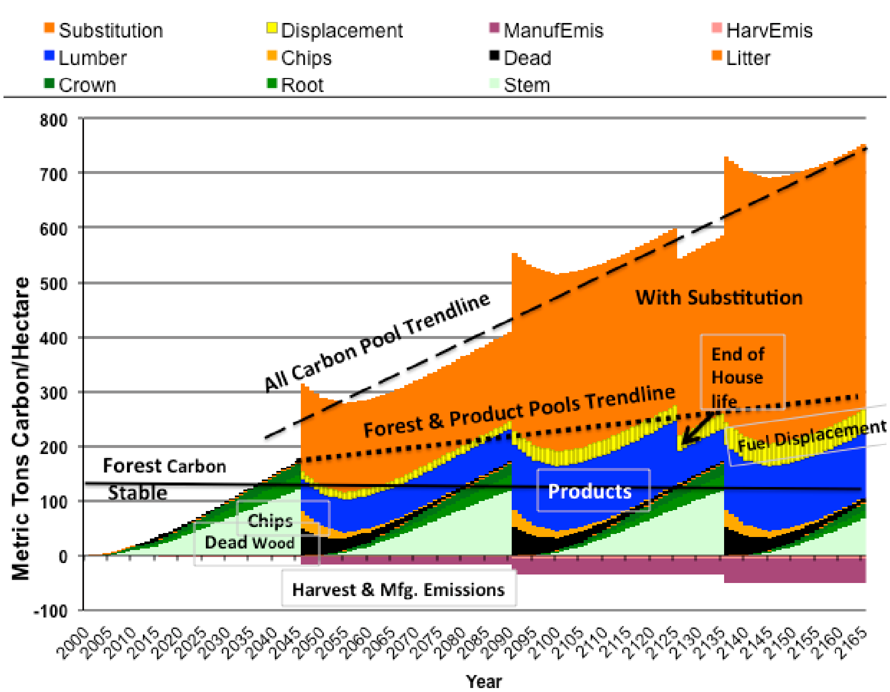


Figure 4. Carbon in the forest and products with substitution for concrete framing on a 45-year rotation

The figure demonstrates the significant role that sustainable forest management coupled with wood production can have on carbon mitigation. The managed forest plus products sequesters 4.5 tonnes Carbon/hectare/yr (tC/h/y), which is more than the trend rate of carbon growth in the forest during its highest growth period (3.8tC/h/y). Soil carbon is not tracked in these examples. Studies have shown that sustainable management is likely to have only temporary short-term impacts on surface layer carbon, and does respond positively to intensive management as soil carbon increases with productivity improvements.

4. Wood is both renewable and sustainable:

Wood growth can be sustained by management and increased by more intensive management. Figure 5 shows the carbon stored in the PNW region Douglas-fir forest plus products and substitution with a 45-year rotation and the impact of fertilization and a commercial thinning on the same rotation. As a second case, the rotation was extended 10 years to see if the response time after the thinning would produce increased storage. There is a significant increase in carbon stored from the intensive management but very little gain by also increasing the rotation age another ten years. Not managing highly productive forests to sequester large amounts of large diameter wood from short rotations is a lost opportunity in product use and carbon sequestration.

Drawing the boundary conditions for a carbon analysis around the forest is only correct if there is no management or harvest, in which case over the long term the forest stores a substantial amount of carbon but it is neither increasing nor decreasing once the stands reach carrying capacity. If there are no disturbances (like fire and wind) the unmanaged old forest that is in a steady state with atmospheric uptake and release plays almost no role in mitigating climate change because it does not continue to reduce GHG emissions. Changes in land management that include conversion to forestry, and especially producing more long-lived products as soon as possible that replace energy intensive substitutes has the largest impact on GHG emissions.

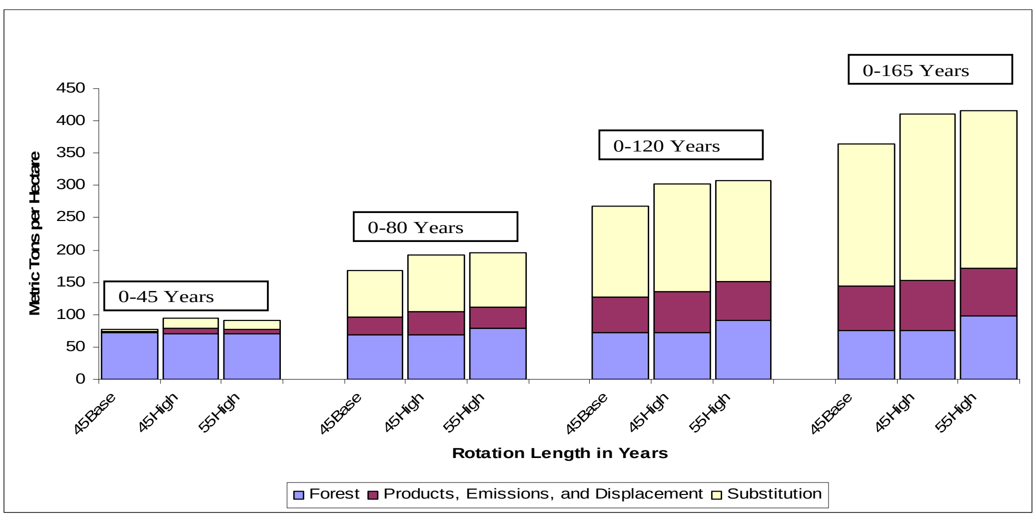


Figure 5. Average carbon in forest, products, and displaced fossil emissions from concrete substitution for different management intensities.

