CORRIM Report: Life Cycle Assessment for the Production of PNW Laminated Veneer Lumber

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Addendum

The original report "CORRIM Report – Module H1 Cradle-To-Gate Life-Cycle Assessment of Laminated Veneer Lumber (LCL) Produced in the Pacific Northwest Region of The United States was revised to meet the Product Category Rule (PCR) Guidance for Building-Related Products and Services Part B: Structural and Architectural Wood Products EPD Requirements. This revision was performed by WoodLife Environmental Consultants under contract with the Consortium for Research on Renewable Industrial Materials as part of the American Wood Council (AWC) EPD development of North American Wood Products.

The report might be reduced in content from the original to include only those reporting requirements for the PCR. Reference to the LCA on Pacific Northwest (PNW) LVL should be made to the original as well as this revised report. The original report can be found in Appendix 2 of this report. Changes and additions from the original report may include additional required reporting impact factors and impact methods (Table A1) per the PCR and ISO (ISO 2006a-b) requirements on sensitivity analysis and interpretation of results.

Table A1 Original and updated reporting requirements

Revised Report					Original Report
Reporting Category Per Tables E1-E5 in ISO 21930:2017	**Indicator Name**	**Abbreviation**	**Units**	**Calculation Method**	**In report**
Core Mandatory Impact Indicators	Global warming potential, biogenic[1]	GWP	kg CO2e	TRACI + Manual	No
Core Mandatory Impact Indicators	Global warming potential, fossil	GWP	kg CO2e	TRACI	Yes
Core Mandatory Impact Indicators	Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	TRACI	Yes
Core Mandatory Impact Indicators	Acidification potential of soil and water sources	AP	kg SO2e	TRACI	Yes
Core Mandatory Impact Indicators	Eutrophication potential	EP	kg PO4e	TRACI	Yes
Core Mandatory Impact Indicators	Formation potential of tropospheric ozone	SFP	kg O3e	TRACI	Yes
Core Mandatory Impact Indicators	Abiotic depletion potential (ADPfossil) for fossil resources;	ADPf	MJ, NCV	CML-IA Baseline V3.05	No
Core Mandatory Impact Indicators	Fossil fuel depletion	FFD	MJ Surplus	TRACI	Yes
Use of Primary Resources	Renewable primary energy carrier used as energy	RPRE	MJ, NCV	CED, NCV	Yes
Use of Primary Resources	Renewable primary energy carrier used as material	RPRM	MJ, NCV	Manual	No
Use of Primary Resources	Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV	CED, NCV	Yes
Use of Primary Resources	Renewable primary energy carrier used as material	NRPRM	MJ, NCV	Manual	No
Secondary material, secondary fuel and recovered energy	Secondary material	SM	kg	N/A	No
Secondary material, secondary fuel and recovered energy	Renewable secondary fuel	RSF	MJ, NCV	Manual	No

[1] This indicator includes both biogenic and fossil-based carbon released. The TRACI method was modified to included CO2, biogenic removals and emissions

Revised Report					Original Report
Secondary material, secondary fuel and recovered energy	Non-renewable secondary fuel	NRSF	MJ, NCV	N/A	No
Secondary material, secondary fuel and recovered energy	Recovered energy	RE	MJ, NCV	N/A	No
Mandatory Inventory Parameters	Consumption of freshwater resources;	FW	m3	Manual	Yes
Indicators Describing Waste	Hazardous waste disposed	HWD	kg	SP: Process Contribution	
Indicators Describing Waste	Non-hazardous waste disposed	NHWD	kg	SP: Process Contribution	
Indicators Describing Waste	High-level radioactive waste, conditioned, to final repository	HLRW	kg or m3	SP: Process Contribution	
Indicators Describing Waste	Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	kg or m3	SP: Process Contribution	Yes
Indicators Describing Waste	Components for re-use	CRU	kg	Manual	No
Indicators Describing Waste	Materials for recycling	MR	kg	Manual	No
Indicators Describing Waste	Materials for energy recovery	MER	kg	Manual	No
Indicators Describing Waste	Recovered energy exported from the product system	EE	MJ, NCV	Manual	No
Must include following if part of GWP					
Additional Inventory Parameters for Transparency	Biogenic Carbon Removal from Product	BCRP	kg CO2e	Manual	Yes
Additional Inventory Parameters for Transparency	Biogenic Carbon Emission from Product	BCEP	kg CO2e	Manual	Yes
Additional Inventory Parameters for Transparency	Biogenic Carbon Removal from Packaging	BCRK	kg CO2e	Manual	No
Additional Inventory Parameters for Transparency	Biogenic Carbon Emission from Packaging	BCEK	kg CO2e	Manual	No
Additional Inventory Parameters for Transparency	Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	BCEW	kg CO2e	Manual	Yes
Additional Inventory Parameters for Transparency	Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	CWNR	kg CO2e	Manual	No

Abbreviations

Cunit	100 cubic feet
EPDs	Environmental Product Declarations
GWP	Global Warming Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
m^3	Cubic meter
MSF	1000 square feet
odkg	Oven Dry Weight Wood in Kilograms
PCR	Product Category Rules
tkm	Metric Tonne – Kilometers

Glossary of Terms

Allocation - A way of dividing emissions and resource use among the different products of a process. The partitioning can be made on weight basis, energy content, or economic value.

Cradle-to-gate - LCA model which includes upstream part of the product life cycle, i.e. all steps from raw material extraction to product at factory gate.

Declared Unit - Quantity of a wood building product for use as a reference unit, e.g. mass, volume, for the expression of environmental information needed in information modules.

Functional Unit - expresses the function of studied product in quantitative terms and serves as basis for calculations. It is the reference flow to which other flows in the LCA are related. It also serves as a unit of comparison in comparative studies.

Life cycle assessment (LCA) - Method for the environmental assessment of products covering their lifecycle from raw material extraction to waste treatment

Life cycle inventory (LCI) - LCA study that goes as far as an inventory analysis but does not include impact assessment.

Life cycle impact assessment (LCIA) - Phase of an LCA study during which the environmental impacts of the product are assessed and evaluated.

Product Category Rules (PCR) - Set of specific rules, requirements, and guidelines for the development of type III environmental declarations for one or more product categories (ISO 14025, ISO 21930)

System boundary - A set of criteria that specifies which unit processes are part of a product system (adapted from ISO 14044)

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1 Background

The environmental consequences of producing a material such as laminated veneer lumber (LVL) are carried forward into the life cycle of products such as wooden structures. CORRIM, the Consortium for Research on Renewable Industrial Materials, has derived life cycle inventory (LCI) data for major wood products manufactured in several regions of the United States. The life cycle inventory data cover from forest regeneration through to final product at the mill gate. Research has covered nine major forest products, both structural and nonstructural, and four major regions: in this report we focus on LVL produced in the US Pacific Northwest (PNW) region.

This report describes the energy and materials for producing LVL in the PNW region of the US through a cradle-to-gate life cycle inventory on the manufacturing process. The environmental impacts, global warming, ozone depletion, acidification, smog, and eutrophication are discussed.

The focus of this report is an industry average LVL production in the PNW region of the United States. LCI data are then used to estimate life-cycle impact assessments (LCIA). This study updates the cradle-to-gate manufacturing for LVL in the PNW (Dancer and Wilson 2004, Wilson and Dancer 2005).

The data collection was performed under "CORRIM Guidelines for Performing Life Cycle Inventories on Wood Products", undated, but current in the fall of 2012, a scientifically sound and consistent process established by CORRIM. It follows ISO 14040 standards (ISO 2006), ISO 21930 (ISO 2017), the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (UL 2019) that will provide the guidance for preparation of North American wood product Environmental Product Declaration (EPD) and Part A: Life Cycle Assessment Calculations Rules and Report Requirements (UL 2018).

2 Goal and Scope

It is the goal and scope that provide the plan for conducting the LCI including data collection, compilation, and interpretation.

2.1 Goal and Objectives

2.1.1 Goals

The primary goal is to generate a gate-to-gate LCA of PNW USLVL manufacturing and use this data to develop a cradle-to-gate profile of PNW USLVL. The cradle-to-gate LCA will follow data and reporting requirements as outlined in the PCR (UL 2019) will provide the guidance for preparation of a business-to-business EPD.

2.1.2 Intended Audience

The primary audience for the results of this LCA report is LVL producers in the US and CORRIM LCA practitioners.

2.1.3 Comparative Assertions

The report does not include product use and end of life phases which are required for comparative assertions relative to substitute products. If future comparative studies are intended and disclosed to the public, the LCA boundary would need to be expanded to include the use and end of life phases consistent with the ISO 14044:2006 guidelines and principles and ISO 21930 core rules for EPDs (ISO 2006, ISO 2017), and compliance with the Wood Products PCR, Part A and B (UL 2018, 2019).

2.2 Scope of Considered System

2.2.1 Functional and declared unit

In accordance with the PCR the declared unit for LVL was one cubic meter. For conversion of units from the U.S. LVL industry measure, 1.0 ft^3 equals 0.02832 m^3 with an oven-dried moisture content of 6%. A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building cannot be stated (UL 2019). The inventory input data is presented as unallocated flows, all input and output flows allocated to the main product. This analysis does not take the declared unit to the use stage no service life is assigned.

The cradle-to-gate LCI was generated by combing the PNW LVL manufacturing data collected by survey with previously published datasets for upstream manufacturing of forestry and harvesting operations, fuels, electricity, and ancillary material use.

2.2.2 System boundary

The cradle-to-gate system boundary is shown in Figure 1. The system boundary begins with regeneration in the forest and ends with LVL at the mill gate (Figure 3). The system boundary includes forest resources (site preparation and planting seedlings, forest management including fertilization and thinning, and final harvest), transportation of roundwood to the primary breakdown facility, dry veneer production, dry veneer transportation to the LVL facility if needed, and LVL production including packaging. LVL production was modeled as a single process representing all the steps necessary to make LVL. Three production steps 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 LVL and coproducts (i.e. sawdust) by mass or economic value depending if the mass or economic allocation approach was selected, respectively. A single unit (i.e. black box) approach was used to model the LVL process because little wood left the system except as the final product and because of the relative simplicity of the LVL manufacturing processes. This simply means all process inputs and outputs were grouped into one LVL process.

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

Excluded from the system boundaries are fixed capital equipment and facilities, transportation of employees, land use, delivery of LVL to construction site, construction, maintenance, use, and final disposal. Disposal of on-site waste from production manufacturing is included in the system boundary. Table 1 lists the inclusion and exclusion within the system boundaries of this study.

Table 2 System boundary inclusions and exclusions for the cradle-to-gate of PNW LVL production

Included	Excluded
• Production of upstream processes for all resources, raw materials, fuels, and energy for LVL production used in forestry operations, harvesting, and softwood LVL manufacturing	• Fixed capital equipment and facilities
• Transportation of materials throughout the cradle-to-gate manufacturing life stages.	• Transportation of employees
• Packaging	• Construction, maintenance, use, and end of life treatment

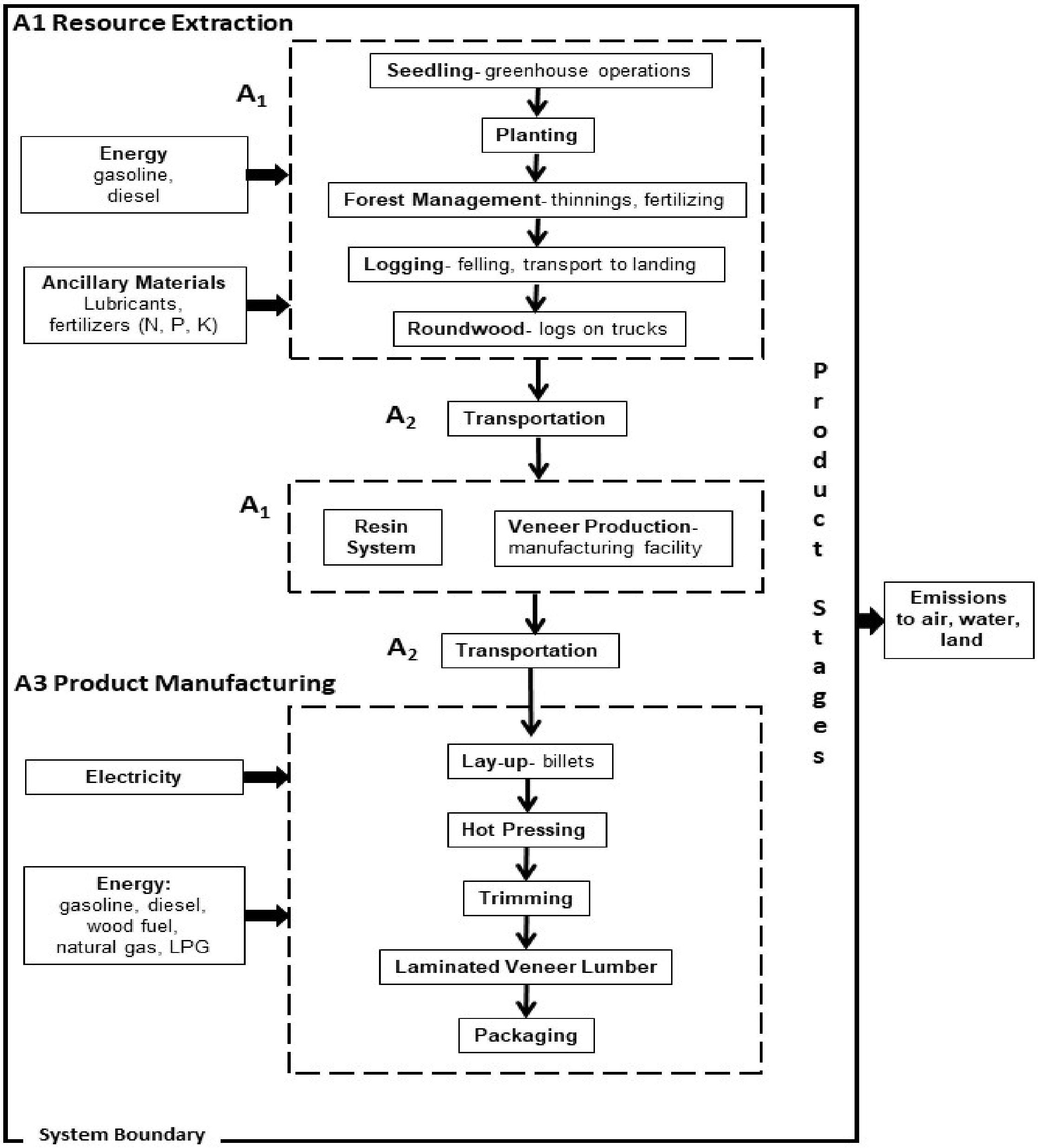

Figure 1 Cradle-to-gate system boundary for laminated veneer lumber production in the PNW region

2.2.3 Allocation rules

Allocation is the method used to partition the environmental load of a process when several products or functions share the same process. The input material is a dry veneer. A mass allocation for these multiple coproduct outputs was conservatively chosen.

