Preventing GHG Emissions through Wood Substitution

Wood substitution addresses climate change in several ways. Wood products from sustainably managed forests can be replenished continually, providing a plentiful and dependable supply of both trees and wood products while supporting other ecological services, such as clean water, clean air, wildlife habitat, and recreation (USFS 2005). Substituting wood for fossil fuel–intensive products also avoids the emissions from the substituted products, and what was forest carbon remains stored in the wood products.

Trees remove carbon dioxide (CO$_2$) from the atmosphere and store it in their roots, stems, trunks, and leaves through the process of photosynthesis. In addition, forested ecosystems store carbon in soil, forest floor, and down dead wood. As forests and their trees mature, their growth slows; however, some studies indicate that as tree growth slows, ecosystem storage of carbon may actually increase as a result of increases in other carbon pools (Zhou et al. 2006; Schulze et al. 2000). Although more definitive research is needed, it appears that both short-rotation management and long-rotation or old-growth management can lead to greater overall carbon sequestration. Intensively managed commercial forests, using short rotations, can sequester significant carbon if the wood products are long-lived (Perez-Garcia et al. 2005). Long rotations and old-growth management mean little or no carbon is stored in wood products but more carbon is stored in the ecosystem. If the only forest management goal is to sequester carbon, both short-rotation intensive management and old-growth management are appropriate; however, if the goal is also to produce wood products, then short-rotation management that leads to long-lived products would be the approach of choice.

**Life-Cycle Assessments**

Public interest in the environmental impacts of forest management has created demand for strategies and policies to improve environmental performance, some of which can have unintended consequences. Harvest reductions, for example, alter the availability of wood, and in turn, the price of building materials. This increases wood imports from other countries or causes consumers to use nonwood substitutes. The environmental consequences of these changes in material flow and uses are difficult to quantify because of the complexity of tracking materials through market transactions (USFS 2005), but contrary to intuition, the use of nonwood substitutes is often detrimental to the environment.

What exactly are the environmental benefits of substituting wood for steel and concrete? The Consortium for Research on Renewable Industrial Materials (CORRIM) was created as a not-for-profit consortium by 15 research institutions to update and expand a 1976 report by the National Academy of Sciences on the effects of producing and using renewable materials (Lippke et al. 2004). CORRIM developed a complete life-cycle inventory of all environmental inputs and outputs, from forest regeneration through product manufacturing, building construction, use, maintenance, and disposal.

![Figure 3-1. Life-cycle assessment from regeneration of trees to disposal of wood materials](Source: CORRIM Presentations, www.corrim.org/ppt/2005/fps_june2005/lippke/index.asp)
Table 3-1. Environmental performance indices for residential construction.

<table>
<thead>
<tr>
<th></th>
<th>Minneapolis home</th>
<th>Atlanta home</th>
<th>Difference</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Embodied energy (gigajoules)</strong></td>
<td>461</td>
<td>461</td>
<td>63</td>
<td>16</td>
</tr>
<tr>
<td><strong>Global warming potential (kg CO₂)</strong></td>
<td>7,047</td>
<td>8,566</td>
<td>1,519</td>
<td>20</td>
</tr>
<tr>
<td><strong>Air emissions index (index scale)</strong></td>
<td>9,729</td>
<td>9,729</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td><strong>Water emissions index (index scale)</strong></td>
<td>53</td>
<td>53</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td><strong>Solid waste (total kg)</strong></td>
<td>13,641</td>
<td>13,641</td>
<td>0</td>
<td>—</td>
</tr>
</tbody>
</table>


positional. It constructed virtual houses (of approximately 2,250 square feet, an average size) and used a life-cycle assessment to determine the associated energy use, air and water pollution, global warming potential, and solid waste production (Lippke et al. 2004). The virtual houses, using framing materials of wood, steel, and concrete, were “built” in two very different locations: Minneapolis (wood versus steel) and Atlanta (wood versus concrete).

