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Life-Cycle Inventory of Manufacturing Prefinished Engineered Wood Flooring in the Eastern United States

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Abstract

Building products have come under increased scrutiny because of environmental impacts from their manufacturing. However, environmental impacts of manufacturing some wood products—such as prefinished engineered wood flooring—have not been determined. This study examined prefinished engineered wood flooring in the eastern United States following the life-cycle inventory approach. To provide a reference to the product system inputs and outputs, a functional unit of one cubic meter of prefinished engineered wood flooring was selected. This study surveyed five engineered wood flooring manufacturers located in the eastern United States. These production facilities represented 18.7% of total annual production in 2007. For the year 2007, primary data collected included annual production, energy consumption and type, material inputs, product outputs, and other co-products. This study estimated an overall conversion (logs to prefinished engineered wood flooring) of 30.1%. Unallocated thermal process energy and electricity consumed was 6,418 MJ/m^3 and 1,113 kWh/m^3 prefinished engineered wood flooring, respectively. Wood fuel at 300 OD kg, or 6,263 MJ/m^3, contributed 97.6% of process thermal energy required. SimaPro modeled the weight-average data to estimate the environmental footprint. Modeling data estimated biogenic and fossil CO_2 emissions at 623 and 1,049 kg/m^3, respectively, and VOCs at 1.04 kg/m^3. Carbon stored in the flooring—1,100 kg-CO_2-equivalents—offsets the fossil CO_2 emitted by 4%. Current prefinished engineered wood flooring manufacturing practices result in a negative carbon balance as long as the carbon is stored in the final product.

Keywords life-cycle inventory, LCI, prefinished engineered wood, flooring, environmental impact

Introduction

The environmental performance of products that are components of residential or commercial buildings is increasingly being examined because of concerns over the environmental impacts of structures. The processing of some building products consumes large amounts of fossil fuels (Khatib 2009). Some research suggests that the main cause of climate change is burning fossil fuels (IPCC 2007). However, wood building products typically consume more biomass than fossil fuels during their manufacturing, a significant environmental advantage (Puettmann and Wilson 2005). Biomass carbon dioxide (CO_2) is considered carbon neutral because the CO_2 emitted from burning biomass will not increase total atmospheric CO_2 if the consumption of biomass is done on a sustainable basis (UNFCCC 2003, EPA 2003).

"Green building" is defined as the practice of improving the energy efficiency of materials, construction, and operation of buildings while reducing the overall environmental impact. The green building market, including non-residential and residential, is likely to almost triple from $36–49 billion in 2008 to $96–140 billion by 2013 (MHC 2008, Murray 2008). Forming a sound policy for building practices, especially for green building, in the United States would likely decrease its environmental burden on the world's resources. In addition, carbon emissions during manufacturing of building materials are expected to play a larger role in consumer selection in the future. Often lacking in the "green building" movement is a scientific method for analyzing product claims to determine their actual environmental performance.

The goal of this study is to document the LCI of prefinished engineered wood flooring production from incoming hardwood logs to prefinished engineered wood flooring. This study shows material flow, energy consumption, solid waste, and air, water, and land emissions for the prefinished engineered wood flooring manufacturing process on a per unit basis for the eastern