2.2.4 Cut off rules

According to the PCR, if the mass/energy of a flow is less 1 percent of the cumulative mass/energy of the model flow it may be excluded, provided its environmental relevance is minor. This analysis for PNW LVL included all energy and mass flows for primary data. No cut-offs were used in the impact assessment.

2.2.5 Data collection

Surveys were used to collect the LCI data in accordance with CORRIM guidelines and ISO standards. This study relied almost exclusively on production and emissions data provided by LVL producers in the PNW, with some secondary data on fuels and electrical grid inputs from the US LCI database and European datasets (Datasmart2018 and Ecoinvent 3.4). Two mills provided data for 2012 LVL and co-product production, raw material and fuel use, electricity consumption, and on-site emissions.

2.2.6 Calculation rules

For U.S. production, LVL is commonly reported in cubic feet. The survey results were converted to a unit production basis, one cubic meter, and a weighted average of input data was calculated based on production. One cubic foot of LVL equals 0.02832 m^3 with an oven-dried moisture content of 6%.

This approach resulted in an LVL complex that represents a composite of the North American mills surveyed but may not represent any mill in particular. The U.S. LCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 8+ (Pré Consultants 2016) was used as the accounting program to track all of the materials. The primary data obtained from the surveys were weight-averaged using the formula shown below (Milota 2004):

$$w_1 = \frac{y_1}{(y_1 + y_2 + y_3)} = \frac{y_1}{Y_{total}} \qquad eq. 1$$

w_1 = weighing factor for mill 1
Y_{total} = total annual production of “y” mills
y_1 = annual production of Mill 1

Missing data were defined as data not reported in surveys by the LVL facilities. When missing data occurred for survey items, they were checked with plant personnel to determine if it was an unknown value or zero. Missing data were carefully noted to make sure they were not averaged as zeros. Any outliers were resolved by contacting mill personnel.

3 Description of Industry

Many engineered structural wood products have been developed in the last several decades, including LVL in the early 1970s (Figure 2). Laminated veneer lumber (LVL) is a structural building material that belongs to the general category of engineered wood products and to the more specific group of structural composite lumber. Structural composite lumber (SCL) was developed in response to the increasing demand for high-quality lumber at a time when it was becoming difficult to obtain this type of lumber from the forest resources. Structural composite lumber products are characterized by smaller pieces of wood glued together into sizes common for solid lumber. One type of SCL is LVL.

Figure 2 Laminated veneer lumber.

3.1 Categories of products and co-products

The main product from PNW LVL mills is LVL. Other products (co-products) are also produced from trimming, sawing, finishing of LVL boards. These co-products could include lay-up scrap, panel trim, and sawdust.

3.2 Annual operating and production statistics of the industry (us total, regional)

Total U.S. LVL production for 2012 was 1.31 million m^3. Two U.S. LVL plants representing 8.5 percent of 2012 U.S. production (0.111 million m3) participated in the study by providing primary data for the PNW region (APA 2014). The PNW is one of the primary regions for producing structural wood products such as LVL (Smith et al. 2004). The surveyed plants provided detailed annual production data about their facilities, including on-site energy consumption, electrical usage, veneer volumes, and LVL production for 2012. Wilson and Dancer (2005) performed a 2000 U.S. LVL LCI study that covered 34 percent (0.187 million m3) of production in the PNW. Production from surveyed facilities in 2012 decreased 40 percent compared with 2000. In addition, unlike the earlier 2000 study, 2012 LVL production data were not available by region. Therefore, LVL production data by region could not be quantified for 2012.

3.3 Typical emission control measures by plant type

Common emission control devices are regenerative thermal oxidizers (RTOs) for the reduction of volatile organic compounds (VOC's) and electrostatic precipitators (ESPs) for the removal of particulate matter or particle pollution (PM). Regenerative catalytic oxidizers (RCOs) can remove more than 99.9 percent of VOCs, but release nitrogen oxides by burning natural gas or liquefied petroleum gas. RCOs are designed to destroy VOCs and other emissions including PM and soot (USEPA 2003a). Electrostatic precipitators are used to collect particulate matter (PM) pollution but are not effective in reducing volatile organic compounds (VOC's) or hazardous air pollutants (HAP) emissions. The surveyed mills reported the installation and use of RCOs. No dangerous substances were reported by industry that fall under ISO 21930 (ISO 2017).

Laminated veneer lumber manufacturers typically generate minimal solid waste on-site; wood processing waste generated during processing can be used for on-site energy generation for dying and pressing processes. The principal solid wastes are boiler ash, some non-combusted wood scraps, and packaging waste. There are typically no on-site water emissions; clean water is either recycled and/or allowed to soak into the ground on-site. On-site reported air emissions such as HAPs, VOCs and PM are associated with wood heating and fuel combustion, drying, and panel pressing.

4 Description of Product

LVL falls into the North American Industry Classification System (NAICS) Code 321215—engineered wood member (except truss) manufacturing, which includes other structural wood engineered products such as finger joint lumber, I-joists, parallel strand lumber, and glued laminated timbers (USCB 2012; ASTM 2014). Additional classification codes for LVL are the United Nations Standard Products and Services Code (UNSPSC) – 111220 00 and Construction Specifications Institute (CSI) code for wood framing 05 11 00, engineered wood products 06 11 13, heavy timber framing 06 13 23, and laminated veneer lumber 06 17 13. It can be used in conjunction with softwood plywood or oriented strandboard (OSB) to make composite I-joists but can also be used as a standalone for headers, beams, and joists (Dancer and Wilson 2004, Puettmann et al. 2013).

4.1 Wood species

Any wood species can be used for LVL production provided its mechanical and physical properties are suitable and it can be properly glued. LVL in the PNW region is primarily made with Douglas-fir (*Pseudotsuga menziesii*). Dry veneer made into LVL comes from logs of many softwood species representing a mix of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), and western larch (*Larix occidentalis*).

4.2 Moisture content

For products and coproducts produced prior to any drying a 50 percent moisture content (MC) on a dry basis was assumed. For products and coproducts produced after drying a 6 percent MC on a dry basis was assumed

5 Life cycle inventory analysis

The LCI was calculated based on 2012 production and the corresponding flows of materials during that period. No data gaps were recorded. As shown in Figure 1, the cradle-to-gate process for LVL production is considered to comprise wood resource (log) extraction, the transport of the logs to the veneer mill and delivery of veneer to LVL production, and LVL production. These, steps are described separately below.

5.1 A1- Resource extraction

5.1.1 Harvesting Operations

Consideration of the logs used in the production of LVL in the PNW region includes the establishment, growth, and harvest of trees. This group of activities is collectively referred to as forest resource management. Data for the forest resources management component of this analysis (Tables 2 and 3) come from Oneil and Puettmann (2017). For more details on the PNW Forest Operations see Oneil and Puettmann (2017).

Table 2 summarizes the management inputs needed to establish crop trees and grow them to harvestable size. It includes per hectare data for inputs needed for planting, site preparation, conifer release, pre-commercial thinning, and fertilization, including fuels needed to apply herbicides and fertilizers and move crews to and from the plantations. In both Oregon and Washington, forest regeneration following harvest is required by law. Minimum stocking standards (number of trees per hectare) and requirements to protect them from being overtopped by competing vegetation are set forth in the Washington Administrative Code (Washington State Legislature 2005, WAC 222-34-010) (WSL 2019) and the Oregon Forest Practices Act (Oregon Department of Forestry 2008, 629-610-0020) (USDA 2008). While regeneration from naturally occurring, seed is permitted under these regulatory frameworks, it is not commonly used because the delays in regeneration can be substantial and costly, and this method can result in a failure to adequately reforest the harvest area. Given that large private and industrial landowners are focused on the efficient production of their crops of trees, it also does not make economic sense to forego planting in favor of an uncertain outcome from naturally regenerated stands. Over the past decade, plantation management strategies have moved away from dense planting for early crown closure to a more targeted approach that relies on early weed control, low-density planting, and post planting herbicide applications as required. All harvested acres are planted, with an average planting density of 1,092 trees per ha (442 trees per acre).

Table 3 Management and Harvest Timeline and Yield (Oneil and Puettmann, 2017)

Prescription Scenarios	Commercial Thin	Ground	Cable
Entry Period/Rotation Age	25	50	50
Planting Density (Trees/ha)	0	1092	1092
Fertilization	None	35	None
Pre-commercial Thin	None	Year 15	None
Number of Trees/ha	0	741	0
Commercial Thin (m3/ha)	92	0	0
at Year	25	0	0
Final Harvest (m3/ha)	0	575	531
at Year	0	50	50
Total Harvest (m3/ha)	92	575	531
Percent Thinned	100%	14%	0%
Average Yield (m3/ha/year)	4	12	11
Percent Land in Category - Base	8%	52%	40%

No primary data using time motion studies or similar methods were collected for this project. Productivity data for forest harvesting operations were based on logging equipment and equipment configurations developed in spreadsheet models used by Johnson et al. (2005) and Han et al. (2014) and cross validated to primary survey data for the suite of available equipment options and sizes that are commonly used in the PNW Douglas-fir region (Table 3). Final fuel consumption rates are based on the allocation of total volume harvested using each harvest system to arrive at an average fuel consumption per cubic meter for the region. Fuel consumption for crew transport to conduct harvest operations was calculated from average haul distance, fuel efficiency of common vehicle types (4 x 4 trucks), and equipment productivity estimates (cubic meters per day per operation). Two-person crews per vehicle were assumed.

Table 4 Harvesting Inputs (per cubic meter) (Oneil and Puettmann, 2017)

System	Fuel Consumption	Lubricant Consumption
	L / m^3	L / m^3
Commercial Thinning (cut-to-length processor, skidder, loader)	2.372	0.043
Ground based Harvesting (feller-buncher, shovel yarder, slide boom processer, loader)	3.172	0.057
Cable Harvesting (hand felling, skyline, cut-to-length processor, loader)	3.029	0.055
Weighted average - ground harvesting systems	3.062	0.055
Overall weighted average - all harvest systems	3.051	0.055
Weighted average, crew transport all harvest operations	0.210	0.002

5.1.2 Veneer manufacturing

Dry softwood veneer plies must be made before LVL can be produced. Veneers can be made during softwood plywood production or as a precursor to LVL at the same production facility. This study uses veneer data provided by Puettmann et al. (2016) on softwood plywood production. Dry veneer ranges in moisture content from 3% to 6% (oven-dry basis). The dry veneer made into LVL comes from logs of many softwood species representing a mix of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), and western larch (*Larix occidentalis*).

5.1.3 Resin production

The LCI for the production of PF resin covers its cycle from in-ground resources to the production and delivery of input chemicals and fuels to the manufacturing of a resin as shipped to the customer. The inputs to produce 1.0 kg of neat PF resin consist of the two primary chemicals: 0.244 kg of phenol and 0.209 kg of methanol, a lesser amount of sodium hydroxide (0.061 kg), and 0.349 kg of water.

5.2 A2 – Transport

Wood raw materials were delivered to the LVL plants by truck and rail. The wood raw material consisted primarily of dry veneer purchased off site or produced on site. However, transportation for dry veneer was only required for LVL plants purchasing dry veneer not for LVL plants producing their own dry veneer. The final dry veneer transportation data modeled was production-weighted between purchased and produced dry veneer.

The average haul distance for feedstock along with the components of the resin system are shown in Table 4. Based on Puettmann et al. (2013), dry veneer distance for the PNW region decreased to 108 km by truck compared with 121 km for the earlier data, roughly a 11 percent decrease. Both surveyed PNW LVL plants purchased dry veneer to produce LVL although one plant produced most of its own veneer. The dry veneer transportation data modeled was production-weighted between purchased and dry veneer for a final value of 52 km.

Table 5 Weighted-average delivery distance (one way) by mode for materials to PNW LVL plant.

Material delivered to mill	Delivery distance (km)
Purchased dry veneer, by truck	108
Phenol-formaldehyde resin, by truck	79
Log with bark to veneer production, by truck	104

5.3 A3 – Product Manufacturing

5.3.1 Material Flows

To evaluate data quality, a weighted-average mass balance of the PNW LVL plants was performed (Table 5). In performing the mass balance for LVL, all unit processes located within the site system boundary were considered. Veneer usage was 585 OD kg for PNW mills, and 23 OD kg of binding agents from the resin system produced 1.0 m^3 (543 OD kg on average) of LVL along with some coproducts (65 OD kg). PF resin made up most of the resin system. Based on the low and similar values calculated for production-weighted coefficient of variation (CoVw) for the final product, LVL shows good consistency between production facilities at 2.9% for the PNW. In addition, the CoVw for total feedstock is 4.1% for the PNW.

Table 6 Mass balance of PNW LVL manufacturing per cubic meter.

	Inputs		
	(OD kg)	Mass (%)	CoVw [a] (%)
Feedstocks			
Purchased veneer	585	96.3	4.1
Total	585	96.3	4.1
Resin system			
PF resin	17.8	2.9	8.3
Sodium hydroxide	3.2	0.5	
Catalyst	0.2	0.0	
Melamine	1.6	0.3	
Total	23	3.7	13.7
Total inputs	608	100	
	Outputs		
	(OD kg)	**Mass (%)**	**CoVw [a] (%)**
Products			
LVL	543	89.3	2.9
Coproducts			
Sawdust, sold	53	8.7	15
Panel trim, sold	3.4	0.5	126
Lay-up scrap	2.9	0.5	–
Tested LVL, used	5.9	1.0	–
Total	65	10.7	46
Total outputs	608	100	

[a] Production weight-averaged coefficient of variation.

5.3.2 LVL Manufacturing

5.3.2.1 Lay-up

The lay-up lines are used to arrange pieces of the proper grades of dry veneer into the assembly process, apply resin to the veneer, and assemble the veneers into a mat before pressing (Baldwin 1995; Wilson and Dancer 2005). At the start of the line, a veneer feeder assembly places pieces of veneer into the lay-up sequence according to the type of LVL produced. Even though LVL can vary in thickness and width, it is most commonly produced in the dimensions of 4.45-cm (1-3/4-in) thick, 121.9-cm (4-ft) wide, and 2.44- to 18.29-m (8- to 60-ft) long. After pieces of veneer are arranged onto the lay-up conveyor, resin is applied to each piece of veneer, except for the top veneer layer in the LVL billet. After resin has been applied, the LVL mat is assembled layer by layer. Inputs include dry veneer and resins. Outputs include LVL billet, lay-up scrap, and small amounts of volatile organic compounds (VOCs) and HAPs. Although a small amount of fugitive VOCs and HAPs are emitted, they are accounted for within the hot- pressing unit process.

5.3.2.2 Hot-pressing

From the lay-up line, the uncured LVL billet is sent for hot-pressing. The heat and pressure applied during hydraulic pressing cures the resin thus binding the veneer layers together. Inputs include uncured LVL billets, outputs include cured LVL billets along with emissions of particulate matter (PM), $PM_{2.5}$, VOCs, and HAPs released from heating of the wood and curing of the resins. Cold-pressing can also occur at some production facilities when wider LVL billet beams are produced.