Figure 3-1 depicts the life-cycle assessment for a wood-frame house. It includes transportation for each stage from forest management (regeneration) to harvesting, product manufacturing, building construction, use and maintenance, and recycling or disposal. Each stage of processing had different effects, providing insight into where opportunities for improvement could have the greatest overall benefit.

Forest resource management can positively affect climate change. However, implementation of any kind of management treatment requires forest operations, such as harvesting, processing or conversion, and transportation of biomass. These operations affect the GHG profile of forestry activities through the direct emissions of the equipment and the relative efficiency of handling biomass volume (Brinker et al. 2002). Operators employ a wide range of equipment and operational methods, from loggers with chainsaws to highly mechanized mass-production logging systems, to reduce environmental impacts and create economic efficiencies. Power technologies for forest equipment are changing with federally mandated transitions to different fuel types and cleaner diesel engines, and alternative-fuel equipment, including hybrids and biofuels, is being tested. Emission reductions must be assessed on a net basis. A low-emissions system may be relatively inefficient at processing carbon volume and thus a poor choice under climate change scenarios (Brinker et al. 2002). However, the energy requirements for harvesting and transportation are substantially lower than for product manufacture, where the energy required for drying is a major factor but can largely be provided by biofuels with negligible net greenhouse gas emissions (Puettmann and Wilson 2005).

Life-cycle inventory analysis reveals that the wood products used in construction store more carbon and use less fossil energy than steel, concrete, brick, or vinyl. Conversely, the manufacture of nonwood products is energy intensive and produces substantial emissions, including global warming potential (GWP) emissions (K. Skog, US Forest Service, Forest Products Laboratory, pers. comm., November 2007).

Table 3-1 presents the summary environmental performance indices for typical Atlanta and Minneapolis houses built to code. With two exceptions (solid waste in the Minneapolis house and water pollution in the Atlanta house), the index measures for the wood-frame designs are considerably lower than for the nonwood frame designs. Notice that for global warming potential, steel has 26 percent higher CO₂ equivalent than wood, and concrete, 31 percent higher CO₂. The difference is particularly significant considering that the framing accounts for only about 6 percent of the mass of the house; the rest of the house’s materials are unchanged.

Life-cycle assessment of building systems, like walls and floors, shows that carbon emissions are very sensitive to design and product selection, with steel and concrete walls and floors producing several times more emissions than wood-dominant assemblies (Lippke and Edmonds 2006). Figure 3-2 shows the GWP differences for four floor designs, not including any insulation or floor covering. The concrete floor produces more than four times the GHG emissions of a dimensional lumber or wood I-joist floor. The steel design is much worse, releasing 731 percent more GWP than wood I-joist floors, largely because the horizontal application of steel in a floor requires a high gauge to reduce bending and bounce.

Figure 3-3 shows similar comparisons for an Atlanta wall, including insulation and cladding. The increase in GWP for the concrete wall over a kiln-dried lumber wall is similar to the floor comparison. The calcification process used to produce concrete increases the GWP for the concrete design’s block, stucco, and lumber frame 427 percent compared with the kiln-dried lumber design’s plywood, vinyl, and lumber (Lippke and Edmonds 2006).

Wood use can substantially alter environmental performance and reduce emissions, especially when wood is substituted for fossil fuel-intensive products and energy. For example, for a Minneapolis steel stud wall, the steel and its required insulation have 44 percent higher GWP than the kiln-dried wood wall; both walls’ cladding and gypsum contribute almost as much to emissions as the framing elements (Figure 3-4, columns 2 and 3). However, substituting wood siding for vinyl siding, wood paneling for gypsum, cellulose for fiberglass, and increasing biofuel use for drying reduces emissions by 75 percent (Figure 3-4, column 1).

Figure 3-5 illustrates the integrated effect of all carbon pools present in a forest as
it matures, along with the carbon removed by product pools based on the life-cycle assessment. It shows a modest increase of carbon in the combined forest and product pools over time (lower red line), unlike the steady state that exists in a forest (green line; i.e., when wood products are not removed). More importantly, as wood products are substituted for fossil fuel-intensive building materials like concrete and steel framing (upper red line), emissions are avoided. The combined pools of carbon stored in the forest, forest products (net of processing, including the bioenergy from bark, or hog fuel, from mill waste), and avoided fossil fuel-intensive substitutes increase over time—with important consequences for carbon policy (USFS 2005).