5. Forests can be intensively managed to increase yields with optimal economic rotations:

The economic returns do not change finding #4. Figure 6 displays the Soil Expectation Value (SEV= the price you could pay for the land and earn 5%, i.e*. **the financial return to the land from perpetual rotations***). While there is a small increase in carbon for the intensively managed 55-year rotation over a 45-year rotation, the cost penalty from the longer rotation is already substantial. The economic returns from more intensive management are not large. Nevertheless, any small incentive related to the increased carbon stored would logically support a significant increase in management intensity as it reduces the risk of making such an investment. The 80 and 120-year rotations have fallen below the 5% discount target with no increased carbon storage and are therefore unlikely scenarios for forestland investors.

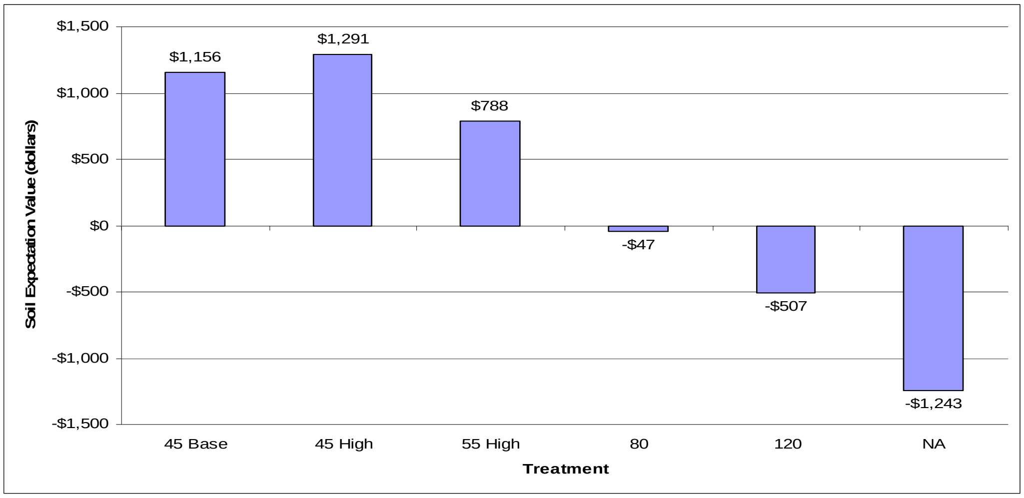


Figure 6. Soil Expectation Value for different rotations and management intensities

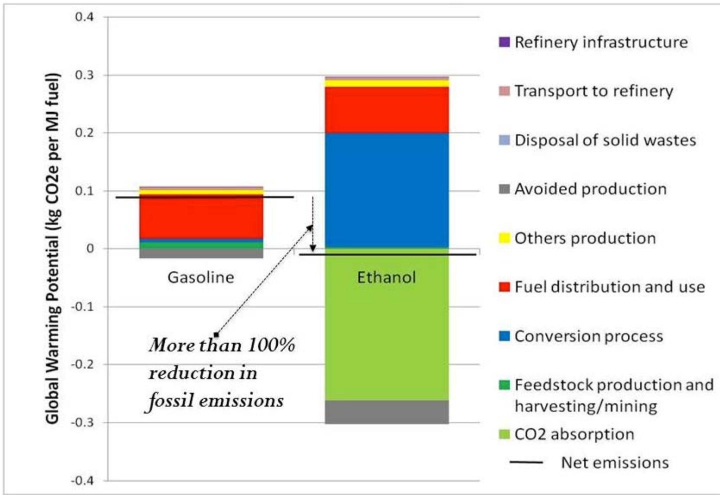
Overall carbon benefits accrue in the forest when land is converted to forestry (afforestation), a one-time increase in storage. Carbon benefits accrue outside the forest when periodic harvests convert the trees to long lived products that contribute to an increasing pool of product storage in buildings. More intensive management that increases volume growth and more long-lived products also increases carbon storage. In the PNW, models indicate that intensive management on 45-50 year rotations for average site productivity is probably optimal for maximum carbon benefit. If carbon credits were applied to substitution, a higher price for carbon in the short term would likely reduce the rotation age to gain quicker access to the carbon value. If substitution is ignored, carbon credits would likely motivate longer rotations and be counter productive to the objectives of reducing total carbon emissions.

6. Displacing CO2 emissions from fossil fuels using woody biomass for fuel:

The PNW examples in #1-5 above only include the use of mill residuals as fuel to offset the need for fossil energy at the mill; a scenario that reflects current practice. If the interest in reducing GHG emissions were translated into a monetary value on fossil fuel GHG emissions, it would pay for the collection of forest residuals and demolition wood as replacements for existing fossil fuel use. A carbon tax comparable to the $30 (Canadian) per ton of CO2, which is equal to the current British Columbia carbon tax, offsets the high cost of residue collection equal to $27/ton of pre-dried wood. This offset is enough to pay for the collection of a large share of forest residuals and demolition wood. Several studies have shown that it will take a much higher carbon value to effectively reduce the carbon in the atmosphere. This higher carbon value would be enough to economically remove most of the available forest residuals that are currently left to decompose or are burned with no recovery of the energy-value. A detailed analysis of the carbon impact from biofuels produces a range of efficiencies in displacing fossil fuel much like the range of impacts for displacing emissions using wood products. The efficiency of converting wood to either products or fuels varies with how the products are used and the fuels that are produced or displaced.