5.3.2.3 Trimming–sawing

After pressing, the LVL billet is sawn to the desired dimensions. The LVL can now be manufactured into flanges for I-joists. The wood residue generated during trimming–sawing is collected pneumatically into a wood waste collection system (i.e. baghouses). After sawing, a protective and cosmetic sealant is sometimes applied to the LVL. Inputs include LVL billets and sealant, and outputs include finished LVL, (used) tested LVL, and wood residues along with emissions of PM, $PM_{2.5}$, and PM_{10} from collecting wood residues and VOCs and HAPs from application and curing of sealant.

Table 6 shows a detailed description of the material and energy inputs and outputs crossing the system boundary of LVL. Under materials, wood feedstocks include purchased and produced dry veneer.

Electricity consumed on site for PNW was estimated to be 77.4 kWh/m^3. Natural gas was the primary fossil fuel used on site. Air emissions were derived from the surveyed mills along with pertinent emissions data categorized by the U.S. Environmental Protection Agency (USEPA 2002, 2003a, 2003b, 2003c). When available, surveyed air emission data as primary data were selected rather than secondary data. Boiler emissions are tracked separately and are not included in Table 6.

Table 7 Unit process inputs–outputs to produce one cubic meter of PNW LVL.

Products	Unit/m^3	Value	Allocation[a]
LVL	m^3	1.000E+00	89.31%
Sawdust, sold	kg	5.27E+01	8.68%
Panel trim, sold	kg	3.41E+00	0.56%
Lay-up scrap	kg	2.94E+00	0.48%
Tested LVL, used	kg	5.88E+00	0.97%
Resources			
Water, well, in ground	L	1.74E+00	
Materials–fuels			
Wood feedstock, purchased dry veneer, oven-dried	kg	5.85E+02	
PF resin	kg	1.78E+01	
Sodium hydroxide	kg	3.192E+00	
Materials–fuels			
Catalyst	kg	2.453E-01	
Melamine	kg	1.567E+00	
Electricity, at grid	kWh	7.744E+01	
Diesel, combusted in industrial equipment	L	3.509E-01	
Propane, combusted in industrial equipment	L	4.771E-01	
Natural gas, combusted in industrial boiler, direct-fired	m^3	1.28E+01	
Wood fuel, combusted in boiler, self-generated	kg	0.000E+00	
Transport, combination truck, diesel power, wood feedstock	tkm	3.239E+01	
Transport, combination truck, diesel powered, PF resin	tkm	2.235E+00	
Transport, combination truck, diesel powered, landfill waste	tkm	1.000E+00	
Hydraulic fluid	kg	1.384E-02	
Greases	kg	1.715E-03	
Motor oil	kg	3.398E-02	
Waxes (sealant)	L	3.022E-01	
Paint	L	2.860E-03	
Wrapping material - packaging	kg	4.601E-01	
Strap Protectors - packaging	kg	8.340E-02	
Strapping - packaging	kg	2.002E-01	
Spacers - packaging	kg	4.672E+00	
Emissions to air			
Acetaldehyde	kg	2.846E-03	
Carbon monoxide	kg	1.023E-02	
Formaldehyde	kg	4.487E-03	
Hexane	kg	2.232E-04	
Lead	kg	6.510E-08	
Methanol	kg	1.178E-01	
Nitrogen oxides	kg	1.302E-02	
PM2.5	kg	5.022E-02	
PM10	kg	1.004E-01	
Particulates, unspecified	kg	1.181E-01	
Phenol	kg	4.422E-05	
Propionaldehyde	kg	3.838E-03	
VOCs	kg	4.641E-01	
Waste to treatment			
Waste to inert landfill	kg	8.639E-01	
Waste to recycling	kg	3.954E-01	

[a] Mass allocation approach.

Most of the air emissions reported in the survey were allocated to veneer drying and the boiler used to generate the steam needed for drying.

5.3.3 Equipment: Type and fuel consumption

Electrically driven cranes may also be used. Electrically driven motors in the mill are used for material conveying and trims saws. The emissions controls equipment is powered by electricity or natural gas. Lifts for transporting products and materials in the mill are powered by liquefied propane gas.

5.3.4 Energy use and generation

Weighted-average energy inputs consumed at the LVL manufacturing site were developed from survey data (Table 7). Electricity and natural gas were the primary energy inputs at 77.4 kWh and 12.8 m^3 for the PNW per m^3 of LVL. The production-weighted coefficient of variation showed large variation for electricity consumption for the PNW at 61%.

Table 8 Weighted-average on-site energy inputs for PNW LVL manufacturing

	Quantity	Unit	CoVw (%) [a]
Energy inputs			
Electricity	77.4	kWh	61%
Natural gas	12.8	m^3	11%
Diesel	0.35	L	37%
Propane	0.48	L	52%
Gasoline	0	L	

[a] Production-weighted coefficient of variation.

5.3.5 Wood-base fuels

Wood-based by-products are commonly used in the wood product industry to produce heat for the thermal energy intense processes drying and hot pressing (Figure 1). Wood fuel was burned primarily on site at the veneer production facility (A1) to generate thermal energy for log conditioning and drying and pressing veneers (Puettmann et al. 2015) (Table 8). For dry veneer production, wood fuel was consumed at a rate of 225 kg/m^3.

Table 9 Raw material primary energy consumption per one cubic meter of cradle-to-gate LVL, PNW, mass allocation.

Fuel	Unit	Total	Forestry operations (A1)	Dry veneer production (A1)	LVL Production (A3)
Wood fuel	OD kg	225	0.00	224.00	1.19

The CORRIM Wood Boiler was used in the current study to model the impacts of wood combusted in boilers at wood product production facilities (excluding pulp and paper). Explanation of this data can be found in Puettmann and Milota (2017) and production-weighted average values are presented in (Table 9).

Table 10 Inputs to wood boiler per bone dry kg of wood fuel combusted (Puettmann and Milota 2017) (From PNW veneer production)

	Value	Units	Allocation, percent
Products			
Wood combusted, at boiler, at mill, kg, US	1.00	kg	98.1
Wood ash, at boiler, at mill, kg, US v1.2	0.0191	kg	1.9
Resources			
Water, process, surface	0.310	kg	
Water, process, well	0.240	kg	
Water, process, surface	0.790	kg	
Water, process, well	0.240	kg	
Materials/fuels			
Bark, Plywood mill, US, PNW	3.55E-01	kg	
Wood waste, Plywood mill, US, PNW	3.59E-02	kg	
Veneer clippings green, softwood, Plywood mill, US, PNW	1.39E-01	kg	
Veneer downfall, softwood, Plywood mill, US, PNW	1.47E-02	kg	
Lay-up scrap, softwood, Plywood mill, US, PNW	1.78E-02	kg	
Panel trim from formatting, Plywood mill, US, PNW	1.66E-01	kg	
Sawdust from formatting, Plywood mill, US, PNW	2.58E-02	kg	
Wood fuel, unspecified/RNA (purchased fuel)	2.45E-01	kg	
Transport, combination truck, diesel powered/US	1.588E-02	tkm	
Diesel, loaders and haulers	8.05E-04	l	
Gasoline, loaders and haulers	3.95E-05	l	
Propane, loaders and haulers[3]	1.21E-05	l	
Engine oil, in engines of loaders and haulers	5.00E-06	kg	
Engine oil, stationary equipment	1.90E-05	kg	
Hydraulic fluid for loaders and haulers	7.00E-06	kg	
Hydraulic oil for stationary equipment	4.50E-05	kg	
Transmission fluid, loaders and haulers	4.00E-07	kg	
Ethylene glycol, at plant	1.07E-06	kg	
Solvent, at plant/US[2]	5.00E-08	kg	
Solvent, at plant/US	6.70E-07	kg	
Water treatment, at plant/US	1.23E-04	kg	
Boiler streamline treatment	3.67E-06	kg	
Oils, mobile equipment	2.00E-06	kg	
Oils, stationary equipment	1.00E-05	l	
Urea, as N, at regional storehouse	3.15E-03	kg	
Disposal, ash, to unspecified landfill	7.59E-03	kg	
Disposal, solid waste, unspecified, to unspecified landfill, RNA	7.26E-06	kg	
Metal, to recycling, RNA	3.96E-08	kg	
Electricity/heat			
Electricity, at grid, US	8.20E-02	kWh	
Natural gas, combusted in industrial boiler/US	1.38E-03	m^3	
Emissions to air			

[2] Solvents may contain substances listed on the US Environmental Agency (EPA) Toxics Release Inventory. US Environmental Protection Agency, Toxics Release Inventory. http://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals. Accessed May 2019

	Value	Units	Allocation, percent
Acetaldehyde	1.05E-06	kg	
Acrolein	8.07E-07	kg	
Benzene	1.69E-07	kg	
Carbon monoxide, biogenic	3.23E-03	kg	
Carbon dioxide, biogenic	1.76E+00	kg	
Wood (dust)	5.62E-04	kg	
Emissions to air			
Formaldehyde	1.26E-05	kg	
HAPs	6.27E-06	kg	
Hydrogen chloride	1.17E-06	kg	
Lead	1.75E-07	kg	
Mercury	1.83E-09	kg	
Methane, biogenic	2.23E-05	kg	
Methanol	7.95E-06	kg	
Nitrogen oxides	1.10E-03	kg	
Particulates, < 10 um	4.71E-04	kg	
Particulates, < 2.5 um	1.39E-04	kg	
Phenol	6.21E-07	kg	
Propanal	5.14E-08	kg	
Sulfur dioxide	7.71E-05	kg	
VOC, volatile organic compounds	8.76E-04	kg	
Dinitrogen monoxide	2.93E-06	kg	
Naphthalene	5.77E-08	kg	
Other Organic	2.11E-07	kg	
Emissions to water			
Suspended solids, unspecified	8.35E-07	kg	
BOD5, Biological Oxygen Demand	2.10E-06	kg	

5.3.6 Packaging

Finished LVL is packaged for transport using wooden runners primarily by mass. Inputs include final product (LVL) and packaging material such as plastic wrapping, and outputs include packaged LVL. Packing materials represent about 1.0% of the cumulative mass of the model flow. The wooden spacers make up the bulk of this mass, representing 86.3% of the total packaging material (Table 10). The wrapping material, cardboard strap protectors, and plastic strapping make up 8.5%, 3.7%, and 1.5% of the packaging by mass, respectively.

Table 11 Materials used in packaging and shipping per cubic meter LVL (Puettmann et al. 2013).

Material	Value	Unit	Percentage
Wrapping material – HDPE[a]- and LDPE-laminated paper, kg	0.4601	kg	8.5
PET[c] strapping	0.0834	kg	1.5
Cardboard strap protectors	0.2002	kg	3.7
Wooden spacers	4.6721	kg	86.3
Total	5.4158	kg	100

[a]High-density polyethylene (HDPE)
[b]Low-density polyethylene (LDPE)
[c]Polyethylene terephthalate (PET)

5.4 Secondary Data Sources

Table 11 list the secondary LCI data sources used in this LCA study for raw material inputs, ancillary materials and packaging, transportation of materials and resources, fuels and energy for manufacturing, water sources, and waste streams.

Table 12 Secondary Data Sources and Data Quality Assessment

A1: Raw Material Inputs				
Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Wood resource	Database: CORRIM dataset Process: Roundwood, softwood, average, at forest road, PNW	North America – Region Specific	2005 -2019	**Technology**: good Process models region-specific technology. **Time**: good Some data is less than 10 years old **Geography**: very good Data is representative of regional production.
Resin	Database: US EI 2.2 (Datasmart2018) Process: Phenol formaldehyde, at plant NREL/US U	North America	2018	**Technology**: very good Process models average North American technology **Time**: good Data is less than 10 years old **Geography**: very good Data is representative of North American
A2: Raw Material Transportation				
Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Trucking	Database: US EI 2.2 (Datasmart2018) Process: Transport, combination truck, Diesel powered NREL/US U	North America	2018	**Technology**: very good Process models average North American technology **Time**: good Data is less than 10 years old **Geography**: very good Data is representative of North American trucking.
A3: Manufacturing				
Energy Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**

Electricity	Database: Ecoinvent 3.4 Process: Electricity, low voltage {WECC, US only}| market for | Cut-off, U	North America – Region Specific egrid	2018	**Technology**: very good Process models average electricity technology specific to regional grids **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of regional electricity generation.
Gasoline	Database: US EI 2.2 (Datasmart2018) Process: Gasoline, combusted in equipment NREL/US U	North America	2018	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American propane production and combustion.
Diesel	Database: US EI 2.2 (Datasmart2018) Process: Diesel, combusted in industrial equipment NREL/US U	North America	2018	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American diesel production and combustion.
Biomass Combustion	Database: CORRIM Data Process: Wood Combusted, at boiler, at mill, kg, US	North America	2015	**Technology:** very good Process represents combustion of biomass in an industrial boiler. **Time:** very good Data is within two years **Geography:** very good Data is representative of North American biomass combustion.
Ancillary Materials and Packaging	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Hydraulic Fluid and Lubricants	Database: US EI 2.2 (Datasmart2018)	North America	2018	**Technology**: very good Process models average North American technology

	Process: Lubricating oil, at plant/US- US-EI U			**Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American processes.
Antifreeze	Database: US EI 2.2 (Datasmart2018) Process: ethylene glycol, at plant/US - US-EI U	North America	2018	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American processes.
Solvents	Database: US EI 2.2 (Datasmart2018) Process: Hexane, at plant/US- US-EI U	North America	2018	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American production
Plastic Strap	Database: US EI 2.2 (Datasmart2018) Process: Polyethylene, HDPE, granulate, at plant/US- US-EI U	North America	2018	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American processes.
Steel Strap	Database: US EI 2.2 (Datasmart2018) Process: Chromium steel 18/8, at plant/US- US-EI U	North American	2016	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American processes.

Greases and oils	Database: US EI 2.2 (Datasmart2018) Process: Proxy Oil and grease, at plant NREL/US U	North America	2018	**Technology**: very good Process models average North American technology **Time**: very good Data is less than 5 years old **Geography**: very good Data is representative of North American processes.

6 Life cycle impact assessment

The life cycle impact assessment (LCIA) phase establishes links between the life cycle inventory results and potential environmental impacts. The LCIA calculates impact indicators, such as global warming potential and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, the impact category, and means of characterizing the impacts are summarized below. Environmental impacts are determined using the TRACI method (Bare 2011, 2012). Each impact indicator is a measure of an aspect of a potential impact. This LCIA does not make value judgments about the impact indicators, meaning comparison indicator values are not valid. Additionally, each impact indicator value is stated in units that are not comparable to others. For the same reasons, indicators should not be combined or added. Additionally, the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. The primary fuels categorized into non-renewable (fossil and nuclear) and renewable (biomass, geothermal, solar, wind, hydro). Table 12 summarizes the source and scope of each impact category reported in this report as required to be in conformance with the PCR.

