Effective Uses of Forest-Derived Products to Reduce Carbon Emissions[1]

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Introduction

This updated research on the uses of forest-derived products summarizes the impacts of forests, forest products, and biofuels on carbon mitigation based on 22 years of research by CORRIM (The Consortium for Research on Renewable Industrial Materials (www.corrim.org)). CORRIM is comprised of 22 university and research associations. Since 1998, CORRIM has developed a data base from primary surveys of representative industries that manage forests and produce wood products, and secondary data of representative forest inventory from the USFS Forest Inventory and Analysis (FIA) program.

The data characterizes the environmental performance of wood from cradle-to-grave. It is based on life cycle inventories of all energy and material inputs and outputs for every stage of processing from forest regeneration, through harvest, processing, transportation, construction, building use, and final disposal. CORRIM has completed a plethora of reports and publications documenting the research. They show the fundamental differences in greenhouse gas (GHG) impacts when using wood and wood derivatives relative to using fossil fuel and materials with high fossil fuel inputs. The research analysis includes evaluations of the net carbon stores in forests and wood products, as well as the substitution of wood products for equivalent non-renewable products. Results consistently show beneficial displacement of fossil carbon emissions when a wood product is used over an alternative. These data have served as the primary information base for many other authors and publications including Malmsheimer et al. (1). They reference the IPPC's Fourth Assessment Report concluding; "In the long term, a sustainable forest management strategy, aimed at maintaining or increasing forest carbon stocks, while providing an annual sustained yield of timber, fiber, or energy from the forest, will generate the largest sustained mitigation benefit (1)."

This technical note provides updated data reflecting changes in technology and regulations over the past 20 years at wood product manufacturing facilities. It provides an integrated perspective of current progress and opportunities to reduce carbon emissions. It is focused on sustainable wood production of jointly produced products and biofuels, including impacts from the competition for feedstocks and the functional substitution of different products and uses. The findings reflect the complexities of tracking carbon. Since every living thing and manufacturing process alters the carbon footprint, every impact depends on a long list of other impacts. Specific measures for each product and process can be compared, including using the same feedstocks for a variety of products each with a different carbon impact. Results illustrate higher and better uses for a given feedstock. However, given the vast number of alternative scenarios, more often than not, any baseline set of comparisons will overlook many options leading to significant "unintended consequences". ***We provide a suite of examples which demonstrate the opportunities for improvement and aid us to better understand the many uses of wood and their associated impacts.***

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1. Technology changes and regulations have altered energy needs and processing emissions

Figure 1 shows a 5-60% increase in energy used between 2000 and 2012 for the production of a range of wood products. Changes are driven by three elements: 1) a more consistent metric for calculating total energy use from LCI data (2); 2) the LCI methodology has shifted from a manual calculation of energy resources to using an international standard impact method; and 3) the industry reported an increased use in emission control devices (ECDs) in 2012 relative to 2000 (3). The wood industry has faced more stringent emission standards for controlling hazardous air pollutants (HAPs). These standards drove an increase in the use of ECDs industry wide for engineered wood products (plywood, glulam, LVL, I-Joist). The ECDs require fossil-based energy sources (4). There are two exceptions: oriented strandboard manufacturing in the US Southeast, which included ECDs in the earliest survey (5) now shows a reduction in energy use, and Pacific Northwest (PNW) lumber does not show a significant change in energy use between the survey years.