CORRIM has also conducted life-cycle assessments for different kinds of wood products. Plywood sheathing has a 3 percent lower environmental impact in a completed house than oriented-strand board (OSB) (although OSB has fewer water-related environmental consequences, probably because at the time of the research, some OSB mills were in compliance with new, stricter water quality standards) (Lippke et al. 2004). Conversely, substituting wood dimension joists for engineered I-joists results in little difference in the environmental performance indices because the greater material efficiency of the I-joists is offset by the increased use of resins and energy (Lippke et al. 2004). However, material use efficiency is by itself very important, since only half as much fiber is used for engineered I-joists as for the equivalent dimension lumber joints.

**Forest Rotations and Conversion**

The sooner wood products can be produced from forests, the sooner they can displace the emissions from fossil fuel-intensive products. Thus, intensive, short-term commercial rotations, while storing less overall carbon in the forest, result in lower carbon emissions when life-cycle assessments include forest and product carbon storage as well as the emissions from substitute products. Some estimates indicate that a forest managed for wood production will provide a net sequestration at least double that of an unmanaged forest in the Pacific Northwest (B. Lippke, University of Washington, pers. comm., August 2007). If, however, the goal is to sequester carbon in the forest, management for long rotation and old-growth will lead to significant ecosystem carbon storage (Harmon et al. 1990).
Carbon stocks are affected by changes in land use. When forestland is converted to nonforest use, the carbon stored both on that land and in its wood products is lost, along with those products’ potential to be substituted for fossil fuel–intensive products.

Unnaturally high fuel loads in many forests provide wood substitution opportunities. Thinning heavily stocked stands and using the wood in long-lived products or converting it into biofuel would avoid the carbon emissions associated with fossil fuels and fossil fuel–intensive products. These same areas would thus contribute to reduced GHG emissions and increased carbon storage in wood products. These policies intended to slow global warming can easily have unintended consequences. A policy that lowers the cost of wood, for example, would motivate builders and consumers to select wood framing and floors in residential construction. As the demand for wood rises, relative to fossil fuel–intensive materials, more investment in growing wood for this market would occur, resulting in further reductions in emissions. However, if a carbon credit is given only to growing trees in forests, it would likely lengthen rotations, reduce the production of wood products, and possibly increase the use of fossil fuel–intensive products, thereby increasing GHG emissions (B. Lippke, University of Washington, pers. comm., November 2007). Developing carbon credit markets that motivate true reductions in carbon emissions must address all carbon pools and their GHG emissions. Such markets will not be successful if they focus only on carbon stored in forests or a single stage of processing.

Measuring the life-cycle inventory of environmental impacts and assessing their effects across all stages of processing are critical to evaluating the consequences of different processes, product uses and designs, and forest management. The values (costs) of these impacts must be accurately reflected in the market if we want to motivate the changes in consumption and investments that will reduce carbon emissions. As an example, the Swedish parliament has recognized an opportunity to reduce GHG emissions by reducing the use of concrete in buildings and has instituted policies, educational campaigns, regulations, and building codes to promote the use of wood (Sathre 2007).

Although wood product substitution does not permanently eliminate carbon from the atmosphere, it does sequester carbon for long durations and can offset the use of more GHG-intensive products. When wood is harvested and used to make lumber, furniture, plywood, or other wood products, carbon is sequestered for the life of the given wood product. Once the wood product has served its useful life, landfill management techniques can further delay the conversion of wood to GHG emissions, or the wood can be used for power generation (offsetting generation by fossil fuel–fired power plants) or recycled into other potentially long-lived wood products. Regardless of the particular pathway followed after a product’s useful life, wood substitution is a viable and important technique to immediately address climate by preventing GHG emissions.

**Figure 3-5. Carbon in forest, product, fuel displacement, and fossil fuel–intensive product substitution pools (Source: Perez-Garia et al. 2005).**