Table 13 Selected impact indicators, characterization models, and impact categories

Reporting Category Per Tables E1-E5 in ISO 21930:2017	Indicator Name	Abbreviation	Units
Core Mandatory Impact Indicators	Global warming potential, biogenic[3]	GWP	kg CO2e
Core Mandatory Impact Indicators	Global warming potential, fossil	GWP	kg CO2e
Core Mandatory Impact Indicators	Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e
Core Mandatory Impact Indicators	Acidification potential of soil and water sources	AP	kg SO2e
Core Mandatory Impact Indicators	Eutrophication potential	EP	kg PO4e
Core Mandatory Impact Indicators	Formation potential of tropospheric ozone	SFP	kg O3e
Core Mandatory Impact Indicators	Abiotic depletion potential (ADP fossil) for fossil resources;	ADPf	MJ, NCV
Core Mandatory Impact Indicators	Fossil fuel depletion	FFD	MJ Surplus
Use of Primary Resources	Renewable primary energy carrier used as energy	RPRE	MJ, NCV
Use of Primary Resources	Renewable primary energy carrier used as material	RPRM	MJ, NCV
Use of Primary Resources	Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV
Use of Primary Resources	Renewable primary energy carrier used as material	NRPRM	MJ, NCV
Secondary material, secondary fuel and recovered energy	Secondary material	SM	kg
Secondary material, secondary fuel and recovered energy	Renewable secondary fuel	RSF	MJ, NCV
Secondary material, secondary fuel and recovered energy	Non-renewable secondary fuel	NRSF	MJ, NCV

[3] This indicator includes both biogenic and fossil-based carbon released. The TRACI method was modified to included CO2, biogenic removals and emissions

Reporting Category Per Tables E1-E5 in ISO 21930:2017	Indicator Name	Abbreviation	Units
Secondary material, secondary fuel and recovered energy	Recovered energy	RE	MJ, NCV
Mandatory Inventory Parameters	Consumption of freshwater resources;	FW	m3
Indicators Describing Waste	Hazardous waste disposed	HWD	kg
Indicators Describing Waste	Non-hazardous waste disposed	NHWD	kg
Indicators Describing Waste	High-level radioactive waste, conditioned, to final repository	HLRW	kg or m3
Indicators Describing Waste	Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	kg or m3
Indicators Describing Waste	Components for re-use	CRU	kg
Indicators Describing Waste	Materials for recycling	MR	kg
Indicators Describing Waste	Materials for energy recovery	MER	kg
Indicators Describing Waste	Recovered energy exported from the product system	EE	MJ, NCV
Additional Inventory Parameters for Transparency	Biogenic Carbon Removal from Product	BCRP	kg CO2e
Additional Inventory Parameters for Transparency	Biogenic Carbon Emission from Product	BCEP	kg CO2e
Additional Inventory Parameters for Transparency	Biogenic Carbon Removal from Packaging	BCRK	kg CO2e
Additional Inventory Parameters for Transparency	Biogenic Carbon Emission from Packaging	BCEK	kg CO2e
Additional Inventory Parameters for Transparency	Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	BCEW	kg CO2e
Additional Inventory Parameters for Transparency	Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	CWNR	kg CO2e

Cradle-to-gate environmental performance results for all reporting indicators listed in Table 13 for PNW LVL. The LCIA results in these tables show the absolute values for A1-Resource Extraction, A2-Transportation, and A3-LVL Production. For GWP, 32 percent of the CO_2 equivalent emissions come from producing LVL (80 kg CO_2 eq), with 61 percent assigned to resource extraction (forestry operations and resin and veneer) (152 kg CO_2 eq). Transportation was 18 kg CO_2 eq or 7 percent of the cradle-to-gate GWP impact.

Table 13 also provides indicators related to energy use, material resource consumption, and the waste generated. The total cradle to gate energy use was 8,892 MJ/m^3. Fossil energy, 3,866 MJ/m^3, is used for machinery, transportation, electricity, and drying. The biomass energy, 4,235 MJ/m^3, was used for veneer production and pressing of LVL panels. Total non-renewable fuel used represents 49 percent of the total energy and is used for machinery, transportation, electricity, and some in drying. Total cradle-to-gate renewable energy total is 4,540 MJ and non-renewable represented 4,352 MJ.

Most of the freshwater use is in the A1 life cycle stage (86%). In the resource extraction stage, veneer production consumed 93 percent (935 L) of the total freshwater use (1,009 L) in A1. Total cradle-to-gate freshwater use was 1,175 L.

Most of the waste is generated in the A1 life cycle stage. Laminated veneer lumber production (A3) generated only 4, 3, and 4 for total waste, hazardous, and non-hazardous waste, respectively. The A1 phase generated 97 percent of the total cradle to gate hazardous waste and 94 percent of the non-hazardous (Table 14). Within the A1 phase, resin production generated 96 percent of the hazardous and 89 percent of the nonhazardous waste (Table 15).

Table 14 Environmental performance of 1 m^3 of laminated veneer lumber, PNW

		Units	A1	A2	A3	Total
Core Mandatory Impact Indicator						
Global warming potential, w/biogenic	GWP	kg CO2e	(1,374.12)	13.72	1,614.40	254.00
Global warming potential, fossil	GWP	kg CO2e	342.38	13.72	151.90	254.00
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	1.21E-05	2.30E-08	8.38E-06	2.05E-05
Acidification potential of soil and water sources	AP	kg SO2e	1.7001	0.0758	0.6255	2.4014
Eutrophication potential	EP	kg Ne	1.0474	0.0070	0.8372	1.8917
Formation potential of tropospheric ozone	SFP	kg O3e	41.55	2.19	17.58	61.32
Abiotic depletion potential (ADPfossil) for fossil resources;	ADPf	MJ, NCV	2,836.60	171.71	857.92	3,866.23
Fossil fuel depletion	FFD	MJ Surplus	765.60	25.79	208.41	999.79
Use of Primary Resources						
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	4,397.12	0.37	142.66	4,540.15
Renewable primary energy carrier used as material	RPRM	MJ, NCV	14,091.83			14,091.83
Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV	3,234.97	174.20	942.75	4,351.92
Non-renewable primary energy carrier used as material	NRPRM	MJ, NCV	617.61	-	-	617.61
Secondary Material, Secondary Fuel and Recovered Energy						
Secondary material	SM	kg	-	-	-	-
Renewable secondary fuel	RSF	MJ, NCV	822.02	-	5.20	827.22
Non-renewable secondary fuel	NRSF	MJ, NCV	-	-	-	-
Recovered energy	RE	MJ, NCV	-	-	-	-
Mandatory Inventory Parameters						
Consumption of freshwater resources	FW	m3	1.0085	0.0013	0.1653	1.1752
Indicators Describing Waste						
Hazardous waste disposed	HWD	kg	0.0250	0.0000	0.0009	0.0259
Non-hazardous waste disposed	NHWD	kg	48.60	1.16	1.95	51.70
High-level radioactive waste, conditioned, to final repository	HLRW	kg or m3	-	-	-	-
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	kg or m3	-	-	-	-
Components for re-use	CRU	kg	-	-	-	-
Materials for recycling	MR	kg	-	-	-	-
Materials for energy recovery	MER	kg	-	-	-	-
Recovered energy exported from the product system	EE	MJ, NCV	-	-	-	-

Table 15 Distribution of waste generation by life cycle stage; A1-Resource extraction, A2-Transporation, and A3 Product manufacturing.

	A1	A2	A3	TOTAL cradle-to-gate
Total Waste	48.62	1.16	1.95	51.73
Hazardous waste	0.02	0.00	0.00	0.03
Non-hazardous waste	48.60	1.16	1.94	51.70
% Hazardous waste	96.53%	0.05%	3.42%	100.00%
% Non-hazardous waste	93.99%	2.25%	3.76%	100.00%

Table 16 Distribution of waste generation in the A1-Resource extraction life cycle stage.

	A1-Resource extraction		
	Forestry operations	Resin Production	Veneer Production
% Hazardous waste	1.78%	96.01%	2.20%
% Non-hazardous waste	3.08%	89.38%	7.55%

7 Interpretation

As defined by ISO (2006a-b), the term life cycle interpretation is the phase of the LCA that the findings of either the LCI or the LCIA, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations. This phase in the LCA reports the significant issues based on the results of the presented in LCI and the LCIA of this report. Additional components report an evaluation that considers completeness, sensitivity and consistency checks of the LCI and LCIA results, and conclusions, limitations, and recommendations.

7.1 Identification of the Significant Issues

The objective of this element is to structure the results from the LCI or the LCIA phases to help determine the significant issues found in the results and presented in previous sections of this report. A contribution analysis was applied for the interpretation phase of this LCA study. Contribution analysis examines the contribution of life cycles stages (A1 and A3), unit process contributions in a multi-unit manufacturing process, or specific substances which contribute an impact.

7.2 Life cycle phase contribution analysis

For global warming impact, 32 percent of the CO_2 equivalent emissions come from producing LVL (A3), with 61 and 7 percent assigned to extraction (A1) and transportation (A2), respectively (Table 15). Resource extraction (A1) represented the highest impacts in all environmental impact categories (GWP, eutrophication, acidification, smog, and ozone depletion). Cradle-to-gate, freshwater use was also almost exclusively consumed during the A1 life cycle stages (86%) (Table 15).

Most of the renewable fuels were used in the A1 life-cycle stage (Table 167). Biomass energy is used in log condition, veneer drying, and pressing of panels in veneer production. Renewable fuels represented the 48 percent of energy consumption cradle-to-gate (A1-A3) (Table 17) and 99 percent in A1 for all biomass use. Non-renewable fuel consumption cradle-to-gate was 49 percent. In summary, cradle to gate total energy for producing PNW LVL, which includes fuel for process heat and equipment and electricity, comes from 44 percent fossil fuels, 6 percent nuclear, 48 percent renewable biomass fuel, and 3 percent other renewable (Table 18).

Table 17 Cradle-to-gate PNW LVL LCIA contribution analysis LCIA results for A1-Resource extraction, A2-Transporation, and A3-Product production

Indicator Name	Abbreviation	Units	A1	A2	A3	Total
Global warming potential, fossil	GWP	kg CO2e	35%	5%	60%	100%
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	59%	0%	41%	100%
Acidification potential of soil and water sources	AP	kg SO2e	71%	3%	26%	100%
Eutrophication potential	EP	kg Ne	55%	0%	44%	100%
Formation potential of tropospheric ozone	SFP	kg O3e	68%	4%	29%	100%
Abiotic depletion potential (ADPfossil) for fossil resources;	ADPf	MJ, NCV	73%	4%	22%	100%
Fossil fuel depletion	FFD	MJ Surplus	77%	3%	21%	100%
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	97%	0%	3%	100%
Renewable primary energy carrier used as material	RPRM	MJ, NCV	100%	0%	0%	100%
Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV	74%	4%	22%	100%
Non-renewable primary energy carrier used as material	NRPRM	MJ, NCV				
Secondary material	SM	kg				
Renewable secondary fuel	RSF	MJ, NCV				
Non-renewable secondary fuel	NRSF	MJ, NCV				
Recovered energy	RE	MJ, NCV				
Consumption of freshwater resources;	FW	m3	85.82%	0.11%	14.07%	100.00%
Hazardous waste disposed	HWD	kg	97%	0%	3%	100%
Non-hazardous waste disposed	NHWD	kg	94%	2%	4%	100%
High-level radioactive waste, conditioned, to final repository	HLRW	kg or m3				
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	kg or m3				
Components for re-use	CRU	kg				
Materials for recycling	MR	kg				
Materials for energy recovery	MER	kg				
Recovered energy exported from the product system	EE	MJ, NCV				

Table 18 Cradle-to-gate PNW LVL LCIA energy use contribution analysis results by fuel type for A1-Resource extraction, A2-Transporation, and A3-Laminated veneer production

	Unit	Total	A1	A2	A3
Non-renewable, fossil	MJ	100%	73.37%	4.44%	22.19%
Non-renewable, nuclear	MJ	100%	82.02%	0.51%	17.47%
Non-renewable, biomass	MJ	100%	35.52%	0.00%	64.47%
Renewable, biomass	MJ	100%	98.97%	0.00%	1.03%
Renewable, wind, solar, geothermal	MJ	100%	70.45%	0.08%	29.46%
Renewable, water	MJ	100%	65.92%	0.11%	33.97%

Table 19 Cradle-to-gate PNW LVL LCIA energy use contribution analysis results by A1-Resource extraction, A2-Transporation, and A3- Laminated veneer production

	Unit	Total	A1	A2	A3
Non-renewable, fossil	MJ	43.48%	37.17%	98.36%	79.04%
Non-renewable, nuclear	MJ	5.46%	5.22%	1.43%	7.82%
Non-renewable, biomass	MJ	0.00%	0.00%	0.00%	0.00%
Renewable, biomass	MJ	47.62%	54.91%	0.04%	4.02%
Renewable, wind, solar, geothermal	MJ	1.18%	0.97%	0.05%	2.85%
Renewable, water	MJ	2.26%	1.73%	0.13%	6.28%
		100%	100%	100%	100%

7.3 Uncertainty Analysis

Some degree of uncertainty is present in the results due to the variation amongst different data providers. Tables 19-20 provides statistics for some of the key modeling parameters found to be most significant in LVL production.

Table 20 Survey data statistics for selected parameters, mass balance

	Weighted average (OD kg)	Mean	Min.	Max.	Mass (%)	CoVw[a] (%)
Inputs						
Feedstocks						
Purchased veneer	585	583	566	600	96.3	4.1
Total, feedstock	585	583	566	600	96.3	4.1
Resin system						
PF resin	17.8	17.6	16.6	18.7	2.9	8.3
Sodium hydroxide	3.2				0.5	
Catalyst	0.2				0.0	
Melamine	1.6				0.3	
Total Resin	23	20	18	22	3.7	13.7
Total inputs	608	603	584	622	100	
Outputs						
Products						
LVL	543	542	531	553	89.3	2.9
Coproducts						
Sawdust, sold	53.0	52.1	46.4	57.8	8.7	15.2
Panel trim, sold	3.4	3.1	0.0	6.1	0.5	126
Lay-up scrap	2.9	3.3	0.0	6.6	0.5	–
Tested LVL, used	5.9	6.6	0.0	13.2	1.0	–
Total Coproducts	65	65	64	66	10.7	2.5
Total outputs	608	607	597	617	100	

[a] Production weight-averaged coefficient of variation.

Table 21 Survey data statistics for Selected Parameters, on-site energy use

Energy inputs	Weighted average	Unit	Mean	Min.	Max.	CoVw (%) [a]
Electricity	77.4	kWh	81.2	47.5	114.9	61%
Natural gas	12.8	m^3	13	12	14	11%
Diesel	0.35	L	0.36	0.27	0.46	37%
Propane	0.48	L	0.46	0.28	0.63	52%

[a] Production-weighted coefficient of variation.

7.4 Completeness, consistency and sensitivity

Evaluating the LCAs completeness, sensitivity, and consistency offers confidence in and reliability of the LCA results. The completeness check process verifies whether information from the life-cycle phases of an LCA are sufficient for reaching the goals and scope and conclusions of the study and making sound interpretations of the results. Three life-cycle stages (forestry operations, wood material production, and LVL production) were checked for data completeness including all input elements such as raw and ancillary materials input, energy input, transportation scenarios, water consumption, and outputs such as products and coproducts, emissions to air, water, and land, and final waste disposals. All input and output data were found to be complete, and no data gaps were identified.