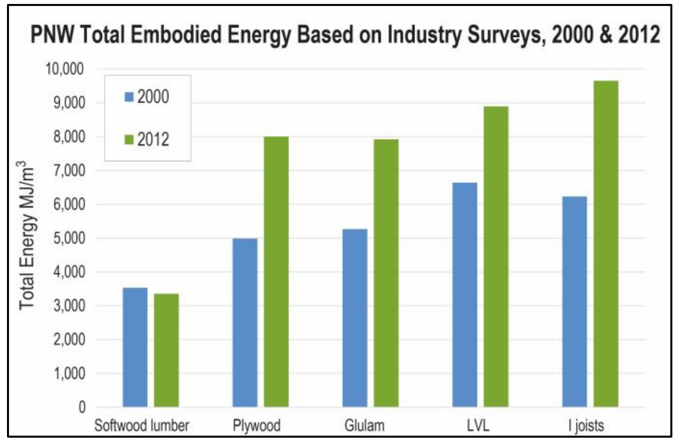

Figure 1. Comparison of cradle to gate total energy use by product for the PNW production region for survey data collected in 2000 and 2017.

Another significant change between 2000 and 2012 has been the substitution of fossil fuels with wood residues (biofuel) for heat energy. This results in a significant decrease in fossil carbon emissions for drying and panel pressing processes. However, this carbon benefit is overshadowed by the increased fossil energy used for ECDs. As a result of the increase in use of biofuel from earlier studies, global warming potential (GWP) impacts for lumber production decreased by 54 kg CO_2/m^3, increasing the net carbon stored in wood products by about 5% (6). Carbon emissions for wood production remain low compared to the amount of carbon stored in the wood product. ***Any diversion of biofuel feedstock from use for onsite energy will only increase production emissions and reduce efficient use of the wood residues. Long term composite panel products displace and store more carbon than is released during production.***

2. Every stage of processing is critical to understand opportunities to reduce emissions and climate change.

Growing Trees Stores Carbon in the Forest: The essential first step for wood to displace fossil fuels and increase carbon stored in products. USFS forest inventory data (Figure 2) shows that naturally regenerated forests reach their maximum carrying capacity at about 80 years in the PNW with an average of 184 t C/ha. Managed forests reach 81% of that potential at 50 years with an average of 150 t C/ha (7). Without management carbon sequestration is slower and uncertain (7). Large trees may continue to grow larger by crowding out adjacent trees but eventually, due to natural aging and disturbances such as windstorms, fire, and disease, the unmanaged forest is likely to emit carbon rather than store more carbon. ***Preserving forests provides a one-time increase in carbon stores, not a sustainable increase.***

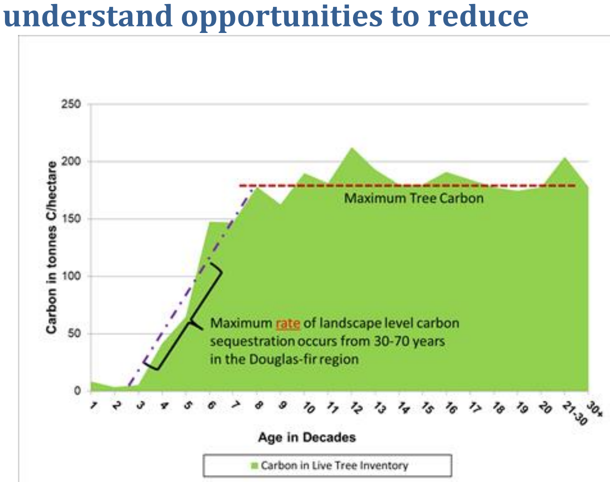

Figure 2. USFS Western Washington carbon inventory by age.