Figure 7 shows the carbon impact for each stage of processing in producing ethanol from fermentation (BioChem) of Short Rotation Woody Crops (SRWC). The reduction in fossil emissions is greater than 100% i.e. better than carbon neutral. The fermentation process provides a relatively inefficient conversion process with only roughly 30% of the mass refined into cellulose for ethanol. Substituting ethanol for fossil fuel does reduce fossil emissions, however a portion of the reduction in fossil emissions is made by burning the large excess share of lignin for electrical energy in place of fossil fuel generated electricity. By comparison when lignin is gasified to produce ethanol, the fossil fuel emission reduction is only 74%, which is still well above EPA's standard for cellulosic fuels (60%). A better efficiency standard for wood use measures the reduction in carbon emissions per unit of carbon in the wood used rather than the comparison to fossil fuel emissions.

Producing ethanol from fermentation or gasification removes about 0.4 units of carbon for every unit of carbon in the wood used. Burning more wood waste for energy, even if not for producing ethanol, can increase the reduction in fossil energy The efficiency of fermentation or gasification to produce ethanol from wood are roughly equal when comparing carbon displaced to the carbon used. In contrast using the feedstock for burning to produce heat for drying in a mill requires less processing and thus is more efficient, reducing about 0.7 units of carbon for every unit of carbon in the wood used.



Results show a hierarchy of wood use efficiency for reducing carbon emissions with ethanol (a transportation fuel) as low as 0.4, as compared to 0.7 for burning the feedstock for dryer heat in lumber mills. Pyrolysis of wood to produce a liquid bio-oil is not a comparable transportation fuel. The closest comparison is residual-fuel-oil (RFO), which is burned by utilities for heat energy. Using bio-oil in place of RFO provides about 0.47 reduction in emissions per unit of carbon in the wood used.

Figure 7. Carbon emissions for Biochem-Ethanol vs gasoline (Global Warming Potential, GWP)

Displacing CO2 emissions by collecting forest residuals: The collection of forest residuals is unlikely to occur in the United States if it is not a part of a sustainably managed commercial harvest. The commercial harvest brings most of the biomass material to the roadside, thus lowering the cost of biofuel feedstock collection and transportation. We model this operational reality by evaluating biofuel removals as a joint production process concurrent with commercial harvest of logs for lumber across successive forest rotations. Carbon impacts are allocated among processes consistent with life cycle inventory allocations for the region. Collection of forest residuals with the initial harvest were assessed relative to the burning of discarded wood at the end of life with no energy recovery.

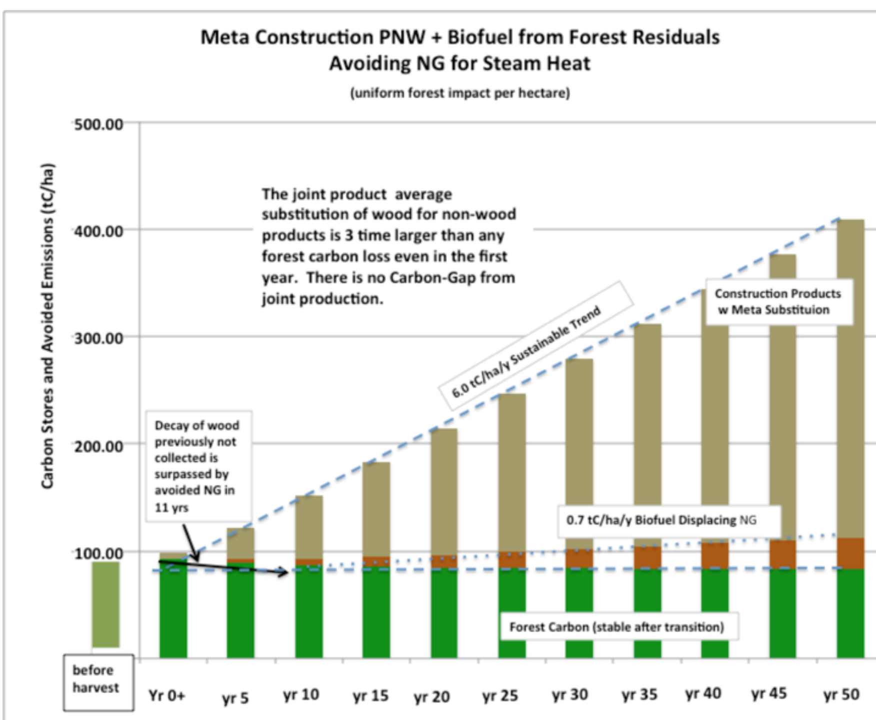
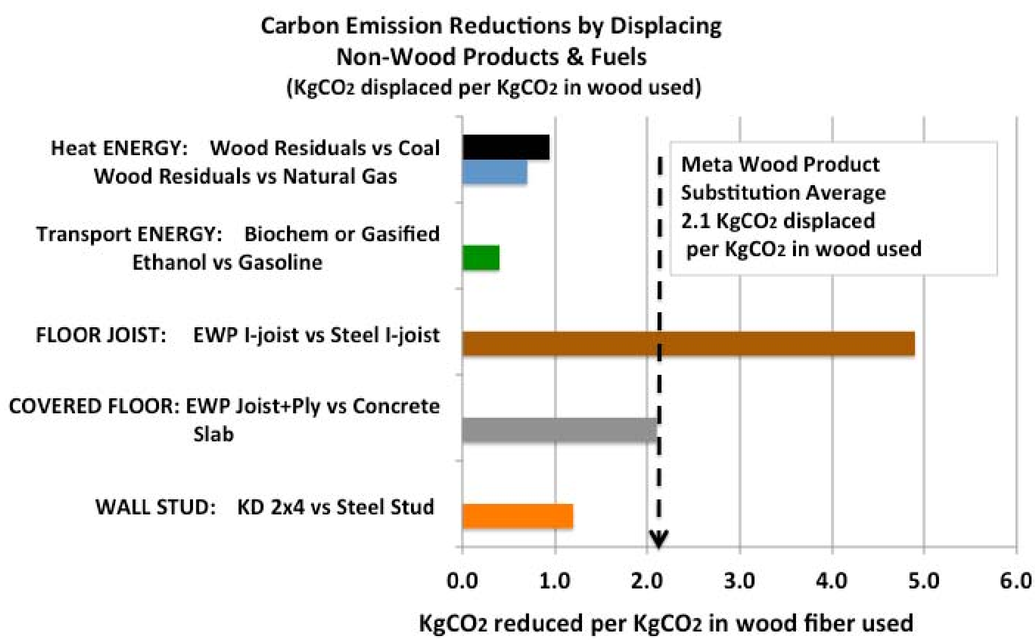