The consistency check process verifies that the assumptions, methods, and data are consistently applied throughout the study and are in accordance with the goal and scope of the LCA. A comprehensive review process was completed for this LCA to make certain consistency was applied to the assumptions made, methods used, models, data quality including data sources, data accuracy, age, time-related coverage, technology, and geographical coverage.

Sensitivity analysis can be applied to the LCA to determine changes in results caused by variations in assumptions, methods, and data. Sensitivity analysis is a systematic approach for estimating the effects of the choices made concerning methods and data on the outcome of a study. Sensitivity analysis is a key component of data quality analysis and can be applied to quantify the impact of changes in assumptions or input data on study results. A sensitivity analysis was completed per ISO standards (ISO 2006a, 2006b) to model the effects of natural consumption and electricity consumption for LVL production. Sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors.

During LVL manufacturing, natural gas is used for curing resin. Changing the consumption of natural gas may have a significant effect on CPEC and GHG emissions. Lower (-20%) and higher (+20%) natural gas consumptions were selected to compare with the baseline fuel mix developed from the mill survey data. Although the usage changed by 20 percent, the outcomes changed approximately 2.5 and 1.1 percent for GHG emissions and CPEC, respectively (Table 21).

Table 22 Key parameters on changing natural gas consumption during LVL production.

Parameter	Unit	Low (-20%)	Surveyed (0%)	High (+20%)
		Values		
GHG emissions	kg CO_2e	212.15	218	223
CPEC	GJ	8.85	8.97	9.05

However, changing electricity consumption by 20 percent affects the outcomes less than 4 percent and 1.6 percent for GHG emissions and CPEC, respectively (Table 22).

Table 23 Key parameters on changing electricity consumption during LVL production.

Parameter	Unit	Low (-20%)	Surveyed (0%)	High (+20%)
		Values		
GHG emissions	kg CO_2e	210	218	225
CPEC	GJ	8.81	8.97	9.10

7.5 Limitations

This LCA was created using industry average data for upstream materials. Variation can result from differences in supplier locations, manufacturing processes, manufacturing efficiency and fuel type used. This LCA does not report all of the environmental impacts due to manufacturing of the product, but rather reports the environmental impacts for those categories with established LCA-based methods to track and report. Unreported environmental impacts include (but are not limited to) factors attributable to human health, land use change, and habitat destruction. In order to assess the local impacts of product manufacturing, additional analysis is required.

This LCA report documents the results of a ‘cradle-to-gate’ analysis and is not a comparative assertion, defined as an environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function. This LCA does not make any statements that the product covered by the LCA is better or worse than any other product.

8 Treatment of Biogenic Carbon

The treatment of biogenic carbon in this LCA follows the requirements set out in the reference PCR. Reporting of biogenic carbon removals and emissions is reported in as per ISO 21930 standard (ISO 2017). When biogenic carbon enters the product system it is characterized in the impact assessment with a factor of -1 kg CO_2 eq. During production, biogenic carbon emissions (CO_2) are released through the combustion of biomass fuels in boilers. As per ISO 21930, when biogenic carbon leaves the product system as CO_2 emission it has a factor of +1 kg CO_2 eq. When any wood material (product and coproducts) that contain biogenic carbon leaves the system boundary, it must be expressed with a factor of +1 kg CO_2 eq.

Forests are understood as a natural system with multiple functions, the production function of timber being one of them. Therefore, natural growth and decay processes including natural disturbances, etc., are not attributable to the production function of forests and are therefore not considered in LCA. Harvesting operations lead to temporal decreases in forest carbon pools in the respective stand. Impacts on forest carbon pools resulting from the sustainable or unsustainable management of forests, however, cannot be defined or assessed on stand level but requires the consideration of carbon pool changes on landscape level, i.e., the level based on which management decisions are made. Resulting from the fundamental principle of sustainable forest management to preserve the production function of forest, total forest carbon pools can be considered stable (or increasing) under sustainable forest management. This is due to the fact that temporal decreases of forest carbon pools resulting from harvesting on one site are compensated by increases of carbon pools on the other sites, forming together the forest area under sustainable forest management.

It is acknowledged that excessive extraction of slash, litter or roots for the purpose of bioenergy generation can lead to decreases in forest carbon pools. These activities, however, are not causally linked to the extraction of timber for the material use of wood. Effects on forest carbon pools related to the extraction of slash, litter or roots are not attributable to the material use of wood and are therefore not considered in this document.

In order to reflect the biogenic nature of wood, its renewability and its potential carbon neutrality, the system boundary between nature and the product system under study is defined as follows:

- Wood entering the product system from nature accounts for the energy content and the biogenic carbon content as material inherent properties.
- All technical processes related to forestry operations intended to produce timber, (e.g. stand establishment, tending, thinning(s), harvesting, establishment and maintenance of forest roads) are considered within the system boundary and are subject to co-product allocations as outlined in the reference PCR.
- Potential implications due to the unknown origin of wood or unsustainably produced timber are considered.
- Human induced impacts on forest carbon pools resulting in deforestation are included.

As the degradation of forest carbon pools resulting from unsustainable management of forests cannot be attributed to a specific log but is a process on landscape level, the effect of forest degradation is considered by not assuming carbon neutrality. In the case of land-use changes from forests to other land uses (e.g., deforestation), the loss of carbon in the forest carbon pools are to be considered.

Consideration of the biogenic carbon neutrality of wood is valid for North American wood products as national level inventory reporting shows overall increasing and/or neutral forest carbon stocks in recent years[4].

Using the method described above, -1,463 kg CO_2e (A1) were removed in the production of 1 m^3 of PNW LVL. One cubic meter of PNW LVL stores 272 kg of carbon or +996 kg CO_2e (C3/C4). The coproducts produced during LVL production account for an additional +119 kg CO_2e (A3) for a total "emission" in wood product leaving the system boundary of +1,083 kg CO_2e. The combustion of wood fuel emitted 355 kg CO_2e. Packaging resulting in removal of -9.9 kg CO_2e) and an emission of +2.6 kg CO_2e (a5). In summary, total removals was -1,463 kg CO_2e and total "emissions" was +1,463 kg CO_2e from cradle-to-gate (A1-A3) (Table 23). In Table 23, CO_2 flows are presented unallocated to consider co-products leaving the product system (A3). In accordance with ISO 21930, emission from packaging (BCEK) is reported in A5 and emission from main product is reported in C3/C4. The system boundary for this LCA only includes module A1-A3.

Table 24 Biogenic carbon inventory parameters

Additional Inventory Parameters		A1	A2	A3	A5	C3/C4	Total
	kg CO2e						
Biogenic Carbon Removal from Product	BCRP	(1,462.50)	-	-			(1,462.50)
Biogenic Carbon Emission from Product	BCEP	-	-	119.10		995.50	1,114.60
Biogenic Carbon Removal from Packaging	BCRK	-	-	(9.9290)			(9.9290)
Biogenic Carbon Emission from Packaging	BCEK	-	-		2.5894		2.5894
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production	BCEW	353.24	-	2.0031			355.24

9 Discussion

In 2013 CORRIM updated Wilson (2005) to reflect updates in electricity grids and wood boilers (Puettmann et al. 2013). At that time, an LCIA was also conducted using the LCI data developed by Wilson (2005). The updates were necessary to comply with the 2015 PCR for North American Structural Wood Products so an EPD on North American LVL could be produced (https://awc.org/pdf/greenbuilding/epd/AWC-EPD-LVL-190328.pdf). This study conducted new mill surveys and reported results based on the 2019 PCR (UL 2019) (Bergman and Alanya-Rosenbaum, 2017).

As noted earlier, total energy for producing 1 cubic meter of LVL from the PNW region was 8,892 MJ, 34 percent higher than (6,642) MJ/m^3 from Puettmann et al. (2013). The 2013 report that only updated to include an LCIA and updates electricity grid mix and wood boiler data. This current study updated the full gate-to-gate LCI data for LVL production based on new surveys to industry. Other changes between the two LCA's is the use of lower and higher heating values. The current study uses LHV. The 2013 study determined total energy use by calculating from the fuel raw material extraction. The current study

[4] National forest carbon stocks are reported under the United Nations Framework Convention on Climate Change. See Table 7.1 for United States forest carbon stocks and Table 7.1 for Canadian forest carbon stocks. Canadian forest carbon stocks have fluctuated near net neutrality in recent years (ranging from -98 Tg to +69 Tg since 1990) while United States forest carbon stocks have shown annual stock increases of 600-900 Tg annually since 1990.

uses a more complete capture of fuel resource use by using the Cumulative Energy Demand Method (CED).

Table 24 shows the changes between the 2013 updated LCA and the current LCA. Global warming impacts increased by 37 percent, while eutrophication increased by over 2000 percent and water use by 52 percent (Table 24). These differences can be attributed to differences in reporting requirements, LCIA methodologies, and LCI accounting methods, as well as better reporting by industry and better representation of the regional industry as a whole. In addition, many of the environmental indicators are a direct reflection of the increased fuel use reported in the most recent surveys Bergman and Alanya-Rosenbaum, 2017). Other measurements in material use also changed primarily because of requirement changes in reporting details between the previous PCR (FPInnovations 2015) and the current PCR (UL 2019) under which this report conforms too.

Table 25 LCIA comparison between updated 2013 data (based on 2007 industry surveys) and current study data (based on 2012 industry surveys) on LVL production in the PNW

	Unit	Current Study	Past Study 2013
Global warming potential	kg CO_2 eq	254.00	185.53
Eutrophication Potential	kg N eq	1.8917	0.0762
Smog Potential	kg O_3 eq	61.32	30.37
Non-renewable fossil	MJ	3,866.23	3,153.66
Non-renewable nuclear	MJ	485.69	249.32
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	305.46	179.47
Renewable, biomass	MJ	4,234.69	3,059.24
Fresh water	L	1,175.17	774.96
Solid waste (hazardous and non-hazardous)	kg	51.73	38.28

10 Conclusions

The cradle to gate LCA for PNW LVL includes the LCI of forest resources and veneer production and the LCI of LVL manufacturing that relies on primary survey data. The survey results were representative operations in the PNW region that would produce structural LVL panels. The survey data are representative of the LVL types and production volumes consistent with trade association production data.

Emissions from the forest resources LCI are small relative to manufacturing emissions. While other processes such as resin and veneer production that are listed in the A1 life cycle stage contribute significantly to the cradle-to-gate impacts. At the LVL production facilities emissions to land and water are small. Mill site airborne emissions originate mainly at the boiler, dryers, and presses.

Laminated veneer lumber production (A3) consumed only 12 percent of the total energy with 86 percent from resin and veneer production and forest operations and 2 percent to transport. Energy generated by renewable fuels, such as woody biomass, represents about 51 percent of the total energy from cradle to gate.

11 Critical review

11.1 Internal Review

The purpose of the LCA Report internal review is to check for errors and conformance with the PCR prior to submittal to for external review. The technical and editorial comments of the reviewers were carefully considered and, in most instances, incorporated into the final document. CORRIM addressed the internal review comments, as appropriate, and maintains a record of all comments and responses for future reference.

11.2 External Review

The external review process is intended to ensure consistency between the completed LCA and the principals and requirements of the International Standards on LCA (ISO 2006) and ISO 21930 - Sustainability in Buildings and Civil Engineering Works - Core Rules for Environmental Product Declarations of Construction Products and Services (ISO 2017), the Product Category Rules for North American Structural and Architectural Wood Products Part B (UL 2019) and Part A: Life Cycle Assessment Calculations Rules and Report Requirements (UL 2018).

Following CORRIM's internal review evaluation, documents were submitted to UL Environment (UL) for independent external review. The independent external review was conducted by Thomas Gloria, Ph.D., Industrial Ecology Consultants, LCACP ID: 2008-03.

12 Acknowledgements

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13 Units and Conversions

Table 26 Wood conversion in developing the laminated veneer lumber

To convert from	to	multiply by
Cubic feet (ft^3)	Cubic meters (m^3)	0.02831685
Pounds (avdp) (lb)	Kilograms (kg)	0.4535924
Cubic inches (in^3)	Cubic centimeters (cm^3)	16.393
Btu's	Joules (J)	1054
Cubic yards (yd^3)	Cubic meters (m^3)	0.7645549
Feet (ft)	Meters (m)	0.305
Gallons (US) (gal)	Liters (L)	3.785
Kilowatt-hours (kWh)	Megajoules (MJ)	3.6
Miles (mi)	Kilometers (km)	1.609
Ounces (avdp) (oz)	Kilograms (kg)	0.028
Square feet (ft^2)	Square meters (m^2)	0.093
Tons (short)	Kilograms (kg)	907.185
Tons (short)	Metric tons (t)	0.9071847
Pounds (lb)	Metric tons (t)	0.0004
Watts (W)	Joules/second (J/s)	1
Yards (yd)	Meters (m)	0.914
Acres (a)	Hectares (ha)	0.405

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15 Appendix 1 Conformance to North American Structural and Architectural Wood Product Category Rules

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Review of LCA Studies of Conformance to North American Structural and Architectural Wood Product Category Rules

March 27, 2020

Introduction

Underwriters Laboratory Environment (ULE) commissioned a life cycle assessment (LCA) expert to perform a verification of supporting LCAs to be used as the basis for Environmental Product Declarations (EPDs) for North American Structural and Architectural Wood products (UN CPC 31 and NAICS 321).

The review was conducted by:

Thomas P. Gloria, Ph.D., LCACP
Managing Director, Industrial Ecology Consultants
Director, Sustainability Programs, Harvard University Division of Continuing Education

This document identifies the LCA studies under review and summarizes the review objectives and the results of revisions made based on a first pass of the review.

LCA Studies Reviewed

The LCA studies reviewed include the following:

LCA Study Title	Practitioner	Date
LCA for the Production of Inland Northwest Softwood Lumber	CORRIM	March 2020
LCA for the Production of Northeast – Northcentral Softwood Lumber	CORRIM	March 2020
LCA for the Production of Oriented Strandboard Production	CORRIM	March 2020
LCA for the Production of Pacific Northwest Glued Laminated Timbers	CORRIM	March 2020
LCA for the Production of Pacific Northwest Engineered I-Joist,	CORRIM	March 2020
LCA for the Production of Pacific Northwest Softwood Lumber	CORRIM	March 2020
LCA for the Production of Pacific Northwest Laminated Veneer Lumber	CORRIM	March 2020
LCA for the Production of Pacific Northwest Softwood Plywood	CORRIM	March 2020
LCA for the Production of Southeast Glued Laminated Timbers	CORRIM	March 2020
LCA for the Production of Southeastern Engineered I-Joist	CORRIM	March 2020
LCA for the Production of Southeastern Softwood Lumber	CORRIM	March 2020
LCA for the Production of Southeast Laminated Veneer Lumber	CORRIM	March 2020
LCA for the Production of Southeast Softwood Plywood	CORRIM	March 2020
A C-to-G LCA of Canadian Glulam	Athena	March 2020
A C-to-G LCA of Canadian Wood I-Joists	Athena	March 2020
A C-to-G LCA of Canadian Surfaced Dry Softwood Lumber	Athena	March 2020
A C-to-G LCA of Canadian Laminated Veneer Lumber (LVL)	Athena	March 2020
A C-to-G LCA of Canadian Oriented Strandboard (OSB)	Athena	March 2020
A C-to-G LCA of Canadian Plywood	Athena	March 2020

Critical Review Objectives

The reviewer reviewed the LCA studies for conformance to the following applicable documents regarding the ability to support Business to Business (BtB) EPDs:

- ISO 14044:2006, Environmental management - Life cycle assessment - Requirements and guidelines;
- ISO 14040:2006, Environmental management - Life cycle assessment - Principles and framework;
- ISO 14025:2006, Environmental labeling and declarations - Type III environmental declarations - Principles and procedures;
- ISO 21930:2017, Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services.