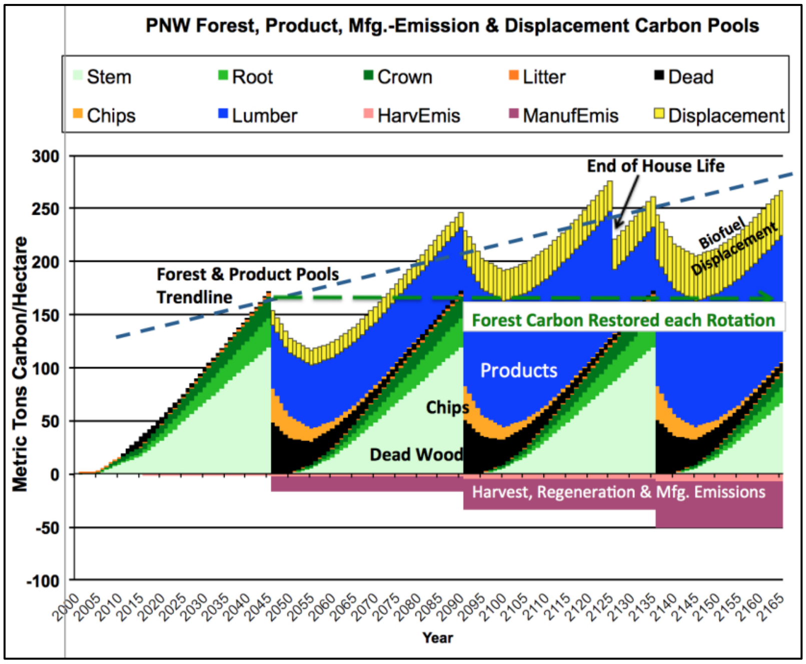

Figure 3. Forest and wood-product carbon pools are substantially larger than processing emissions.

Harvesting and replanting transfers carbon from the forest to products. Continued investment in managed forests stabilizes forest carbon. Forest growth provides the essential beginning of life cycle carbon storage accounting. For managed forests (Figure 3) forest carbon remains below a maximum (light green Stem and darker green Crown and Root), and harvests transfer roughly half the carbon to wood products (blue), and biofuel (yellow) on a sustained basis. Forest regrowth offsets the removals while keeping the average carbon across the whole forest stable. Carbon stored in wood-products and used as biofuel for heat energy displaces emissions from fossil fuel. Intensively managing forests leads to increases in: yield, carbon stores, and the feedstock supply for many products and uses. ***Forests must be sustainably managed to sustain wood-supply for future uses.***

Sustainably managed forests accumulate removals to displace and store carbon year after year. Sustainable wood products manufacturing transfers carbon stored in the forest to the wood products, and their end uses, resulting in a sustainable increase in carbon stores year after year. Additional gains occur from the displacement of fossil intensive products and recycling the wood after first use. Short lived products (orange) (Figure 3) are used and decompose within the rotation. The forest residuals (black) (Figure 3) are left behind to decompose or are piled and burned during site preparation and replanting. In most cases it is too costly to remove these residuals due to the relatively low cost of natural gas (NG). Sustainable management acts like a pump that transfers forest carbon to other uses and storage pools. Products can remain in service beyond the first rotation but are shown for tutorial purposes to be burned at end of life (80 years) with no energy recovery. There is substantial variation in the end of product life age, which would smooth the transition shown. The processing energy for wood-products harvesting (pink) (Figure 3) and manufacturing (magenta) is shown as a carbon emission (below zero). These emissions are partially offset by biofuel use (yellow above) resulting in a sustainable total net carbon trend above 1-ton C/Ha/year exclusive of product substitution for fossil intensive products or end of life recycling.

Some Products can store more carbon and displace more fossil emissions than others. Adding together the carbon stored in wood products and the avoided fossil carbon emissions from substituting wood for non-wood products provides an estimate of the total carbon reduction to the atmosphere (Table 1). A PNW wood wall stud stores a net 16.7 kg CO_2/m^2 (carbon stored minus production emissions) and can displace 18 kg from steel studs for a total carbon stored plus displaced of 34.7 kg CO_2/m^2 (Table 1). Wood wall studs that displace concrete blocks, which uses more energy

Table 1 PNW net wood carbon stored & non-wood fossil carbon displaced (emission) for wall and floor components