Figure 8. Total sustainable carbon trend increase from jointly produced wood products and heat from woody biofuel

Figure 8 shows the impact of producing products that substitute for fossil-intensive products, along with the collection of forest residuals to produce biofuels that displace natural gas (that otherwise would decompose over decades). The average carbon across the forest is reduced slightly reflecting the removal of forest residuals rather than leaving them to decompose. Once the forest residuals have decayed, the forest carbon remains stable as the harvest moves from one stand to another, and the sustainable trend of avoided fossil emissions from the production of the biofuel and wood products continues to accrue. Figure 8 shows the large amount of carbon displaced by solid wood products and substitution relative to the fossil fuel avoidance from the use of biofuel. We use the meta-analysis average from substitution studies shown in Figure 9 for the substitution parameter. Figure 8 assumes that 40 percent of forest residuals are collected which still leaves a substantial amount of dead wood for ecological values. In this case the production of woody biofuels contributes approximately 10 percent improvement to the emission reductions from solid wood products because of the lower carbon efficiency of wood conversion for biofuel relative to solid wood products. The end of solid wood product life after approximately 80 years reduces the rate at which wood products accumulate carbon unless the wood is recovered and reused.

Comparing biofuel displacement with wood product displacement: Figure 9 displays the ratio of carbon dioxide emission reductions relative to carbon dioxide used for both biofuels and wood product uses. Values range from a low of 0.4 emission reduction for ethanol vs gasoline to a high of 4.9 for Engineered Wood I-joists used in Floors displacing Steel beams. In contrast a wood stud substituting for a metal stud for an interior wall has a displacement efficiency of only 1.2 as it is much lighter gauge than floor joists that must be stiff to avoid bounce. This complex array of alternative uses produces a hierarchy of the best ways to reduce carbon emission and many opportunities for improvement over current uses.



The substitution of wood for fossil fuel displacing fossil emissions is almost universally accepted, whereas the substitution of wood products for non-wood products is often ignored thereby leaving out the most important aspect of using wood to reduce carbon emissions.

Figure 9. Carbon emission reductions per unit of carbon in the wood used for a range of biofuel and wood product uses

7. Recycling demolition wood (recovery and reuse, reprocess, burn to displace NG, or landfill):

At the end of a first life wood may be recovered and recycled into products or used as a biofuel or even disposed in a landfill. If landfilled, the gas from decomposition is either captured and flared to eliminate methane, a potent green house gas, or captured and used for its energy value while substituting for a fossil fuel.

In this section we make a number of comparisons to a "base case" (Products w Mill CoP to heat) that excludes the impact of collecting demolition wood but includes the heat from burning mill residuals as a part of current practice in Figure 10.

For the base case uncollected demolition wood is burned without recovery and returned to the atmosphere with no second life. Over time under sustained management rotations and no end of life recovery the carbon mitigation trend grows at 4.6 tonnes C/hectare/yr (tC/h/y) for a PNW forest. If the recovered material is both clean and easily reused "Products reused", reprocessing is minimal and the sustainable carbon mitigation rate is increased from 4.6 to 7.9tC/h/y, a 72% increase. However there will likely be very little demolition wood of this quality. If the demolition wood needs to be "Reprocessed" such as into fiberboards, the additional energy in processing reduces the trend increase to 6.6tC/h/y for a 44% increase over the base case. Since much of the demolition wood will likely be lower quality, if the material is recovered and burned for its heat energy to "Avoid NG" the mitigation rate in displacing natural gas falls to 5.4tC/h/y for a 19% increase over the no-collection alternative. Diverting the material to the landfill is very uncertain, as the technology for recollecting the gases from decomposition may not be in place and the leakage of decomposition gases and exposure to oxygen may be severe which accelerates the decomposition process and produces more methane. Nevertheless we have made two comparisons here based on assumptions commonly used in the literature. It is also very difficult to be more efficient than burning the material in a boiler for heat even though the carbon stored in the landfill extends the life of the original carbon in products making it a better option than just burning waste material at the end of normal life.