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- UL Environment: PCR for Building-Related Products and Services - Part A: Calculation Rules for the LCA and Requirements, v.3.2, December 2018.
- UL Environment: Part B: Structural and Architectural Wood Products EPD Requirements UL 10010-9 v.1.0. September 2018.

Review Results
A first pass review was performed, revisions were made by the LCA practitioners, Athena Sustainable Materials Institute (Athena) and the Consortium for Research on Renewable Industrial Materials (CORRIM). The documents listed above were reviewed against the general requirements for conformance:

- Are methods used to carry out the LCA were consistent with ISO 14040/14044 standards?
- Are methods used to carry out the LCA were scientifically and technically valid?
- Are data used were appropriate and reasonable in relation to the goal of the study?
- Do interpretations reflected the limitations identified and the goal of the study?
- Was the study report transparent and consistent?

Summary
On the basis of the objectives set forth to review the aforementioned LCA studies, **the reviewer concludes that all studies conform to the applicable standards.** The reviewer greatly appreciates the responsiveness and cooperation of all parties involved in the review process.

Respectfully,

Thomas P. Gloria, Ph.D., Newton, Massachusetts

16 Appendix 2 Original LCA Report

CRADLE-TO-GATE LIFE-CYCLE ASSESSMENT OF LAMINATED VENEER LUMBER (LVL) PRODUCED IN THE PACIFIC NORTHWEST REGION OF THE UNITED STATES

CORRIM FINAL REPORT

Module H1

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Revised April 2017

(values for water were revised in Tables 15, 25, 30, and 35)

Bergman R, Alanya-Rosenbaum S. 2017a. Cradle-to-gate life-cycle assessment of laminated veneer lumber produced in the Pacific Northwest region of the United States. CORRIM Final Report. Module H1. Revised April 2017. 92 p.

Information contained in this report is based on new survey data (2012) and supersedes information in the original Phase I report (Wilson and Dancer 2004). This report is a cradle to gate LCA and includes all forestry related upstream processes and packaging of final product. CORRIM REPORT - Life Cycle Assessment of Laminated Veneer Lumber (LVL) Production has not been certified but is written in compliance to the Product Category Rules North American Structural and Architectural Wood Products (June 2015) and can serve as a LCA for an Environmental Product Declaration.

1 EXECUTIVE SUMMARY

1.1 Study Goals

The goal of this study was to update life-cycle assessment (LCA) data associated with laminated veneer lumber (LVL) production in the Pacific Northwest (PNW) region of the United States from cradle-to-gate mill output. The authors collected primary mill data from LVL production facilities per Consortium on Research for Renewable Industrial Materials (CORRIM) Research Guidelines. Comparative assertions were not a goal of this study.

1.2 Method

The authors collected primary mill data through a survey questionnaire mailed to LVL plants. This survey tracked raw material inputs (including energy), product and byproduct outputs, and pertinent emissions to water and air as well as solid waste generation. The study incorporated and translated an industry-standard production unit to a metric production unit (one cubic meter was the declared unit). Secondary data, such as premill gate processes (e.g. forestry operations, dry veneer production, electricity production), were from peer-reviewed literature per CORRIM guidelines, public databases, or other life-cycle inventory (LCI) studies completed concurrently. Primary and secondary data were used to calculate material and energy balances. With these material and energy data, the LCA was constructed to conform to internationally accepted standards. The LCI flows and LCIA results were generated using LCA modeling software populated by the U.S. LCI Database. The study based all allocations on the mass and economic value of the products and coproducts produced from cradle to gate. The LCIA was performed using the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI 2) method. Five impact categories were examined, including global warming potential (GWP (kg CO_2-eq)), acidification (kg SO_2-eq), eutrophication (kg N-eq), ozone depletion (kg chlorofluorocarbons-11-eq), and photochemical smog (kg NOx-eq).

1.3 Life-Cycle Inventory

Cradle-to-gate LCI flows for LVL manufacturing were presented by three life stages, (1) forestry operations, (2) dry veneer production, and (3) LVL production. The majority of the raw material energy consumption occurred during dry veneer production, followed by LVL production, with a small portion arising from forestry operations. Emission data produced through modeling found that estimated biomass and fossil carbon dioxide (CO_2) emissions were 397 and 199 kg/m^3 for the PNW, respectively. Veneer production occurs at veneer mills spread across the United States, and the wood is dried prior to arrival at LVL plant facilities. The production of LVL was modeled as a single unit process because the final product, LVL, by mass was made up of about 90% products with the remainder being coproducts.

The amount and type of energy used during production of building materials such as LVL are important to the holistic environmental impact of the product. Total cumulative primary energy consumption (CPEC) for the cradle-to-gate production of PNW LVL was 8.97 GJ/m^3. Use of renewable energy in manufacturing LVL was substantial. Renewable biomass represented 52.5% of the total cumulative energy consumption for all stages of production. As for the other two life-cycle stages, forestry operations consumed relatively little energy, and this energy came exclusively from fossil fuels. This energy was only about 1.8% of the total cumulative energy consumption. In addition, the veneer production stage consumed roughly the same percentage of nonrenewable fossil fuel as the production of LVL itself. Energy consumed during phenol-formaldehyde (PF) resin production along with the additives of the resin system was included in fossil fuel use for LVL as an upstream process. In summary, to produce one cubic meter of PNW LVL from cradle to gate, 52.5% of the cumulative energy was from biomass (wood fuel) and 41.8% was from nonrenewable fossil fuels, which leaves a small portion of energy needs coming from nuclear energy (as electricity; 3.5%) and the remaining 1.8% from hydro, wind, solar, and geothermal sources.

1.4 Life-Cycle Impact Assessment

Environmental performance results for GWP, acidification, eutrophication, ozone depletion, and smog (the five impact areas) are provided. Also provided are environmental performance results for energy consumption from nonrenewable fossil and nuclear fuels and renewable sources (wind, hydro, solar, geothermal, and biomass), material resource consumption from renewable and nonrenewable sources, and solid waste. Impacts from the five environmental areas associated with LVL production were small compared with the impacts associated with dry veneer production.

1.5 Interpretation

Emissions from the forest resources LCI are small relative to manufacturing emissions (dry veneer and LVL). At the LVL production facility, emissions originate at the boiler and during hot-pressing and sawing. Boiler emissions released are a function of the fuel burned whereas other emissions are a function of the unit process and associated emission control device.

Cradle-to-gate LCI results showed that 199 kg fossil CO_2 were released in the production of one cubic meter of PNW LVL. LVL is primarily made of wood and therefore stores carbon. Carbon content for wood products is assumed to be 50% by mass of oven-dried (OD) wood. Excluding the resin system, the carbon stored in the wood portion of one cubic meter of LVL on a production-weighted average is equivalent to 959 kg CO_2 emissions if left to decay.

Data quality was high. A mass balance was performed to verify data quality. Inputs and outputs were consistent for the two surveyed mills on a cubic meter basis. In addition, total wood mass in and total wood mass out was calculated. Difference for overall wood mass was less than 2%. A difference less than 10% is considered good for wood product production.

Energy inputs from the 2012 study were compared with earlier CORRIM reporting on LVL production. As expected from the higher CPEC, the on-site energy inputs from the updated data were substantially higher than from earlier reported PNW LVL production. In particular, electricity and natural gas consumption drove the energy increase with differences of 41 and 76%, respectively. However, with that being said, no statistical analysis was conducted on the earlier data and different companies provided the primary 2000 only speculation can made on the apparent differences. In this study, the weighted coefficient of variation representing the variability in the collected process data is calculated and presented in the report. Also in this study, a sensitivity analysis was performed investigating the impact to the overall output from the variation of energy inputs into LVL production.

1.6 Sensitivity Analysis

A sensitivity analysis was completed per International Organization for Standardization (ISO) 14040 standards to model the effects of natural gas consumption and electricity consumption for LVL production. The five environmental impacts associated with LVL production previously listed were small compared with the impacts associated with dry veneer production energy use. For the sensitivity analysis, neither on-site natural gas nor electrical consumption during LVL production showed a substantial contribution to the overall process compared with dry veneer production, which had a relatively large effect for the environmental indicators associated with energy consumption.

1.7 Key Findings

In this study, cradle-to-gate CPEC of LVL production for the U.S. was substantially higher compared with earlier CORRIM studies as well as a more recent Canadian study. A corresponding LCA update for southeastern cradle-to-gate LVL showed a similar conclusion. Yet, the authors can only speculate regarding the apparent differences because of the lack of statistical data analysis from earlier studies. Two scenario analyses indicated that LVL production itself was a minor contributor to the overall process because veneer production largely outweighs LVL production in terms of energy inputs. As for energy inputs for LVL production itself, one possible explanation is the greater use of emission control devices outside of baghouses because of increased regulatory controls in the United States since the 2000s when Phase I survey data were collected.

2 ACKNOWLEDGMENTS

Primary 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). We especially thank those companies and their employees that participated in the surveys to obtain production data. In addition, this research was supported in part by an appointment to the U.S. Forest Service Research Participation Program administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the U.S. Department of Energy and the U.S. Department of Agriculture Forest Service. ORISE is managed by Oak Ridge Associated Universities (ORAU) under DOE contract number DE-AC05-06OR23100. All opinions expressed in this report are the authors' and do not necessarily reflect the policies and views of USDA, DOE, or ORAU/ORISE.

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3 BACKGROUND

CORRIM has derived LCI data for major wood products and wood production regions in the United States. The LCI data cover forest regeneration through to the final product at the mill gate. Research has covered nine major forest products including both structural and nonstructural uses and four major regions: this report focuses on industry-average LVL production in the PNW region of the United States. LCI data are then used to estimate life-cycle impact assessments (LCIA). This study updates the cradle-to-gate manufacturing LCIA data for LVL in the PNW (Wilson and Dancer 2004). Treatment of biogenic carbon was taken from the Norwegian Solid Wood Product product category rules (PCR) (Aasestad 2008) and the PCR for North American Structural and Architectural Wood Products (FPInnovations 2015) to ensure comparability and consistency. Using the LCIA outcomes, APA – The Engineered Wood Association and its members can explore potential process and parameter improvements and new conversion technologies along with the identification of environmental hotspots internally. Intended audiences include LCA practitioners along with building specifiers looking for green building products with documentation. The LCA is in conformance with the PCR for North American Structural and Architectural Wood Products (FPInnovations 2015) and ISO 14040 and14044 standards (ISO 2006a, 2006b). This report follows data and reporting requirements as outlined in the PCR and contains the LCA components for producing a North American environmental product declaration (EPD) (ISO 2006c).

4 INTRODUCTION

Documenting the environmental performance of building products is becoming widespread because of many green marketing claims made without scientific merit (i.e. green washing). Developing EPDs for building products is one way to accomplish this objective for scientific documentation and to counter green washing (ISO 2006c; Bergman and Taylor 2011). In addition, developing wood product LCI data helps construct product LCAs that are then incorporated into developing whole-building LCAs in environmental footprint software such as the Athena Impact Estimator for Buildings (ASMI 2016). Conducting whole-building LCAs provides for points that go toward green building certification in rating systems such as LEED v4, Green Globes, and the ICC-700 National Green Building Standard (Ritter et al 2011).

4.1 Life-Cycle Assessment

LCA is an internationally accepted method to analyze complex environmental impacts of a product or process. It is intended to be an objective and holistic examination of a product that identifies and quantifies energy and materials used and emissions and wastes released to the environment. It also assesses the impact of that energy and material use and emissions to the environment. LCA studies can evaluate full product life cycles, often referred to as cradle-to-grave, or incorporate only a portion of the product's life cycle, referred to as cradle-to-gate or gate-to-gate. This study is a cradle-to-gate LCA and includes forestry operations, dry veneer production, and the manufacture of LVL that is ready to be shipped at the mill gate.

As defined by ISO (2006a), LCA is a multiphase process consisting of (1) goal and scope definition, (2) LCI, (3) LCIA, and (4) interpretation (Figure 1). These steps are interconnected, and their outcomes are based on goals and purposes of a particular study.

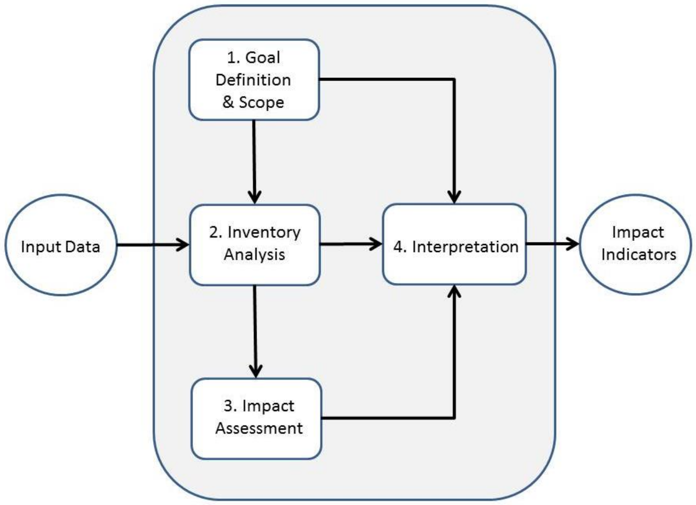

Figure 1. Steps involved in a life-cycle assessment (ISO 2006a).

The key component for conducting an LCA is the LCI step, which is the process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases occurring within the system boundaries.

The LCIA process uses models to characterize and assess the effects of environmental releases identified in the LCI in impact categories, such as global warming, acidification, carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog. For assessing the environmental impacts of LVL production, the TRACI 2.0 impact method was used. TRACI is a midpoint-oriented LCIA method developed by the U.S. Environmental Protection Agency specifically for North America using input parameters consistent with U.S. locations (Bare 2011). TRACI is available through the LCA software used for modeling the LVL process (PRé Consultants 2016).

Life-cycle interpretation is the phase in which the findings of the LCI and/or the LCIA are evaluated in relation to the goal of the study to reach conclusions and recommendations. This final step in an LCA involves investigation of significant environmental aspects (e.g. energy use and greenhouse gases), their contributions to the indicators under consideration, and determination of which unit processes in the system they come from. For example, if the outcome of an LCIA indicates a particularly high value for GWP, the analyst could refer to the inventory to determine which environmental flows are contributing to the high value and from which unit processes those outputs are coming.