WALL COMPONENT: Wood stud displacing a steel stud or concrete block kg CO_2/m^2		
Wood stud:	**Steel stud:**	**Total kg CO_2 reduced**
Stores net 16.7	Emits 18.0	34.7
Wood stud:	**Concrete block:**	**Total kg CO_2 reduced**
Stores net 16.7	Emits 27.5	44.2
FLOOR COMPONENT: Wood based joist displacing a steel joist kg CO_2/m^2		
Dimension joist:	**Steel joist:**	**Total kg CO_2 reduced**
Stores net 30.0	Emits 42.3	72.3
Wood I-Joist[a]	**Steel joist:**	**Total kg CO_2 reduced**
Stores net 14.7	Emits 42.3	57.0

[a] Does not include the 30% reduction in forest area needed for wood I-joist.

in production, results in 44.2 kg reduction in CO_2/m^2 of wall. Floors require greater stiffness and strength than walls so the carbon impacts are different. A dimension floor joist displacing a steel joist results in 72.3 kg in CO_2/m^2, or over twice as much reduction as derived from the wall stud. Since Engineered Wood Products (EWP) such as wood I-Joists use much less wood than dimension joists, the carbon stored is cut almost in half thus reducing the total CO_2 benefit to 57 kg/m^2. However, forest resource efficiency is increased because fewer acres are needed for fiber production for I-joists as compared to dimension lumber.

Wall assemblies often include plywood sheathing for both wood and steel studs. In this case, the change in CO_2 reflects only the additional connecting hardware as CO_2 in the sheathing is common to both wood and steel assemblies (Table 2). However, when the wood wall assembly replaces a concrete block wall plus a gypsum cover, the carbon benefit in the wood wall is increased. In the PNW the concrete block has higher emissions due to seismic strength standards. Displacement varies by as much as 300% depending on the alternate material. ***The range of opportunities to displace and store CO_2 is large depending upon the design of assemblies and the products used.***

Table 2 PNW net wood carbon stored & non-wood fossil carbon displaced (emission) for wall and floor assemblies.

WALL ASSEMBLIES	Total kg CO_2 reduced
Wood stud + plywood displacing Steel stud + plywood	34.7
Wood stud + plywood displacing Concrete block + gypsum	105.6
FLOOR ASSEMBLIES	**Total kg CO_2 reduced**
Dimension joist + plywood displacing Steel joist + plywood	70.9
Wood I-Joist + plywood displacing Steel Joist + plywood	50.6
[a] Does not include the 30% reduction in forest area needed for wood I-joist.	

Using woody biomass for fuel displaces CO_2 emissions from fossil fuels but does not retain any carbon in storage. The fossil carbon displaced per unit of carbon in the wood used becomes a basic efficiency measure of carbon displaced (the output), per unit of carbon used (the input). The most efficient biofuel option is the historic baseline for drying lumber of 56% mill residuals and 44% NG mix resulting in 0.72 CO_2 displaced per CO_2 in the wood used (Figure 4). This value is boosted by low impact in handling and transportation of the residues when compared to the many alternatives to produce heat and power at wood production facilities. The range of efficiencies in using wood residues to displace fossil emissions runs from 0.21 when pellets are made from open market purchases that use fossil fuels for drying, to 0.64 when pellets are made from flooring residual waste, to 0.4 when residuals are gasified to produce ethanol that displaces liquid fuels for transportation, like gasoline (Figure 4).