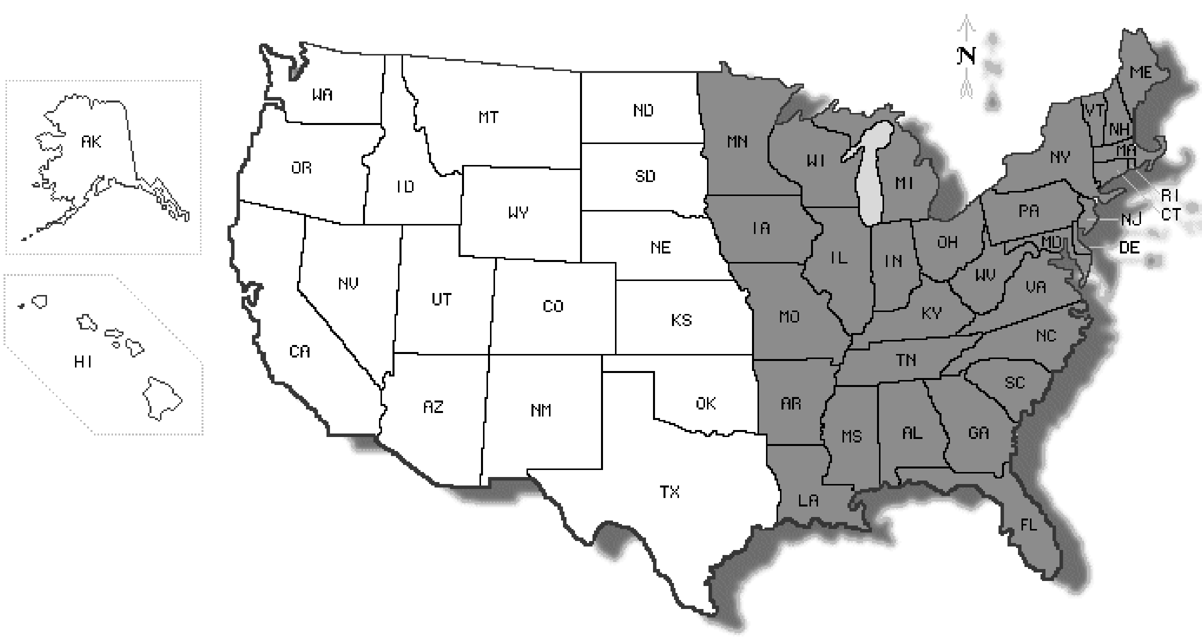

Figure 1: Shaded states represent the studied area

United States (Figure 1). We collected primary data by surveying veneer mills and flooring plants with a questionnaire, telephone calls, and a site visit; this study used secondary data from peer-reviewed literature per Consortium on Research for Renewable Industrial Materials (CORRIM) guidelines (CORRIM 2010). We calculated material and energy balances by a spreadsheet algorithm using data from primary and secondary data sources. From these material and energy inputs and reported emission, environmental impacts were estimated by modeling weight-averaged data through SimaPro 7 software (PRé Consultants, Amersfoort, Netherlands) (PRé Consultants 2010). SimaPro has been used in previous CORRIM-initiated LCI studies of hardwood lumber (Bergman and Bowe 2010), softwood lumber (Milota et al. 2005), and softwood plywood (Wilson and Sakimoto 2005). This LCI study conformed to relevant ISO standards (ISO 2006a,b).

Methods

Scope of the Study

The scope of this study covered the life-cycle of manufacturing prefinished engineered wood flooring from hardwood logs in the eastern United States. LCI data from this study may help in a comparative analysis of prefinished engineered wood flooring with other wood and non-wood flooring options. The life-cycle inventory model provides a “gate to gate” analysis of the cumulative costs of manufacturing and shipping industrial products. Analyses included prefinished engineered wood flooring’s contribution to energy consumption, air pollution, water pollution, solid waste pollution, and climate change.

Functional Unit

Material flows, energy use, and emission data were standardized to a per unit volume basis for 1.0 m^3 of prefinished engineered wood flooring, the final product of the prefinished engineered wood flooring manufacturing process. Based on U.S. industry measures, 1.0 m^3 of prefinished engineered wood flooring equals 1,130 ft^2 (3/8-in. basis) or 1.13 thousand ft^2 (3/8-in. basis). In the United States, wood flooring is usually sold in square feet (ft^2) at various thicknesses. Rough green veneer and rough dry veneer were assumed to be 2.62 and 2.43 m^3/thousand board feet after shrinkage and sanding, respectively (Bergman 2010, Koch 1985). Allocating all material and energy on a per unit basis of 1.0 m^3 prefinished engineered wood flooring standardized the results to meet ISO standards and the unit processes may be used to construct a cradle-to-gate and cradle-to-grave LCI and LCAs (ISO 2006a,b; CORRIM 2010).

Elementary Flows

Figure 2 shows wood flow through the product system. Manufacturing started with hardwood logs as raw material and ended with the final product of prefinished engineered wood flooring. Typical manufacturing included eight unit processes—log yard; bucking and debarking; block conditioning; peeling and clipping; veneer drying; layup; trimming, sanding, sawing and moulding (profiling); and prefinishing.