4.2 Description of the Product

Many engineered structural wood products have been developed in the last several decades, including LVL in the early 1970s (Figure 2). LVL falls into the North American Industry Classification System (NAICS) Code 321215—engineered wood member (except truss) manufacturing, which includes other structural wood engineered products such as finger joint lumber, I-joists, parallel strand lumber, and glued laminated timbers (USCB 2012; ASTM 2014). LVL comprises many dry wood veneers glued together with their grain orientation in the same direction (Wilson and Dancer 2005; USEPA 2002; Stark et al 2010). It is designed to be used in the same manner as solid wood products such as sawn lumber. The veneers are made from rotary peeling of veneer logs. It can be used in conjunction with softwood plywood or oriented strandboard (OSB) to make composite I-joists but can also be used as a standalone for headers, beams, and joists (Wilson and Dancer 2004, Puettmann et al 2013). Any wood species can be used for LVL production provided its mechanical and physical properties are suitable and it can be properly glued. LVL in the PNW region is primarily made with Douglas-fir (*Pseudotsuga menziesii*). Dry veneer made into LVL comes from logs of many softwood species representing a mix of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), and western larch (*Larix occidentalis*).

Figure 2. Laminated veneer lumber.

5 METHOD

5.1 Goal

The goal of this study was to update the cradle-to-gate LCIA of LVL manufacturing for the PNW region. The authors updated the gate-to-gate LVL manufacturing LCI data developed by Wilson and Dancer (2005) and linked it to available forest resource LCI data (Johnson et al 2005; Puettmann et al 2013) and dry veneer production LCI data (Kaestner 2015; Puettmann et al 2015) to construct the cradle-to-gate LVL plant output LCA. The LVL LCA data will be used to construct the cradle-to-gate LCA for I-joist production (Bergman and Alanya-Rosenbaum 2016a).

5.2 Scope

In accordance with international standards (ISO 2006a, 2006b; ILCD 2010), the scope of this LCA study covered the life-cycle stages of LVL from forest resource activities through veneer production to the final LVL product leaving the plant. Impacts from dry veneer production were included in the analysis using LCI data developed from updating softwood plywood for the PNW (Kaestner 2015; Puettmann et al 2015). This LCA provides a cradle-to-gate analysis of cumulative energy of manufacturing and transportation of raw materials to the veneer and LVL production facilities. Analyses included CPEC of LVL production and environmental impacts such as GWP.

5.2.1 Allocation rules

Selecting an allocation approach is an important part of an LCA study. In this study, all primary energy and environmental outputs were assigned to various coproducts by mass allocation. The decision was based on the fact that LVL as the final product contained more than 90% of the mass leaving the system and because specific gravity of both LVL and associated coproducts were similar. In this study, economic allocation was performed in addition to mass allocation, because PCRs suggest using economic allocation for a multioutput process when the difference in revenues is more than 10% (FPInnovations 2015). The results of analysis using economic allocation are provided in Appendix E.

5.2.2 Functional and declared unit

In accordance with the PCR (FPInnovations 2015), the declared unit for LVL was one cubic meter. A declared unit was used in instances in which the function and the reference scenario for the whole life cycle of a wood building product could not be stated (FPInnovations 2015). For conversion of units from the U.S. LVL industry measure, 1.0 ft^3 equals 0.02832 m^3 with an oven-dried moisture content of 6%. All input and output data were allocated to the declared unit of product based on the mass of products and coproducts in accordance with ISO 14044 (ISO 2006b). Because the analysis did not take the declared unit to the stage of being an installed building product, no service life was assigned.

5.2.3 System boundaries

The system boundary begins with regeneration in the forest and ends with LVL at the mill gate (Figure 3). The system boundary includes forest resources (site preparation and planting seedlings, forest management including fertilization and thinning, and final harvest), transportation of roundwood to the primary breakdown facility, dry veneer production, dry veneer transportation to the LVL facility if needed, and LVL production including packaging. LVL production was modeled as a single process representing all the steps necessary to make LVL. Three production steps 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 LVL and coproducts (i.e. sawdust) by mass or economic value depending if the mass or economic allocation approach was selected, respectively. A single unit (i.e. black box) approach was used to model the LVL process because little wood left the system except as the final product and because of the relative simplicity of the LVL manufacturing processes. This simply means all process inputs and outputs were grouped into one LVL process.

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

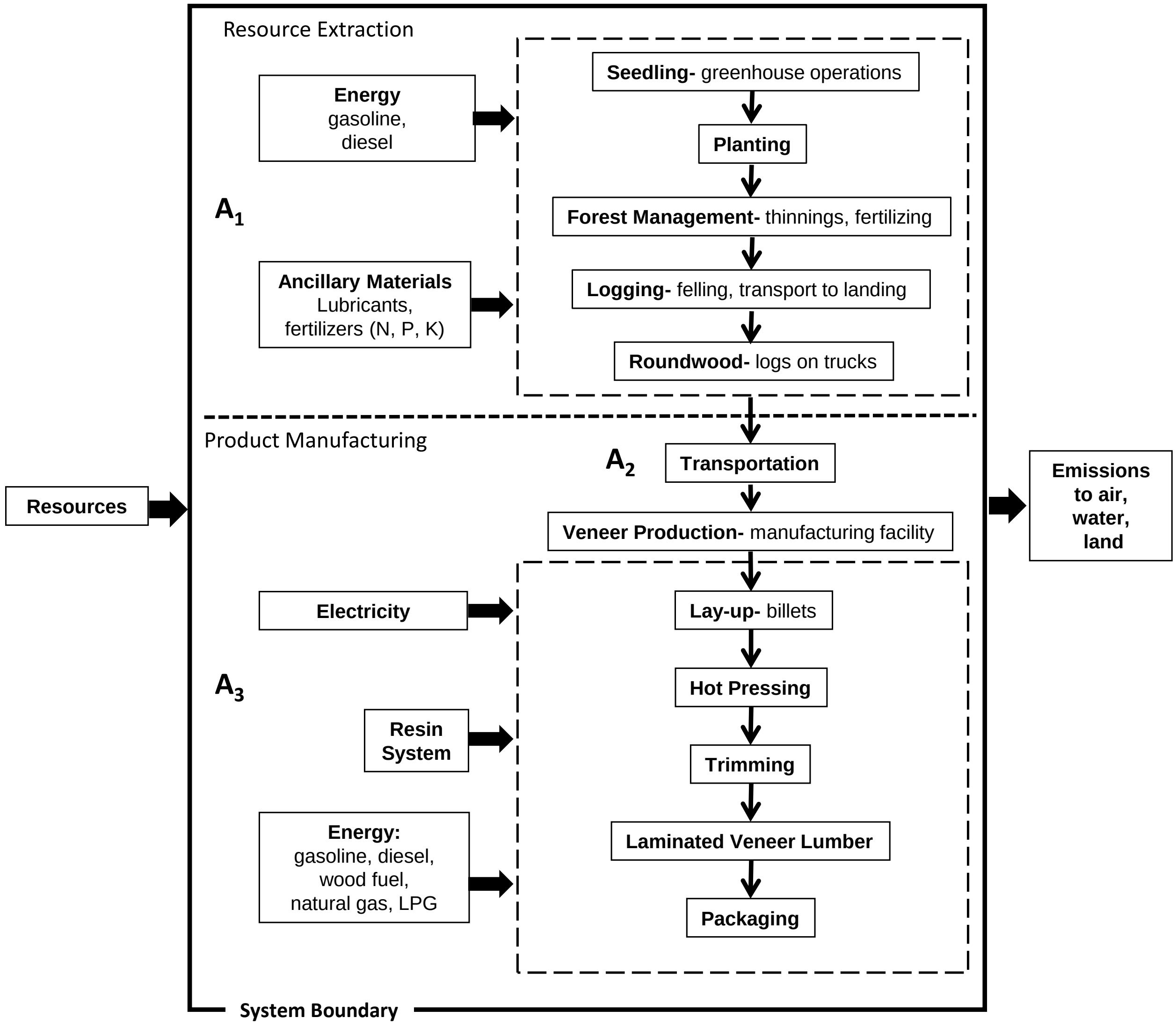

Figure 3. Cradle-to-gate system boundary and process flow for production of PNW LVL.

5.2.4 Cut-off rules

According to the PCRs, if the mass/energy of a flow is less 1% of the cumulative mass/energy of the model flow, it may be excluded, provided its environmental relevance is minor. This analysis included all energy and mass flows for primary data.

In the primary surveys, manufacturers were asked to report total hazardous air pollutants (HAPs) specific to their wood products manufacturing process, regardless of whether they were less than the 1% cutoff or not. These included formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde (propanal). If applicable to the wood product, HAPs are reported later in the LCI data section.

In the primary surveys, manufacturers were asked to report total HAPs specific to their wood products' manufacturing process. Under Title III of the Clean Air Act Amendments of 1990, the EPA has designated HAPs that wood products facilities are required to report as surrogates for all HAPs. These are methanol, acetaldehyde, formaldehyde, propionaldehyde (propanal), acrolein, and phenol. All HAPs are included in the LCI; no cut-off rules apply. If applicable to the wood product, HAPs are reported in Table 12 and included in the impact assessment. Table 12 shows all air emission greater than 10^{-4} to simplify and report on the dominant releases by mass. There were no cut offs used in the impact assessment. Therefore, a complete list of all air emissions (including less than 10^{-4}) is located in Appendix B of this report.

5.2.5 Data quality requirements

This study collected data from representative LVL manufacturers in the PNW that use average technology for their region. The dry veneer produced at the product manufacturing facilities in the PNW region is the raw wood input to LVL production.

Total U.S. LVL production for 2012 was 1.31 million m^3. Two U.S. LVL plants representing 8.5% of 2012 U.S. production (0.111 million m^3) participated in the study by providing primary data for the PNW region (APA 2014). The PNW is one of the primary regions for producing structural wood products such as LVL (Smith et al 2004). The surveyed plants provided detailed annual production data about their facilities, including on-site energy consumption, electrical usage, veneer volumes, and LVL production for 2012. Wilson and Dancer (2005) performed a 2000 U.S. LVL LCI study that covered 34% (0.187 million m^3) of production in the PNW. Production from surveyed facilities in 2012 decreased 40% compared with 2000. In addition, unlike the earlier 2000 study, 2012 LVL production data were not available by region. Therefore, LVL production data by region could not be quantified for 2012.

5.2.6 Critical review

An internal critical review of the survey procedures, data, analysis, and report will be completed to assess conformance with CORRIM and ISO 14040 standards by Dr. Maureen Puettmann, WoodLife Environmental Consultants, Corvallis, Oregon.

The review will provide assurances that the study methodology, data collection, and analyses were scientifically sound and in conformance with internationally accepted standards and CORRIM research protocol (ISO 2006b; ILCD 2010; CORRIM 2014, FPInnovations 2015).

5.2.7 Assumptions and limitations

All flow analyses of wood and bark in the process were determined on an oven-dry weight basis with a weighted-production density of 543 kg/m^3.

Although small in quantity relative to the wood mass, impacts from production of the resin system were included in the analysis.

5.2.8 Data collection

Primary data for the LCI were collected through surveys in accordance with CORRIM and ISO 14040 standards (Appendix F). This study relied almost exclusively on production and emissions data provided by LVL producers in the United States, with secondary data on electrical grid inputs, fuels, and forest resource processes obtained from the U.S. LCI database (Goemans 2010; NREL 2012). The survey data represent LVL production in terms of input materials, electricity and fuel use, and emissions for the 2012 production year. The two production facilities surveyed were selected to be representative of U.S. production practices.

5.2.9 Calculation rules

For U.S. production, LVL is commonly reported in cubic feet. The survey results were converted to a unit production basis, one cubic meter, and a weighted average of input data was calculated based on production. One cubic foot of LVL equals 0.02832 m^3 with an oven-dried moisture content of 6%. This approach resulted in an LVL complex that represents a composite of the North American mills surveyed but may not represent any mill in particular. The U.S. LCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 8+ (Pré Consultants 2016) was used as the accounting program to track all of the materials. The primary data obtained from the surveys were weight-averaged using the formula shown below (Milota 2004):

$$\bar{P}_{weighted} = \frac{\sum_{i=1}^{n} P_i x_i}{\sum_{i=1}^{n} x_i}$$

Where $\bar{P}_{weighted}$ is the weighted average of the values reported by n mills, P_i is the reported mill value, and x_i is the fraction of the mill's value to total production of the surveyed mills for that specific value. Because the surveyed mill data varied between facilities, a statistical analysis was conducted. In this study, the weighted coefficient of variation (CoV_w) was calculated (NIST ITL 1996). The weighted coefficient of variation (CoV_w) is the weighted standard deviation (sd_w) divided by the weighted mean ($\bar{P}_{weighted}$):

$$sd_w = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x}_w)^2}{\frac{(N' - 1)\sum_{i=1}^{N} w_i}{N'}}}$$

$$CoV_W = \frac{sd_w}{\bar{P}_{weighted}}$$

Where w_i is the weight of the i^{th} observation, N is the number of nonzero weights, and $\bar{x}_w$ is the weighted mean of the observations.

Missing data were defined as data not reported in surveys by the LVL facilities. When missing data occurred for survey items, they were checked with plant personnel to determine if it was an unknown value or zero. Missing data were carefully noted to make sure they were not averaged as zeros. Any outliers were resolved by contacting mill personnel.

5.2.10 Life-cycle impact assessment method

The LCIA was performed using the TRACI 2 method (Bare 2011). TRACI is a midpoint-oriented method developed by the U.S. Environmental Protection Agency specifically for the five impact categories that were examined, which include global warming (GW (kg CO_2-eq)), acidification (kg SO_2-eq), eutrophication (kg N-eq), ozone depletion (kg chlorofluorocarbons-11-eq), and photochemical smog (kg NOx-eq).

The LCIA phase establishes links between the LCI results and potential environmental impacts. The LCIA calculates impact indicators, such as GWP and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, impact category, and means of characterizing the impacts are summarized in Table 1. Environmental impacts are determined using the TRACI method (Bare 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (FPInnovations 2015).

Table 1. Selected impact indicators, characterization models, and impact categories.

Impact indicator	Characterization model	Impact category
Greenhouse gas (GHG) emissions	Calculate total emissions in the reference unit of CO_2 equivalents for CO_2, methane, and nitrous oxide.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the stratosphere including CFCs HCFCs, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total hydrogen ion (SO_2) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of SO_2 mole- eq. is used as a reference unit.	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photochemically oxidized. Smog forming potential of O_3 is used as a reference unit.	Photochemical smog
Releases to air potentially resulting in eutrophication of water bodies	Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit.	Eutrophication

Each impact indicator is a measure of an aspect of a potential impact. This LCIA does not make value judgments about the impact indicators, meaning that no single indicator is given more or less value than any of the others. Additionally, each impact indicator value is stated in units that are not comparable with others. For the same reasons, indicators should not be combined or added.