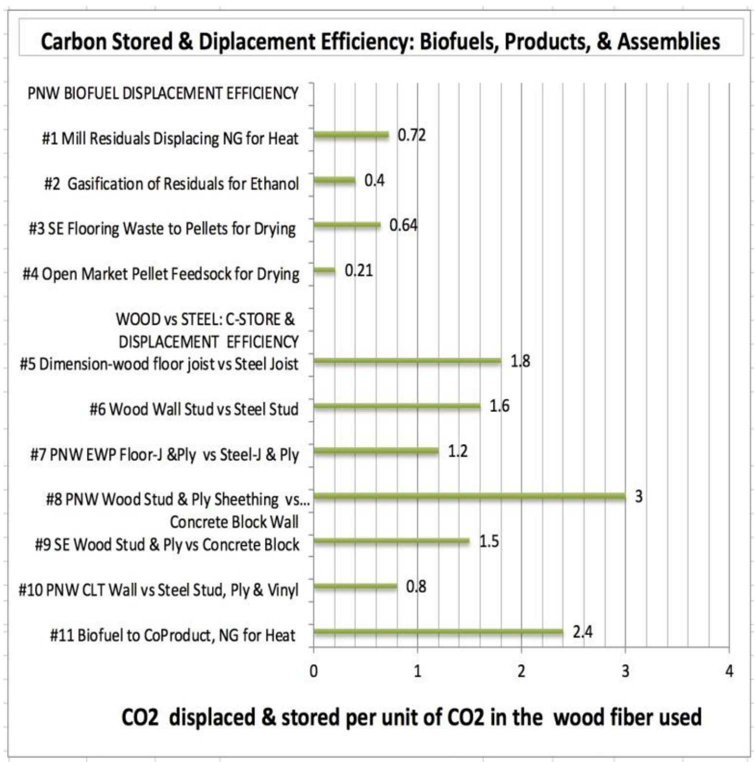

Figure 4. Carbon emission reductions per unit of carbon in the wood used for a range of biofuel and wood uses.

When wood product components are produced with biofuels, the efficiency increases to well over 100%. Figure 4 shows output over input ratios of 1.8 (180%) for floor joists, 1.6 for wall studs, and as high as 3.0 when wood wall assemblies displace concrete block under PNW seismic code standards. In the SE this same wall assembly achieves a 1.5 displacement with no seismic code standard. Using cross laminated timber (CLT) as a wall assembly to displace wood residential walls only produces an efficiency of 0.8. The relatively low value arises because CLT uses so much more wood. The real opportunity for CLT is in high rise buildings where it displaces more concrete and steel and can potentially be reused repeatedly. When wood residues are used as a feedstock for wood composite panels, the efficiency can be as high as 2.4 as compared to 0.4 for transport fuels like ethanol. This is a 600% improvement in efficiency of use (Figure 4).

Recycling demolition wood (recovery and reuse, reprocess, burn to displace NG, or landfill). At the end of its first useful 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 or flared to eliminate methane, a potent greenhouse gas. The gas that is captured and used for energy is a direct substitution for fossil fuel (8). Lippke and Puettmann (8) provide many more simulations of end of life impacts compared to a base case using 56% biofuel and 44% NG for drying wood at manufacturing facilities. Reusing wood material in buildings could potentially increase the trend growth of carbon stores and displacement by as much as 72% if no reprocessing is required (8). When reprocessing is required there is still a potential 44% increase in carbon mitigation (8). If the material could only be recovered for heat energy the additional carbon mitigation benefit is estimated at 19%.

Using updated LCI data and a base simulation that uses 50% more biofuel resulted in a 3.06 t C/ha/year (metric tons carbon per hectare per year) carbon stored and displaced trend (Figure 5). Using a