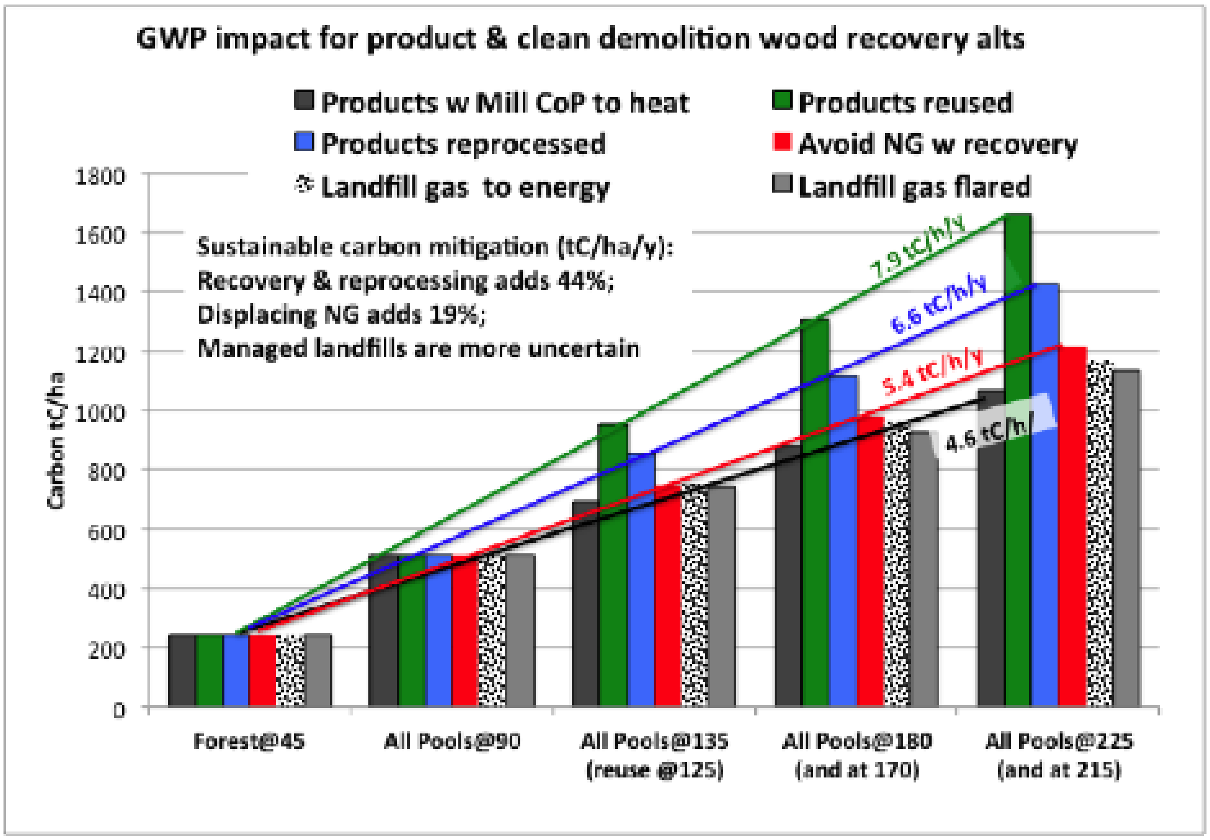
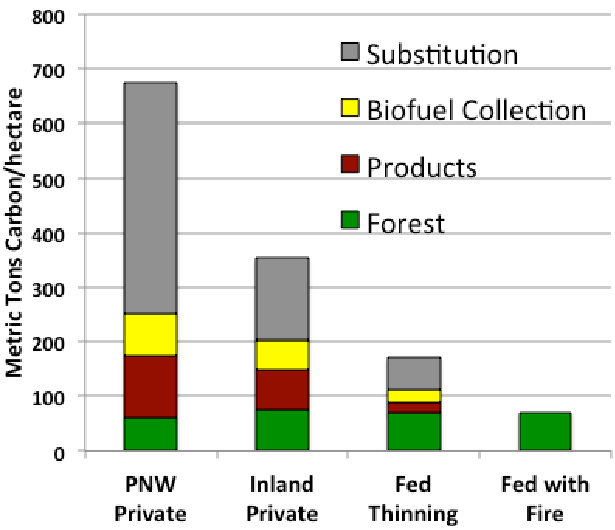


Figure 10. Assessments of sustained carbon mitigation for alternative uses of recovered wood from a PNW forest stand

