Life-Cycle Inventory Analysis of Laminated Veneer Lumber Production in the United States

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Abstract

Documenting the environmental performance of building products is becoming increasingly common. Developing environmental product declarations (EPDs) based on life-cycle assessment (LCA) data is one way to provide scientific documentation. Many U.S. structural wood products have LCA-based "eco-labels" using the ISO standard. However, the standard requires underlying life-cycle inventory (LCI) data to be of recent age. This study updates the gate-to-gate manufacturing LCI data for laminated veneer lumber (LVL) for Pacific Northwestern (PNW) and for southeastern (SE) United States. Modeling the primary industry data per 1.0 m^3 of LVL through LCI analysis provides the inputs and outputs from veneer logs to LVL starting at the forest landing. For PNW and SE, cumulative mass-allocated energy consumption associated with manufacturing 1.0 m^3 of LVL was found to be 5.64 and 6.87 GJ/m^3, respectively, with about 25% of the primary energy derived from wood residues. Emission data produced through modeling found that estimated biomass and fossil CO_2 emissions in kg/m^3 were 127 and 139 for the PNW and 108 and 169 for the SE. One m^3 (~535 OD kg wood potion) of LVL stores about 980 kg CO_2 equivalents. The amount of carbon stored in LVL thus exceeds total CO_2 emissions during manufacturing by about 350%. This study provides the necessary gate-to-gate LVL manufacturing LCI data for the cradle-to-gate LCA to develop an updated EPD.

Keywords**:** environmental product declaration, life-cycle inventory, laminated veneer lumber, life-cycle analysis, LCA, wood.

Introduction

Documenting the environmental performance of building products is becoming widespread because green building programs and concerns that some green-marketing claims are misleading (i.e., green-washing). Developing environmental product declarations (EPDs) for building products is one way to provide scientific documentation and to counter green-washing (Bergman and Taylor 2011). Life-cycle inventory (LCI) data are the underlying data for subsequent development of life-cycle assessments (LCAs) and EPDs. EPDs are similar to nutritional labels for food. The LCI was in conformance with the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2013) and ISO

14040/14044 standards (ISO 2006a, b). This report follows data and reporting requirements as outlined in the PCR and contains the LCI components for producing a North American EPD (ISO 2006c; FPInnovations 2013). At present, there are many EPDs for structural wood products made in North America.

LCI compiles all raw material and energy inputs and outputs associated with the manufacture of a product on a per-unit basis within defined system boundaries. These boundaries can be limited to only one stage within the product lifecycle (e.g., gate-to-gate). Multiple sequential LCI stages are usually combined to produce an LCA. LCAs describe the total environmental impact for a particular product, referred to either as cradle-to-gate (raw material extraction to mill gate output) or as cradle-to-grave (raw material extraction to waste disposal) analysis.

Description of laminated veneer lumber

Many engineered structural wood products have been developed in the last several decades, e.g., laminated veneer lumber (LVL) in the early 1970s (Figure 1). LVL is comprised of many thin layers of dry wood veneers glued together with resins to form lumber-like products (USEPA 2002; Stark et al. 2010). The veneers are laid with their grain orientation in the same direction (Wilson and Dancer 2005). LVL is designed to be used in the same manner as solid wood products such as sawn lumber. The veneers are typically made from rotary peeling veneer logs.

Figure 1. Laminated veneer lumber.

Goal

The goal of this paper is to document the gate-to-gate LCI of LVL manufacturing for Pacific Northwest (PNW) and Southeast (SE) United States as part of a cradle-to-gate LCA. The paper documents material flow, energy type and use, emissions to air and water, solid waste production, and water impacts for the LVL manufacturing process on a per unit volume basis of

1.0 m^3. Primary mill survey data were collected through a structured questionnaire mailed to LVL plants. This survey tracked raw material inputs (including energy), product and byproduct outputs, and pertinent emissions to water, air, and land.

An industry standard production unit (i.e., reference unit) was translated to a metric production unit. Secondary data, such as pre-mill gate processes (e.g., wood and electricity production), were from peer-reviewed literature per CORRIM guidelines (CORRIM 2010). Material and energy balances were calculated from primary and secondary data. Using these material and energy data, the environmental impact was estimated by modeling emissions using the software package SimaPro 8 (Pré Consultants 2015), which follows internationally accepted standards and uses the U.S. LCI Database (NREL 2012).

A large sample is required to attain results that are representative of the LVL industry. CORRIM (2010) protocol targets a minimum of 5% of total production with preferred percentage of 20% for an industry such as the LVL industry that has relatively few manufacturers.