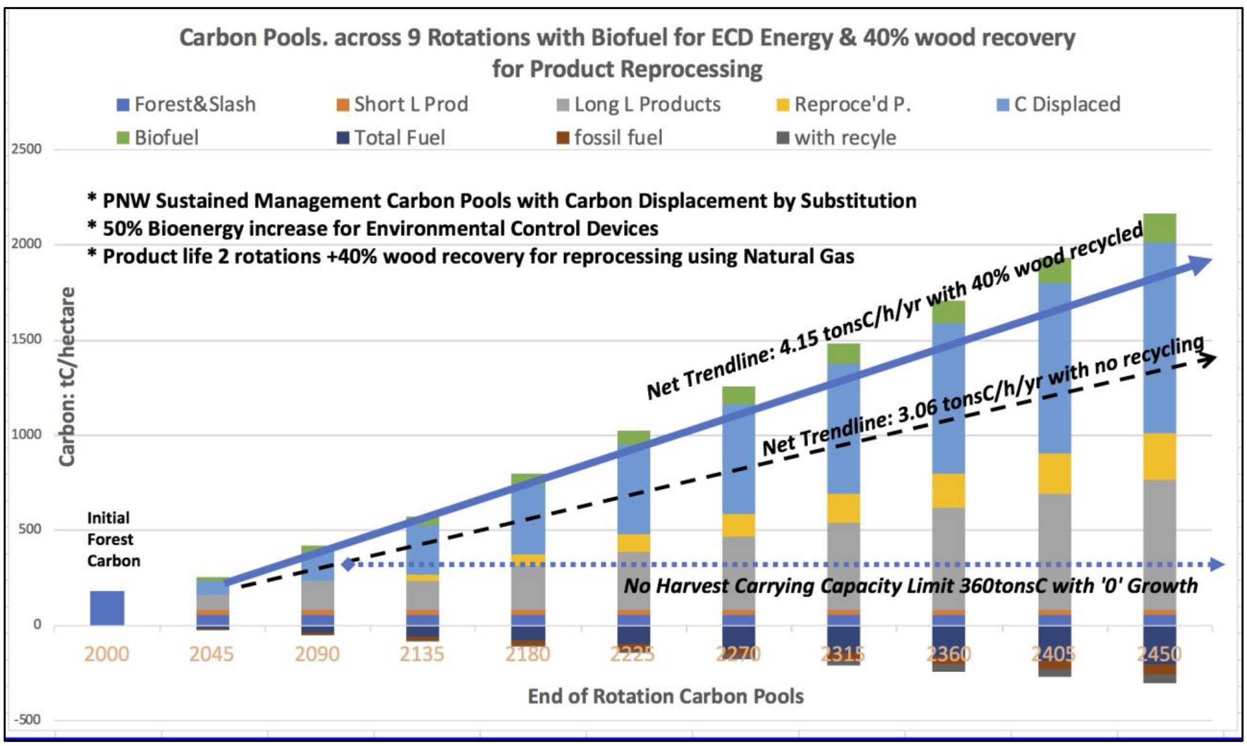

Figure 5. Growth in carbon pools with updated LCI data and 40 % recovery of demolition wood for reprocessing using natural gas

plausible demolition wood recovery scenario of 40% for reprocessed products, even including the NG needed for the incremental processing energy, increased the carbon stored and displaced trendline to 4.15 tons C/ha/yr. This results in a 36% sustained growth trend increase for 40% wood recovery compared to a no wood recovery option.

3. Opportunities for Improvement: Recognize and Avoid Unintended Consequences

The research data suggests that there are many opportunities to substantially improve carbon displacement and storage. Examples above are but a few of them. Policies made using only a few selected benchmark comparisons are likely to ignore many potentially better options and therefore will result in unintended consequences. A classic example is diverting co-product feedstock to biofuel for heat or energy. Avoiding unintended consequences is critical for effective reduction in carbon emissions, investments, and policies. A few policy examples may be the best learning tool for avoiding unintended consequences.

Subsidies to produce cellulosic ethanol - Production subsidies raise the price that ethanol producers can pay for their feedstock. This allows them to bid the feedstock away from other wood producers like wood composite panels that displace far more carbon emissions than the subsidized ethanol producers. The problem of subsidizing one producer and ignoring the unintended consequences to other producers affects many so-called carbon mitigation policies. More often than not the incentives that have been tried result from perceived impacts rather than based upon measured comparisons. At present, there are no subsidies directed at the high end of the displacement possibilities that would result in more efficient use of wood to displace fossil intensive products. To the contrary, “green” building standards such as LEED have given preference to imported recycled steel over locally produced wood products just because it was recycled, not because it shows efficient GHG displacement.