8. Regional forest management and outputs vary significantly:

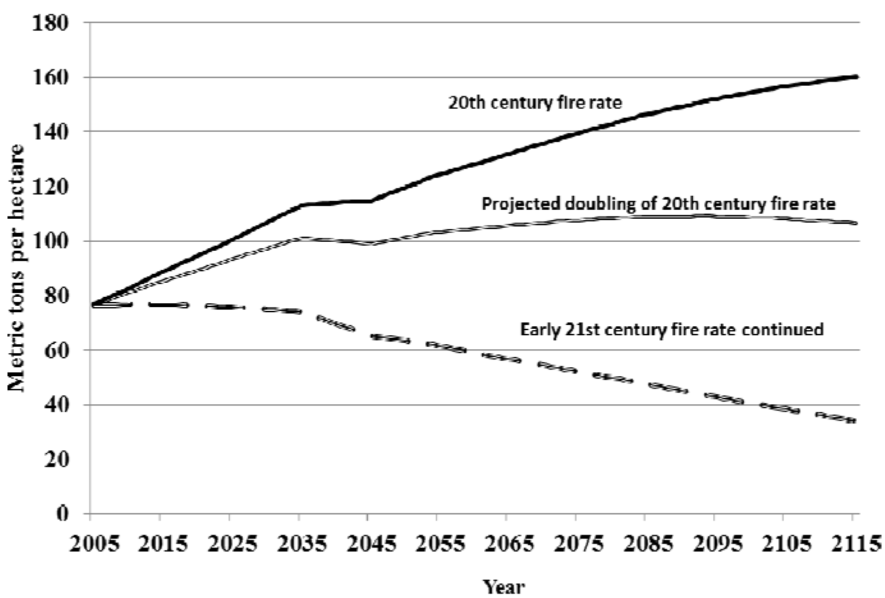
Wood produced from PNW forests is directed towards the construction markets with more than 55% of the log volume ending up in long-lived products such as lumber and panel products. In contrast, the SE region directs a much larger share of their logs to pulp and paper production resulting in a slower rate of carbon mitigation for the same unit of land. In the Inland NW land productivity is much lower and fire risks much higher. The region also contains a much higher share of federally owned forests that are not managed for timber production, but are sometimes treated to reduce fire risk. Figure 10 highlights the different carbon impacts by region and owner for the PNW and Inland NW regions. Biofuel collection is shown as an optimistic projection.

PNW forests generate almost twice the yield of Inland NW private forests because of higher land-productivity and therefore generate almost twice the carbon storage benefit. Federal forest with fuel reduction thinnings produce about half the carbon storage benefit of Inland private forests because the treatments produce fewer logs suitable for long-lived applications. Federal Forests with historic fire intervals and no treatments produce no products. In many cases they are emitting rather than storing carbon due to the recent increases in fire rates.



Impact of Changing Fire Rates: Since 2000, the acres burned during wildfires have almost doubled. A century of fire suppression has resulted in more carbon storage on federal lands and that higher carbon storage is correlated with greater fire risk due to ladder fuels and high stand densities. Recent fire rates on federal lands are many times higher than on state and private lands and climate impacts research indicates that we can expect at least a doubling of the burned area in the future. The first decade of the 21st century fire rates are even higher than the predicted doubling for the Inland Northwest analysis region.

Figure 11. Regional Carbon Comparisons across all carbon pools in 100 years.



Fire simulations show that based on the fire rates of the ***20th century***, in conjunction with fire suppression, forest carbon could increase further albeit not accounting for the impact of other mortality agents like the mountain pine beetle. The projected ***doubling*** of fire rates essentially caps the carbon that will be stored in the forest. Early ***21st century*** fire rates indicate the Inland Northwest National Forests will become carbon emission sources if they are not actively managed to reduce fire risks.

Figure 12. The impact of changing fire rates on forest carbon storage potential for Inland Northwest National forests

9. Carbon taxes (or incentives) will affect the cost of sustaining critical habitat.

While sustainable management provides habitat for many species, commercial forests do not provide old forest habitat. To better understand the role of forests and the growing importance of carbon on Old Forest Habitat (OFH), life cycle measures for a range of management treatments for a sample of stands in the PNW were compared. A present value was calculated using a 5% discount rate (cost of money) on the revenue stream for current market prices for timber. The value of carbon in the forest, in products, and displaced emissions was based on a mid-range estimate of carbon prices ($25/t CO_2) on the European Climate Exchange (ECX). These values were calculated for a range of management treatments including a typical 45-year commercial harvest rotation, a biodiversity-pathway designed to produce the Old Forest Habitat quickly, a long (100 year) rotation, and no harvest assuming no unusual disturbances. These results demonstrate the impact of carbon values on the cost to produce OFH across this range of scenarios.

A metric for OFH was calculated based on the percentage of time that the treated stand is not statistically different from the old stands within a population of all forest stands in the Olympic Experimental State Forest, which is situated in the northwest corner of Washington State. The statistical test for measuring any difference between treated stands and the old forest stands is characterized by trees per acre (TPA), quadratic mean diameter (QMD), canopy closure, and canopy layers as these variables were shown to have the greatest significance in characterizing the difference between the old forests from the total sample. The inventory data are shown in Figure 13, for the two most significant explanatory variables (QMD and TPA) as compared to stand conditions in areas with Spotted Owl nests (black circles). Spotted Owl nests are generally near the center of the distribution of diameter and density for the old forests.