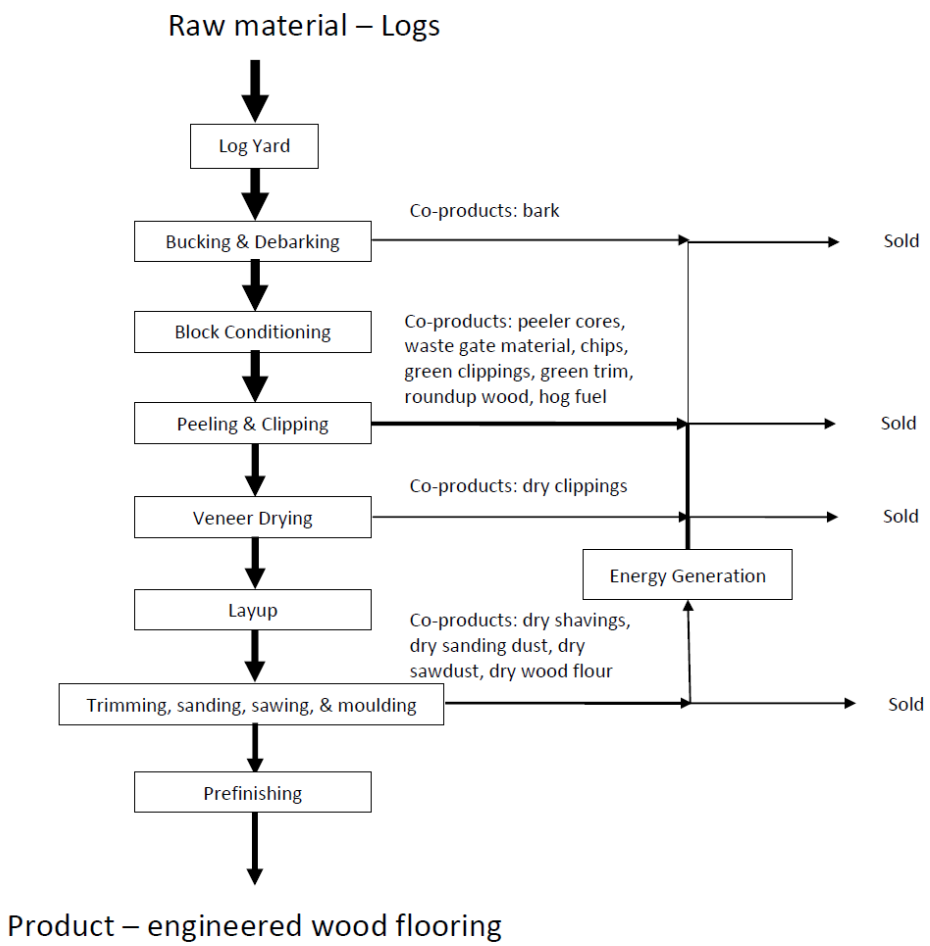

Figure 2: Description of product elementary flows

Results

Product Yields

For the mass balance, the LCI study examined the eight main unit processes and the overall process to track material flows. Using a weight-averaged multi-unit approach, 1,255 OD kg of incoming hardwood logs with a specific gravity of 0.510 and density of 944 kg/m^3 and 177 OD kg of purchased rough dry veneer with a density of 613 kg/m^3 (specific gravity of 0.578) produced 1.0 m^3 of prefinished engineered wood flooring. Boilers burned 194 OD kg of both green and dry wood fuel produced on-site (Table 1) for thermal process energy. Overall, a difference of 3.7% was calculated based on the overall mass balance that included intermediate products such as rough green and rough dry veneer.

Manufacturing Energy

Prefinished engineered wood flooring production required both electrical and thermal energy for processing logs into prefinished engineered wood flooring. All the thermal energy was produced on-site, whereas electricity was produced off-site and delivered through a regional power grid. Electrical energy was required for all unit processes; thermal process energy was required just for block conditioning, veneer drying, layup, and prefinishing processes. Total electrical consumption was 1,113 kWh/m^3 prefinished engineered wood flooring. A total process energy (unallocated) of 6,418 MJ was consumed per cubic meter prefinished engineered wood flooring (Table 2). Wood fuel at 300 oven-dry kg or 6,263 MJ/m^3 contributed 97.6% of process thermal energy required, with the remainder from propane (2.2%) and natural gas (0.2%).

Table 1: Wood mass balance for producing 1.0 m^3 of prefinished engineered wood flooring

	Wood mass balance (OD kg)			
Material	In	Out	Boiler fuel	Sold
Green logs (white wood only)	1255			
Green logs (bark only)[a]	66.9			
Dry veneer (purchased)	177			
Green bark		66.9	6.0	60.9
Green roundup wood		2.8	2.8	0.0
Green peeler cores		0.2	0.0	0.2
Green veneer clipping		0.6	0.6	0.0
Green trim		0.6	0.6	0.0
Green chips		532.8	0.1	532.7
Green hog fuel		175.3	175.3	0.0
Green waste gate material		0.1	0.0	0.1
Dry clipping		7.6	4.6	3.1
Dry sawdust		106	2.7	103
Dry shavings		11.1	0.8	10.3
Dry sanding dust		17.8	0.2	17.6
Engineered wood flooring		578		
Sum	1,499	1,499	194	728

[a] About half the bark was included under green hog fuel.