The renewable fuel standard (RFS) - Utilities are forced to gain access to renewable feedstock and pay higher prices that bid it away from better uses. At the same time the RFS fragments the biofuel supply base which makes it more difficult to invest in scale-facilities that can more efficiently reduce carbon emissions. The lack of clear priorities for how forests and forest products might be best utilized to mitigate climate change creates market uncertainty, which discourages investment (9). This contributes to an infrastructure barrier that has stalled the expanded use of biofuels even though it is mandated by federal laws such as the Energy Independence and Security Act of 2007 (10). Renewable fuel standards do not address the need for a cost on fossil emissions consistent with the objective of reducing them. They also ignore the reality that emissions will increase with lower costs for fossil fuels and especially when they are subsidized.

Any subsidy directed at low valued uses of a feedstock is likely to be counterproductive - If the subsidy is aimed at the producers that actually reduce emissions the most, like wood I-joists displacing steel I-joists, there is at least a much lower chance that the increased use of the feedstock will actually be taken away from some producer doing a better job at carbon mitigation.

Nearly every manufacturing process alters carbon with potential cascading effects - While we can compare product A with product B, and can show that B looks better than A using life cycle assessment for both alternatives, it can just as easily be counterproductive once you learn the impact of A vs. C or D or X, especially for competing feedstocks. It is literally impossible to certify that B is better than A without knowing how B impacts all other alternatives. Cap and Trade or carbon offsets are not defensible in spite of their great political support because they ignore so many alternative uses that are likely to result in better displacement of fossil carbon emissions.

The high European fossil fuel taxes have resulted in transporting pellets from the US to Europe. This helps Europe reach their carbon mitigation objectives but is it efficient? The sale of US pellets to the European market demonstrates how markets respond to a cost on emissions. Accounting protocols dictate that imported pellets result in a net reduction of carbon emissions for the importing country. However, the high tax on fossil fuel in Europe takes away the opportunity for producer nations, like the USA, that could have reduced emissions more efficiently with an equal tax. Pellets do provide manufacturing flexibility relative to other low-grade biofuels. Plant size can be adjusted from small to large to match the current raw material availability as well as investor capital. Plants can be readily expanded as desired and investment-to-production output is low. As a contrast, new composite wood product facilities require both large capital investments and dedicated raw material supplies. In addition, they can only utilize a subset of milling residues while both log and mill residues (dirty or clean) can be utilized for various grades of pellets. Trading sulfur emissions among a small number of emitters may have been effective in reducing sulfur emissions but the sources of carbon emissions are well beyond the same degree of accountability.

The greatest unintended consequence probably derives from the subsidies to fossil fuel production and consumption resulting in a price advantage for their use - Skovgaard and van Asselt (11) provide a review of the complexities of fossil subsidies and their implications for climate change mitigation. In scaling the impact of subsidies, their review included the International Energy Agency's estimated impact on consumption to be $300 billion. For comparison the International Monetary Fund's (IMF) estimated impact was $5.3 trillion using a price-gap approach that includes both producer and consumer impacts. Either estimate is large enough to suggest a significant disadvantage for non-fossil fuel alternatives. Subsidies favoring fossil fuels can be hidden even though critical, such as the military protection required to keep the shipping lanes for fossil fuels open.

An efficient inducement for less fossil carbon emissions would be to levy a pollution fee on their use - An efficient inducement to reduce emissions must increase the cost of the emission proportional to the volume of the carbon emitted and be passed through the market affecting every transaction. Economists suggest a carbon tax as the best way to improve carbon mitigation. They do however call attention to the fact that such a tax becomes an increased cost drag on the economy. That drag on income can be neutralized by rebating the tax revenues to the consumers and producers impacted, i.e. a tax offset resulting in no change in total income but a reduction in income to fossil intensive producers/consumers. In effect, a tax with offsetting rebates is not a tax but rather a pollution fee and rebate. Its goal is to change consumer buying behavior but not their income. Since the tax and rebate system will not be global, at least initially, the devil is in the detail on how to prevent a "Carbon Negative Producer" from losing market share at the border. It would be counterproductive if the tax system reduces the production from "Carbon Negative Producers" such as wood manufacturers. The details require that the tax rebate to users must be larger than any tax increase on carbon negative producers that purchase some fossil fuels for their production (all do). The market then determines the best feedstock uses to avoid the high cost of fossil emissions. For regionally specific carbon emission fees, second order subsidies or partial exemptions can be used to offset the loss in product competitiveness at the regional border for carbon negative producers. Using rebates from tax revenues to consumers and producers has been successfully tested in British Columbia. They have avoided reducing economic growth from the tax, given the rebate to consumers thus maintaining income, and reduced fossil emissions (12).