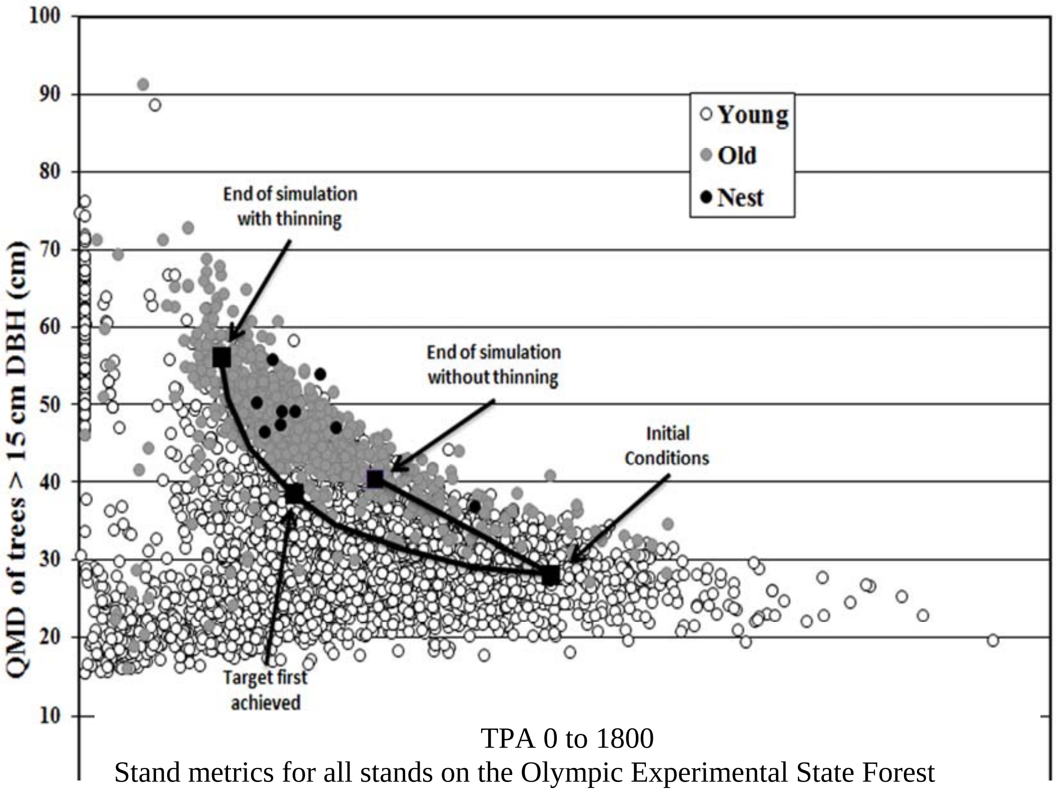


Figure 13. Thinning treatments to move a young high-density stand to be statistically equivalent to Old Forest Habitat (OFH) (modeled by TPA, QMD, canopy closure & layering)

If the young stand was not thinned, its growth trajectory barely reaches OFH conditions in 100 years. Better options are available. A thinning simulation identified as the bio-pathway was selected from a range of thinning treatments because the stand spent the largest amount of time (35% of the time) in OFH conditions at the least cost. In that sense the thinning treatment was customized to the initial stand condition. Figure 13 shows that both no-harvest or no-management over a 100-year rotation alternatives barely approach the conditions of OFH after 100 years, and meets the threshold for OFH only 14% of the time. In contrast, the bio-pathway thinned stand produced the lowest density and highest QMD of all possible pathways and was within the target zone for the greatest amount of time over the 100-year simulation.

The present value (PV) is computed for the merchantable timber, forest carbon, total carbon (forest carbon + products carbon including a meta average for the impact of wood substituting for fossil intensive products) and the total for both forest and products carbon. The market value for the bio-pathway treatment is substantially reduced by the long rotation thinnings; however it is much better than not thinning or harvesting. The forest carbon is not much different across all options, as the larger trees tend to offset the impact from early thinnings. The total merchantable value of forest and products is substantially larger for the commercial (45 yr) rotation, though this scenario produces no OFH.

The cost (the loss compared to a commercial rotation) for each treatment (Figure 14) was $96 for each percent of time that the stand was in OFH for the bio-pathway case. The cost increases to over $400 for the long rotation and no harvest cases. This result demonstrates two critical points: 1) the value of carbon is not complementary to OFH for forest stands similar to our sample and 2) the bio-pathway approach to thinning is critical to reducing the cost of producing OFH.

The literature on simulations to reduce global carbon emissions suggests that carbon values must rise far above the recent ECX experience in order to make progress toward global emission reduction targets. Hence carbon values should eventually be much higher and dominate these value differences in the future, substantially increasing the cost of OFH compared to carbon values.