Method

Scope

This study covered the manufacturing stage of LVL from veneer production and/or layup to the final product leaving the mill according to ISO 14040 and 14044 standards (ISO 2006a,b; ILCD 2010). Impacts from (offsite) veneer production were included in the analysis using secondary data from the U.S. LCI Database (NREL 2012). This manufacturing stage LCI provided a gate-to-gate analysis of cumulative energy of manufacturing and transportation of raw materials. Analyses included LVL production's cumulative energy consumption and environmental outputs like CO_2 emissions.

Selecting an allocation approach is a vital part of a LCI study. In the present study, all primary energy and environmental outputs were assigned by mass allocation. The decision was justified by the understanding that the wood residues are coproducts with a value rather than a waste material.

Six U.S. LVL plants representing 43.2% of 2012 U.S. LVL production, 0.456 million m^3 provided primary data for the PNW and SE (APA 2014). Total U.S. LVL production for 2012 was 1.31 million m^3. The PNW and the SE are the primary regions for producing structural wood products such as LVL (Smith et al. 2004). The surveyed plants provided detailed annual production data on their facilities, including on-site energy consumption, electrical usage, veneer volumes, and LVL production for 2012. Two of the six surveyed plants were in the PNW with the remaining four in the SE. Wilson and Dancer (2005) performed a 2000 U.S. LVL LCI study that covered 34% and 52% of production in the PNW and SE, respectively. LVL production data by region are no longer available.

Declared unit

The study used a declared unit of 1.0 m^3 of LVL. LCI flows including cumulative energy consumption were reported per 1.0 m^3 of the final product, LVL.

System boundary

Defining system boundaries determined the unit processes to include and standardized material flows, energy use, and emission data. The cumulative system boundary is shown by the solid line in Figure 2 and includes both on- and off-site emissions for all material and energy consumed. Three unit processes exist in manufacturing LVL: (1) lay-up, (2) hot pressing, and (3) sawing and trimming, with energy generation as an auxiliary process. All emissions (i.e., outputs to the environment) and energy consumed were assigned to the LVL and the co-products (i.e., sawdust) by mass.

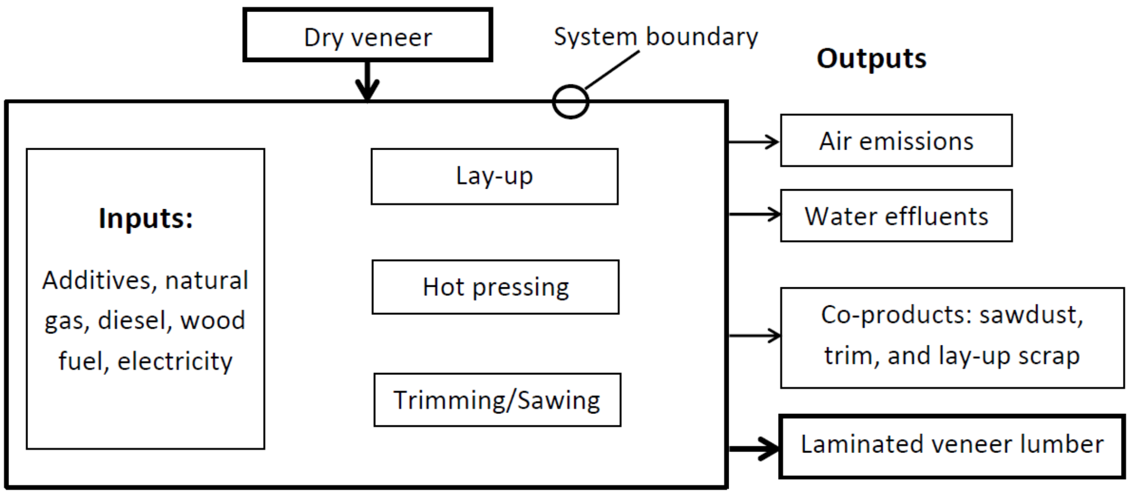

Figure 2. System boundary for laminated veneer lumber manufacturing life-cycle stage

Fuel resources used for the cradle-to-gate production of energy and electricity were included within the cumulative system boundary. Off-site emissions include those from grid electricity production, transportation of feedstock and additives to the plant, and fuels produced off-site but consumed on-site. Ancillary material data such as motor oil, paint, and hydraulic fluid were collected and were part of the analysis.

Results and Discussion

Six LVL plants provided detailed primary data on mass flow, energy consumption, fuel types and air emissions. Data were weight-averaged based on each mill's production volume and expressed on a per 1-m^3 unit basis.

Material

To evaluate data quality, a mass balance was performed (Table 1). In performing the mass balance for LVL, all unit processes located within the site system boundary were considered.

Veneer usage was 585 and 612 oven-dry (OD) kg for PNW and SE mills, respectively, and 23 OD kg of binding agents (additives) produced 1.0 m^3 (553 OD kg on average) of LVL along with some co-products (~70 OD kg on average). Phenol-formaldehyde (PF) resin made up most of the additives.