One possible way to support the increased use of biofuel to all producers is to reduce the cost of collecting the currently unused feedstock available to all producers - Providing a tax credit for collecting forest residuals and demolition wastes rather than subsidizing a specific producer can avoid the subsidy being used to steal the feedstock from other more carbon efficient producers. Even tax credits for growing forests increases the supply for all users while market prices efficiently allocate feedstock without bias to different uses.

Economists suggested estimating the social cost of emissions to be used as a criterion for evaluating regulations - EPA provided estimates of the social cost of carbon emissions (13). While their estimate excluded many costs, their estimated values exceeded the cost of collecting forest residuals and other wastes suitable for biofuel. However, no cost on carbon emissions has been introduced as a response to EPA's estimated loss in value from fossil carbon emissions.

4. Summary and Conclusions

Using fossil fuels and fossil fuel derived products generates a one-way flow of emissions to the atmosphere which contributes to climate change. Using wood derived from solar energy results in a two-way flow of emissions to (and from) the atmosphere. From a carbon perspective, preserving forests instead of sustainably harvesting forest carbon to displace fossil fuels and fossil intensive products wastes the opportunity to substantially improve carbon mitigation outcomes.

The best uses of wood provide an advanced "carbon negative technology" with high leverage to displace fossil emissions. That leverage is not matched by solar cells that neither store carbon nor displace fossil intensive building products. There may be new and better opportunities to replace wood-based biofuel on the horizon such as algae. Dovetail Partners Inc (14) in their review of 2nd and 3rd generation biofuels noted in their ‘Bottom Line’: “For the near-to mid-term, at least, algae-derived biofuels are unlikely to pose competitive risks to the emerging second-generation cellulose-based biofuels industry”. Replacing wood products carbon-negative technology in structural uses by still undeveloped carbon recapture technology appears to be even further out in time. But leveraging the structural strength of wood fiber to displace carbon intensive building materials is a near term, implementable solution.

Some policies subsidize improving the efficiency of using fossil fuels. At best this only reduces the rate of increase of emissions that are a forcing element driving climate change. Subsidies are also directed at the lowest efficiency uses of wood rather than the highest efficiency uses that displace fossil emissions and store wood in products. Trading carbon credits between producers that need to reduce their emissions by buying from those that are carbon negative producers will often simply redirect the feedstock away from more efficient uses, including those that have not yet been analyzed. Using wood residues in composite wood panels is far more efficient at reducing carbon emissions than using them to substitute for fossil energy. More effort is required to better understand the best uses of wood for carbon mitigation and how to avoid unintended consequences. Market solutions are an efficient way to raise the cost of carbon emissions which will provide a comparative advantage for carbon negative technologies.

There are regional and rural opportunities to increase economic activity while reducing carbon emissions and increasing efficiency. Some regional opportunities that better use wood resources are enormous and can provide substantial rural economic benefits. Some states are putting a priority on regional opportunities to reduce emissions and contribute more to rural economies by greatly increasing their understanding of better practices and implementing them. Ironically science is not the limiting factor. Understanding how to better use the science to avoid unintended consequences requires educational outreach customized to each region’s opportunities in order to gain the support of the public, investors, and policy makers.

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