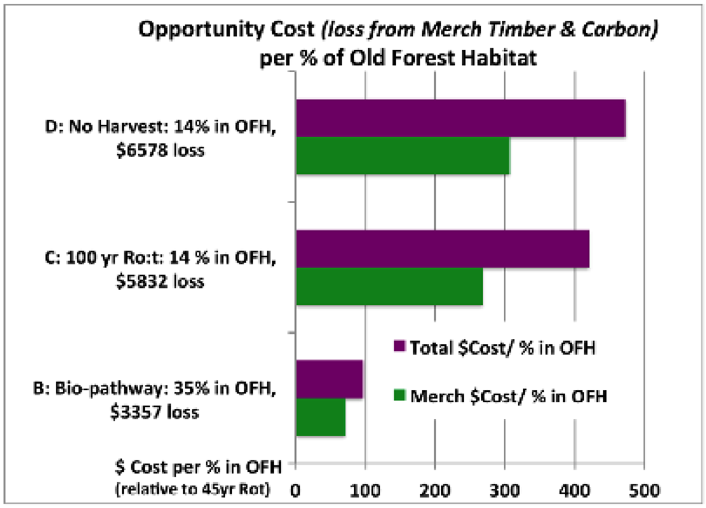


Figure 14. Cost of non – commercial alternatives per % of Old Forest Habitat produced

An owner opting for the bio-pathway at the time of a first thinning treatment (commercial rotation vs bio-pathway) would face an opportunity cost of nearly $994 per 1% in OFH. This cost is almost 10 times higher than the opportunity cost if the treatment alternative was chosen at the time of regeneration. Not locking in a plan to produce old forest habitat upon regeneration substantially increases the cost by delaying the decision of when to apply the first thinning treatment to a point when the stand has a much higher market value.

Different forest types will produce different results. Dry forests with a high risk of wildfires can benefit from thinnings that reduce the cost of fires. The Okanogan National Forest, a dry forest in Central Washington State, was evaluated for non-market benefits from reducing fire risks. The study included the cost of fighting fires, fatalities, facility losses, timber losses, regeneration and rehabilitation costs, and community values. These values were estimated from the historical data on fires and accumulated as an avoidable cost. Not included for lack of data were other values including lost habitat, smoke, and water erosion. The value of carbon was estimated separately using the same $25/t CO_2 assumption that was used in Figure 14.

The benefits were estimated based on the probability of a fire as a function of the risk measured by the amount of ladder fuels. Using these metrics, the accumulated benefit of avoiding fire was $3,655/ha for the Okanogan National Forest. The fire risk reduction treatment cost for removing small diameter material was estimated at $1433/ha for a net benefit of $2223/ha. The carbon benefit alone was estimated at $2516/ha for a total net benefit of $4739/ha. The total no action liability for the 530,000 hectare Okanogan forest was $2.7 billion. The net savings after treatment costs was estimated at $1.3 billion.

While the ability to develop opportunity costs for producing many non-market forest values exists, the question of whether the value exceeds the cost is more difficult, especially when the value of benefits cannot be estimated from past experience. Experimental choice surveys have shown that both Urban and Timber Rural populations are willing to pay up to 2% of their income for biodiversity, aesthetics and to avoid rural job losses. Estimating the costs of producing non-market benefits that can be altered by forest management and wood product uses can be developed as an important element in a decision support framework to reduce environmental burdens and improve the production of both timber values and non-market benefits. Estimating values for some non-market benefits such as avoiding the costs of fires can also be developed based on the experience from prior fires. Estimating many non-market values via experimental choice surveys is useful to gain insights in relative values. However due caution is needed for interpretation of results because of the tendency to overestimate some values because many other values are not included in the choice set.

The life cycle analysis of a stand structure is needed to understand the impacts on habitat. LCI/LCA data does exist for many US forests and product uses as important inputs to the results demonstrated. CORRIM (the

Consortium for Research on Renewable Resources) life cycle inventory data is available on the National Renewable Laboratory's US Life Cycle Database website. In spite of data limitations, there are many opportunities for improvement that can be identified by comparing life cycle impacts for a wide range of management alternatives with their environmental burdens and benefits.

10. Unintended Consequences of Policies:

Policies directed at improving the efficiency of using fossil fuels do not reduce carbon emissions, they only reduce the rate of increase. Using wood can reduce emissions more than 100% of fossil alternatives and hence can be carbon negative, providing the kind of technology essential to lowering emission levels.

For incentives to actually lower GHG emissions, they should focus on the uses of wood with the highest leverage to reduce emissions, not the lowest. For example: (a) Carbon credit schemes aimed at increasing forest carbon storage increase the return for not harvesting, which results in the need for more fossil intensive products that increase rather than decrease carbon emissions; (b) Renewable fuel standards for utilities effectively require them to outbid other users for feedstock, which fractionates the supply region and makes it difficult to invest in economically scaled biofuel production facilities; (c) Tax credits for ethanol increase the use of the feedstock that is used in panel manufacturing, which provides much larger carbon mitigation leverage than does ethanol; (d) Even direct subsidies for removing more forest residuals are based on assumptions on what will be removed without incentives, an unstable baseline; (e) Incentivizing the lowest valued use of carbon inherently steals feedstock from better uses. Current incentives do not focus on best uses.

An effective policy requires increasing the cost proportional to the carbon emissions with the most logical option being a pollution tax on fossil emissions. In this case the market rewards the best use of products to achieve the greatest carbon mitigation improvement. That demand will also make it economic to do a better job of using the lower grade feedstocks.

British Columbia instituted a tax on fossil fuel emissions. Their carbon tax was offset by other tax cuts to avoid the negative income impacts that accrue from a tax increase. The tax has increased progressively over the first four years from \$10 (Canadian)/tonne of CO_2 to \$30/tonne. Since the introduction of their income neutral carbon tax, their per capita fossil fuel consumption has declined by 19% relative to the rest of Canada and there has been no detectable economic decline from the tax. Studies indicate that to date, the tax has worked as intended and is contributing to significant emission reductions.

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Further Reading

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