Table 1. Mass balance of LVL manufacturing per m^3

	Inputs	Mass	CoV[a]	Outputs	Mass	CoV[a]
	Pacific Northwest			Southeast		
		Mass	CoVw		Mass	CoVw
	(OD kg)	(%)	(%)	(OD kg)	(%)	(%)
Feedstocks						
Produced veneer	0			254	32.1%	155%
Purchased veneer	585	96.3	4.1%	358	64.4%	73.0%
TOTAL, FEEDSTOCK	585	96.3	4.1%	612	96.4%	6.5%
Additives						
Phenol-formaldehyde resin	17.8	2.9%	8.3%	23	3.6%	30.2%
Sodium hydroxide	3.2	0.5%		0		
Catalyst #2	0.2	0.0%		0		
Melamine	1.6	0.3%		0		
TOTAL, ADDITIVES	23	3.7%		23	3.6%	30.2%
TOTAL, IN	608	100%		635	100.0%	
Products						
Laminated veneer lumber	543	89.3%	2.9%	563	88.7%	4.0%
Co-Products						
Sawdust, sold	53	8.7%	15%	44	6.9%	46%
Sawdust, wood fuel	0			9	1.5%	221%
Panel trim, sold	3.4	0.5%	126%	6	0.9%	101%
Lay-up scrap	2.9	0.5%	–	13	2.0%	–
Tested LVL, used	5.9	1.0%	–	0		
TOTAL, CO-PRODUCTS	65	10.7%	46%	72	11.3%	46%
TOTAL, OUTPUTS	608	100%		635	100%	

[a] Production weight-averaged coefficient of variation.

Energy inputs

Weighted-average energy inputs consumed at the LVL manufacturing site were developed from survey data (Table 2). Electricity and natural gas were the primary energy inputs at 77 kWh and 15 m^3 for the PNW and 112 kWh and 19 m^3 for the SE per m^3 of LVL. Thus, less electricity and natural gas was consumed in the PNW. The production-weighted coefficient of variation showed large variation for natural gas consumption for the SE at 53% although consumption was similar to the PNW.

Carbon

Carbon in wood products can be considered a long-term storage. Carbon content for wood products is assumed to be 50% by mass of OD wood. Therefore, the carbon stored in the wood portion of 1.0 m^3 (~535 OD kg) of LVL is equivalent to 980 kg CO_2[1] pulled from the atmosphere

[1] 535 OD kg wood * (0.5 kg carbon/1.0 OD kg wood) * (44 kg CO_2/kmole/12 kg carbon/kmole) = 980 kg CO_2

during forest growth. Basically, the CO_2 value is equivalent to the CO_2 removed from the atmosphere during tree growth that is now stored in the final product.

Table 2. Weighted-average on-site energy inputs for LVL manufacturing

	Pacific Northwest			Southeast		
	Quantity	Unit	CoVw[a] (%)	Quantity	Unit	CoVw[a] (%)
Energy inputs						
Electricity	77	kWh	61%	112	kWh	67%
Natural gas	15	m^3	9%	19	m^3	53%
Wood fuel	–	kg		32	kg	221%
Diesel	0.35	L	37%	0.74	L	69%
Propane	0.48	L	52%	0.78	L	10%
Gasoline	–	L		0.59	L	244%

[a] Production-weighted coefficient of variation.

Cumulative energy consumption

Cumulative energy consumption for manufacturing LVL was 5.64 and 6.87 GJ/m^3, with wood fuel accounting for about 26.3% and 26.9% for the PNW and SE, respectively (Table 3). Natural gas, wood residues, and coal were the three most important energy sources. Most of the wood fuel was consumed at the veneer manufacturing stage where drying the wood was accomplished via steam boilers fueled primarily by wood (residues) and not fossil fuels. In addition, most LVL facilities use natural gas as the heat source for hot pressing the veneer into billets. Furthermore, natural gas (and coal) are used to fuel the electricity grid. Therefore, natural gas is the largest fuel input for making LVL for both regions.

Table 3. Cumulative energy (higher heating values (HHV)) consumed during production of LVL—cumulative, allocated gate-to-gate LCI values[a]

	Pacific Northwest			Southeast		
Fuel[b,c]	(kg/m^3)	(MJ/m^3)	(%)	(kg/m^3)	(MJ/m^3)	(%)
Natural gas[d]	31.8	1,732	30.7	37.4	2,035	29.6
Wood residue	71	1,486	26.3	88	1,848	26.9
Coal[d]	44.6	1,167	20.7	62.3	1,630	23.7
Crude oil[d]	18.7	849	15.1	18.6	845	12.3
Uranium[d]	–	285	5.0	–	17	0.2
Hydro	0.00024	92	1.6	0.00130	497	7.2
Energy, other	–	33	0.6	–	0	0.0
Total		5,640	100		6,870	100

[a] Includes fuel used for electricity production and for log transportation.
[b] Values are allocated and cumulative and based on HHV.
[c] Energy values were found using their HHV in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.
[d] Materials as they exist in nature and have neither emissions nor energy consumption associated with them.