Table 2: Material and energy consumed on-site (unallocated)

Fuel type	Quantity (units/m^3)
Fossil fuel[a]	
Natural gas	0.3 m^3
Propane	5.36 L
Electricity[b]	
Off-site generation	1,113 kWh
On-site transportation fuel[c]	
Off-road diesel	7.01 L
On-road diesel[d]	4.26 L
Gasoline	0.57 L
Propane	0.04 L
Renewable fuel[e]	
On-site wood Fuel	194 kg
Purchased wood fuel	106 kg
Water use	
Surface water	972 L
Ground water	2,838 L

[a] Energy values were determined using their higher heating values (HHV) in MJ/kg: 54.4 for natural gas and 54.0 for propane.
[b] Conversion unit for electricity is 3.6 MJ/kWh.
[c] Energy values were determined using their higher heating values (HHV) in MJ/kg: 45.5 for off-road and on-road diesel and 54.4 for gasoline.
[d] Transportation of panels and veneer between facilities; not accounted for in other transportation data
[e] Values given in oven-dry weights (20.9 MJ/OD kg)

Environmental Impacts

Table 3 shows the lower environmental impact of on-site compared with accumulative emissions for the facilities surveyed. Carbon dioxide (CO_2) emissions were separated by two fuel sources, biogenic (biomass-derived) and anthropogenic (fossil-fuel-derived). Cumulative total emission values of 623 and 1,059 kg were reported from SimaPro for biomass CO_2 and fossil CO_2, respectively. The percentage of biomass CO_2 to total CO_2 increased from 37.3% to 64.8% from the total (cumulative) to on-site scenarios. Emissions of volatile organic compound (VOC) gases were roughly the same at approximately 1 kg regardless of scenario, thus indicating the on-site manufacturing process was a significant contributor to the overall amount of VOCs, not grid electricity.

Table 3: Life-cycle inventory results for total cumulative and on-site emissions on a per unit basis of prefinished engineered wood flooring (allocated)

Substance	Total cumulative (kg/m^3)	Total on-site (kg/m^3)
Water emissions		
Biological oxygen demand (BOD)	1.09	1.06
Cl^-	14.9	7.9
Suspended solids, unspecified	0.933	0.591
Oils, unspecified	0.0911	0.0865
Dissolved solids	12.6	3.94
Chemical oxygen demand (COD)	1.52	1.45
Other solid outputs[a]		
Waste in inert landfill	28.4	28.4
Recycled material	9.34	9.34
Solid waste[b]	41.0	41.0
Air emissions		
Acetaldehyde	2.17E–01	2.17E–01
Acrolein	4.90E–05	1.10E–05
Benzene	2.32E–03	2.14E–03
Carbon dioxide (biomass)	6.23E+02	6.10E+02
Carbon dioxide (fossil)	1.05E+03	3.31E+02
Carbon monoxide	5.57E+00	5.02E+00
Methane	2.65E+00	1.21E+00
Formaldehyde	4.00E–02	3.98E–02
Mercury	4.84E–04	3.36E–02
Naphthalene	6.99E–04	6.96E–04
Nitrous oxides	3.76E+00	1.61E+00
Non-methane, volatile organic compounds (NMVOC)	5.79E–01	5.02E–01
Organic substances, unspecified	8.05E–02	7.97E–02
Particulate (PM10)	1.38E–01	1.38E–01
Particulate (unspecified)	6.10E–01	1.71E–01
Phenol	1.92E–02	1.92E–02
Sulfur dioxide	5.05E+00	5.58E–01
VOC	1.04E+00	9.99E–01

[a] Includes solid materials not incorporated into the product or co-products and leave the system boundary
[b] Solid waste is mostly boiler ash from burning wood. Boiler ash is either spread as a soil amendment or landfilled, depending on the facility.

For wood products manufacturing, carbon storage in the final product offsets the CO_2 emissions from burning fossil fuels (Lippke et al. 2010). Using results from Birdsey (1992), we estimated a carbon content of 51.7% for the studied mixed hardwood species in the eastern United States. Therefore, the amount of carbon stored in a cubic meter of prefinished engineered wood flooring was calculated at 1,100 kg CO_2-equivalents.[1] Therefore, the carbon stored in the final product does offset the fossil CO_2 emissions of 1,049 kg by about 5%.

Conclusions

The following main conclusions were based on the life-cycle inventory:

- The amount of carbon stored in prefinished engineered wood flooring exceeded the fossil carbon emissions by about 5%. Therefore, as long as prefinished engineered wood flooring and its carbon stay in products held in end uses, the carbon stored will exceed the fossil carbon emitted in manufacturing.
- Burning fuel for energy generates CO_2. Nearly all energy produced on-site for manufacturing prefinished engineered wood flooring came from burning woody biomass. Burning biomass for energy does not contribute to increasing atmospheric CO_2 so long as forests are regrowing and reabsorbing the emitted CO_2.
- Increasing on-site wood fuel consumption would reduce fossil greenhouse gases but increase other gases and especially particulate emissions. Particulate matter may be captured prior to release to the atmosphere using commercially available technology but not without increased costs.

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[1] Multiplying (mass of flooring) * (carbon content) * (carbon to carbon dioxide conversion) = 578 kg * 51.7% * 44/12 = 1,096 kg CO_2-equivalents

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