Emissions

Emission data produced through modeling found that estimated biomass and fossil CO_2 emissions in kg/m^3 were 127 and 156 for PNW and 108 and 169 for SE (Table 4). Therefore, the amount of carbon stored in LVL, 980 kg is equivalent to about 350% of the total carbon emissions released (as CO_2) during manufacturing. For on-site, burning natural gas for hot pressing LVL was the main source of fossil CO_2. Most of the biogenic CO_2 emissions came from processing logs into dry veneer and was consistent with energy inputs of wood residues shown in Table 2. Other large sources of fossil CO_2 emissions were from generating electricity (off-site) and from manufacturing dry veneer. Surprisingly, most of nitrogen oxides (NOx) released, about 98% were derived from the production of PF resin. As for water effluents, chloride comes from three main sources: production of dry veneer and natural gas and the combustion of electricity. More specifically, NOx comes from the extraction and processing of natural gas.

Table 4. Cumulative environmental outputs for producing 1 m^3 of LVL[a]

Substance	Pacific Northwest (kg/m^3)	Southeast (kg/m^3)
Water effluents		
BOD5 (Biological oxygen demand)	1.25	1.05
Chloride	4.21	4.56
COD (Chemical oxygen demand)	6.13E-02	6.67E-02
DOC (Dissolved organic carbon)	2.86E-04	3.60E-04
Oils, unspecified	3.16E-03	3.49E-03
Suspended solids, unspecified	5.62	5.96
Industrial waste[b]		
Waste in inert landfill	0.77	3.05
Waste to recycling	0.36	58.36
Solid waste[c]	13.46	4.3
Air emissions		
Acetaldehyde	5.24E-02	4.75E-02
Acrolein	2.64E-01	2.13E-03
Benzene	2.68E-03	2.27E-03
CO	0.63	0.55
CO_2 (biomass (biogenic))	127	108
CO_2 (fossil)	156	169
CH_4	0.46	0.52
Formaldehyde	1.77E-02	5.02E-03
Mercury	4.73E-06	3.70E-06
Methanol	7.36E-02	5.58E-02
NOx	36.2	45.6
Non-methane VOC	2.21E-02	2.12E-02
Particulate (PM10)	7.99E-02	7.94E-02
Particulate (unspecified)	0.37	0.29
Phenol	1.51E-03	5.28E-04
Propanal	3.43E-03	3.41E-03
SOx	1.93E-03	1.91E-03
VOC	0.59	0.33

[a] Includes the impacts of manufacturing dry veneer.
[b] Includes solid materials not incorporated into the product or co-products but left the system boundary.
[c] Solid waste was boiler ash from burning wood. Wood ash is typically used a soil amendment or landfilled.

Wood products typically consume more energy during the manufacturing stage than any other stage (Puettmann and Wilson 2005; Winistorfer et al. 2005; Puettmann et al. 2010). To compare with an earlier CORRIM study on making 1.0 m^3 of LVL in the PNW and SE, cumulative allocated energy consumptions are 4.43 and 5.75 GJ/m^3 (Puettmann and Wilson 2005; Wilson and Dancer 2005). Like the present study, Wilson and Dancer (2005) used mass allocation. As stated previously, primary energy is energy embodied in the original resources such as crude oil and coal before conversion.

Conclusions

EPDs present life-cycle data in a concise and consistent format to enable industry to communicate with customers. This study provides the underlying gate-to-gate LCI data for updating the North American LVL EPD. Future efforts will work on incorporating the LCI data into a cradle-to-gate LCA and then eventually into an EPD for LVL.

Structural wood products such as LVL used in building construction can store carbon for long periods, which is typically greater or far greater than the carbon dioxide emissions released during manufacturing (Puettmann and Wilson 2005; Bergman and Bowe 2010; Puettmann et al. 2010). The amount of carbon stored in LVL if allowed to decay is equivalent to about 350% of the total carbon dioxide emissions released during manufacturing.

Acknowledgments

I gratefully acknowledge funding for this project was through a cooperative agreement between the USDA Forest Service Forest Products Laboratory and the Consortium for Research on Renewable Industrial Materials (13-CO-11111137-014). In addition, I appreciate the reviews provided by Scott Bowe (University of Wisconsin), Indroneil Ganguly (University of Washington), and Adam Taylor (University of Tennessee-Knoxville).

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