6 DETAILED DESCRIPTION OF DATA AND PROCESSES

6.1 Forestry Operations

Logs used in the production of LVL in the PNW include in their life-cycle the upstream activities associated with establishment, growth, and harvest of trees. This group of activities is collectively referred to as forest resource management. Forest operations modeled as inputs to dry veneer and LVL production were based on forest resource LCI data inputs from the PNW softwood forests (Johnson et al 2005; Puettmann et al 2013). Forestry operations vary regionally (Johnson et al 2005) but typically include some combination of growing seedlings, regeneration, site preparation, planting (where applicable), thinning, fertilization (where applicable), and final harvest. Harvesting included felling, skidding, processing, and loading for both commercial thinning and final harvest operations. For PNW forests, reforestation occurs primarily by planting, which requires input from human-related activities (i.e., the technosphere) for seedlings, site preparation, planting, and precommercial thinning (Table 2). Weighted-average allocation to different processes takes into account inherent differences in site productivity and energy usage by different kinds of logging equipment. Inputs to the forest resources management LCI include seed, electricity used during greenhouse operations, fertilizer used during seedling production and stand growth, fuel and lubricants needed to power and maintain equipment for thinning, and harvest operations. The primary output product is a log destined for softwood veneer. The coproduct, nonmerchantable (logging) slash, is generally left at a landing. Slash disposal was not modeled as it was assumed to decay in situ.

Table 2. Inputs to the regeneration phase and midrotation fertilization per hectare of PNW forest (Puettmann et al 2013).

Inputs	**Unit**	**Low intensity**	**Medium intensity**	**High intensity**	**Weighted average**
		Reforesting 1 ha			
Diesel and gasoline	L	12	12	12	12
Seedlings, at greenhouse	p[a]	988	1,482	1,482	1,275
Nitrogen in fertilizer					
In seedlings	kg	0.04	0.06	0.06	0.05
On site	kg	-	-	396.78	47.61
Phosphorous in fertilizer					
In seedlings	kg	0.07	0.11	0.11	0.09
On site	kg	-	-	67.25	8.07
Potassium in fertilizer					
In seedlings	kg	0.17	0.26	0.26	0.22
On site	kg	-	-	-	-

[a] p = individual seedling.

In the PNW region, most harvested volume comes from forest operations on private lands where investment in timber is the precursor to harvest. For all nonfederal land managers in the PNW region, reforestation is a statutory requirement as harvests are administered under state forest practices acts. Harvested lands are reforested for the next crop cycle with the sequence of treatments from planting to harvest averaging 45 years (Johnson et al 2005; Puettmann et al 2013). Forestry operations and their associated impacts are not stationary and will change based on both past and prospective technologies, evolving forest management procedures, and market demands. Given that the nature of productivity gains is not confirmed or well developed, this assessment was based on data representing the current state of the art in forest operations: it does not discount future operations or estimate potential productivity gains from future technologies. Outputs representing quantities of product, measures of consumed resources, and the emissions associated with those consumed resources were developed as a weighted average across the hectares managed for timber production. These quantities of product are used as inputs to the LVL manufacturing LCI, and the consumed resources and emissions are tracked for inclusion in the cradle-to-gate LCI.

6.2 Product Manufacturing

6.2.1 Resource transport

Wood raw materials were delivered to the LVL plants by truck and rail. The wood raw material consisted primarily of dry veneer purchased off site or produced on site. However, transportation for dry veneer was only required for LVL plants purchasing dry veneer not for LVL plants producing their own dry veneer. The final dry veneer transportation data modeled was production-weighted between purchased and produced dry veneer.

6.2.2 Veneer manufacturing

Dry softwood veneer plies must be made before LVL can be produced. Veneers can be made during softwood plywood production or as a precursor to LVL at the same production facility. This study uses veneer data provided by Puettmann et al (2015) on softwood plywood production. Dry veneer ranges in moisture content from 3% to 6% (oven-dry basis). The dry veneer made into LVL comes from logs of many softwood species representing a mix of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies* *concolor*), western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), and western larch (*Larix occidentalis*).

6.2.3 Phenol-formaldehyde resin

The LCI for the production of PF resin covers its cycle from in-ground resources to the production and delivery of input chemicals and fuels to the manufacturing of a resin as shipped to the customer (Wilson 2010). The PF resin survey data were from 13 plants in the United States that represented 62% of total production for the year 2005 (Wilson 2009). The inputs to produce 1.0 kg of neat PF resin consist of the two primary chemicals: 0.244 kg of phenol and 0.209 kg of methanol, a lesser amount of sodium hydroxide (0.061 kg), and 0.349 kg of water. Electricity is used for running fans and pumps and for operating emission control equipment. Natural gas is used for boiler fuel and emission control equipment, and propane fuel is used in forklifts.

6.2.3.1 Energy generation

Energy for the manufacturing of LVL comes from electricity, natural gas, diesel, and liquid petroleum gas (LPG). Electricity is used to operate the lay-up and hot-pressing equipment, as well as pneumatic and mechanical conveying equipment, fans, and other equipment in the plant. Natural gas is used for generating heat for the presses. Diesel is used for the equipment that transports materials outside of the plant, and LPG is used in forklift trucks, which are operated inside the plant. Other types of fuels, including wood, are used to generate energy in the plywood plants to produce dry veneer. These energy sources are not analyzed in this report, but the burdens that are created are carried over into the LVL final product. Puettmann (2015) gives information on the energy consumption for producing dry veneer.

6.2.4 LVL manufacturing

6.2.4.1 Lay-up

The lay-up lines are used to arrange pieces of the proper grades of dry veneer into the assembly process, apply resin to the veneer, and assemble the veneers into a mat before pressing (Baldwin 1995; Wilson and Dancer 2005). At the start of the line, a veneer feeder assembly places pieces of veneer into the lay-up sequence according to the type of LVL produced. Even though LVL can vary in thickness and width, it is most commonly produced in the dimensions of 4.45-cm (1-3/4-in) thick, 121.9-cm (4-ft) wide, and 2.44- to 18.29-m (8- to 60-ft) long. After pieces of veneer are arranged onto the lay-up conveyor, resin is applied to each piece of veneer, except for the top veneer layer in the LVL billet. After resin has been applied, the LVL mat is assembled layer by layer. Inputs include dry veneer and resins, and outputs include LVL billet, lay-up scrap, and small amounts of volatile organic compounds (VOCs) and HAPs. Although a small amount of fugitive VOCs and HAPs are emitted, they are accounted for within the hot-pressing unit process.

6.2.4.2 Hot-pressing

From the lay-up line, the uncured LVL billet is sent for hot-pressing. The heat and pressure applied during hydraulic pressing cures the resin thus binding the veneer layers together. Inputs include uncured LVL billets, outputs include cured LVL billets along with emissions of particulate matter (PM), $PM_{2.5}$, VOCs, and HAPs released from heating of the wood and curing of the resins. Cold-pressing can also occur at some production facilities when wider LVL billet beams are produced.

6.2.4.3 Trimming–sawing

After pressing, the LVL billet is sawn to the desired dimensions. The LVL can now be manufactured into flanges for I-joists. The wood residue generated during trimming–sawing is collected pneumatically into a wood waste collection system (i.e. baghouses). After sawing, a protective and cosmetic sealant is sometimes applied to the LVL. Inputs include LVL billets and sealant, and outputs include finished LVL, (used) tested LVL, and wood residues along with emissions of PM, $PM_{2.5}$, and PM_{10} from collecting wood residues and VOCs and HAPs from application and curing of sealant.

6.2.4.4 Packaging

Finished LVL is packaged for transport using wooden runners primarily by mass. Inputs include final product (LVL) and packaging material such as plastic wrapping, and outputs include packaged LVL. Packing materials represent about 1.0% of the cumulative mass of the model flow. The wooden spacers make up the bulk of this mass, representing 86.3% of the total packaging material (Table 3). The wrapping material, cardboard strap protectors, and plastic strapping make up 8.5%, 3.7%, and 1.5% of the packaging by mass, respectively.

Table 3. Materials used in packaging and shipping per cubic meter LVL (Puettmann et al 2013).

Material[a]	Value	Unit	Percentage
Wrapping material – HDPE[a]- and LDPE[b]-laminated paper, kg	0.4601	kg	8.5
PET strapping	0.0834	kg	1.5
Cardboard strap protectors	0.2002	kg	3.7
Wooden spacers	4.6721	kg	86.3
Total	5.4158	kg	100

[a]High-density polyethylene (HDPE)
[b]Low-density polyethylene (LDPE)
[c]Polyethylene terephthalate (PET)

6.3 Air Emissions

The main on-site emission sources were from burning natural gas for thermal energy and from hot presses. Natural gas boilers do not typically use emission control devices (ECDs). ECDs such as baghouses are the primary collectors of particulate matter. To decrease VOC emissions from dryers, mills use regenerative catalytic oxidizers (RCOs), which are sometimes referred to as regenerative thermal oxidizers (RTOs) and wet scrubbers. RCOs are designed to destroy VOCs and other emissions including PM and soot (USEPA 2003a).

7 INPUTS AND OUTPUTS

7.1 Material Transportation

The average haul distance for feedstock along with the components of the resin system are shown in Table 4. Based on CORRIM Phase I (Puettmann et al 2013), dry veneer distance for the PNW region decreased to 108 km by truck compared with 121 km for the earlier data, roughly a 11% decrease. Both surveyed PNW LVL plants purchased dry veneer to produce LVL although one plant produced most of its own veneer. The dry veneer transportation data modeled was production-weighted between purchased and dry veneer for a final value of 52 km.

Table 4. Weighted-average delivery distance (one way) by mode for materials to PNW LVL plant.

Material delivered to mill	Delivery distance (km)
Purchased dry veneer, by truck	108
Phenol-formaldehyde resin, by truck	79
Log with bark to veneer production, by truck	104

7.2 Wood Boiler

Table 5 lists the wood boiler process inputs and outputs for product manufacturing in the PNW and the SE. The wood boiler profile is a composite process developed in 2014 using data collected from U.S. softwood lumber and plywood industries (Puettmann and Milota 2015). No wood boiler fuel was consumed on site at the LVL plants. The wood boiler data was only included to provide information for potential scenario analysis and to show what upstream emissions occurred when wood fuel was burned.

Table 5. CORRIM wood boiler process for manufacturing LVL.[a]

Products	Unit	Value	Percentage
Wood combusted, at boiler, at mill, RNA[b]	kg	1.0000	98.13
Wood ash, at boiler, at mill, RNA	kg	0.0191	1.87
Resources			
Water, process, surface	kg	0.31	
Water, process, well	kg	0.24	
Water, municipal, process, surface	kg	0.79	
Water, municipal, process, well	kg	0.24	
Materials–fuels			
Wood fuel	kg	1.0000	
Transport, combination truck, diesel powered/U.S., Athena	tkm	1.38E-03	
Diesel, combusted in industrial equipment/U.S.	l	8.05E-04	
Gasoline, combusted in equipment/U.S.	l	3.96E-05	
Liquefied petroleum gas, combusted in industrial boiler/U.S.	l	1.21E-05	
Lubricants	l	1.91E-05	
Engine oil	l	2.22E-05	
Hydraulic oil	l	0.00E+00	
Antifreeze	l	4.81E-07	
Ethylene glycol, at plant/RNA	kg	1.07E-06	
Solvents	kg	7.17E-07	
Water treatment	kg	1.23E-04	
Boiler streamline treatment	kg	3.67E-06	
Urea, as N, at regional storehouse/RER[c] U AWC[d]	kg	3.15E-03	
Disposal, ash, to unspecified landfill/RNA	kg	7.59E-03	
Disposal, solid waste, unspecified, to unspecified landfill/RNA	kg	7.26E-06	
Disposal, metal, to recycling/RNA	kg	3.96E-08	
Electricity–heat			
Electrical grid, SERC[e]	kWh	8.20E-02	
Natural gas, combusted in industrial boiler/U.S.	m^3	1.38E-03	
Emissions to air			
Acetaldehyde	kg	1.05E-06	
Acrolein	kg	8.07E-07	
Benzene	kg	1.69E-07	
Carbon monoxide, biogenic	kg	3.23E-03	
Carbon dioxide, biogenic	kg	1.76E+00	
Wood (dust)	kg	5.62E-04	
Formaldehyde	kg	1.26E-05	
Emissions to air	**Unit**	**Value**	
HAPs, unspecified	kg	6.27E-06	
Hydrogen chloride	kg	1.17E-06	
Lead	kg	1.75E-07	
Mercury	kg	1.83E-09	
Methane, biogenic	kg	2.23E-05	

Methanol	kg	7.95E-06	
Nitrogen oxides	kg	1.10E-03	
Particulates, <10 um	kg	4.71E-04	
Particulates, <2.5 um	kg	1.39E-04	
Phenol	kg	6.21E-07	
Propanal	kg	5.14E-08	
Sulfur dioxide	kg	7.71E-05	
VOCs	kg	8.76E-04	
Dinitrogen monoxide	kg	2.93E-06	
Naphthalene	kg	5.77E-08	
Other organic	kg	2.11E-07	
Emissions to water			
Suspended solids, unspecified	kg	8.35E-07	
Biological oxygen demand (BOD_5)	kg	2.10E-06	

[a]Boiler data from Puettmann and Milota (2015)
[b]RNA = North America
[c]RER = Europe, U = Unit
[d]AWC = American Wood Council
[e]SERC stands for Southeastern Electric Reliability Council, and

7.3 Energy sources

Energy sources consumed on site were derived from on-site and off-site sources. On-site sources, process (thermal) energy used at the plant was provided by burning natural gas. Thermal energy was commonly produced in the form of steam and then used in the hot-pressing unit process. Outputs from generating thermal energy included steam from the boilers and combustion gases like fossil CO_2. The main off-site source was (grid) electricity, which released its emissions off site. Table 6 shows the electrical grid composition for LVL production in the PNW region. Natural gas (31.8%) and coal (30.2%) power comprises most of the PNW (Western Electricity Coordinating Council (WECC)) grid. Outputs included electricity and emissions primarily of fossil CO_2.

Table 6. Percentage of energy source for electricity to produce PNW LVL (NREL 2012).

Energy source	Amount of energy used for electricity (%)[a]
Natural gas	31.8
Coal	30.2
Oil	0.3
Nuclear	9.4
Hydro	22.2
Wind	2.4
Biomass	1.0
Geothermal	1.9
Miscellaneous	0.8
Total	100.0

[a] WECC - Representative of year 2008 mix of fuels used for utility electricity generation in the western United States and Canada. It is comprised of Washington, Idaho, Montana, Portland, British Columbia, Alberta, California, Utah, Nevada, Arizona, New Mexico, Colorado, Wyoming, and parts of Nebraska, Texas, and Mexico.

7.4 Gate-to-Gate LVL Production

Table 7 shows a detailed description of the material and energy inputs and outputs crossing the system boundary of LVL. Under materials, wood feedstocks include purchased and produced dry veneer. Electricity consumed on site for PNW was estimated to be 77.4 kWh/m^3. Natural gas was the primary fossil fuel used on site. Air emissions were derived from the surveyed mills along with pertinent emissions data categorized by the U.S. Environmental Protection Agency (USEPA 2002, 2003a, 2003b, 2003c). When available, surveyed air emission data as primary data were selected rather than secondary data. Boiler emissions are tracked separately and are not included in Table 7.

Table 7. Unit process inputs–outputs to produce one cubic meter of PNW LVL.

Products	**Unit/m^3**	**Value**	**Allocation[a]**
LVL	m^3	1.000E+00	89.31%
Sawdust, sold	kg	5.27E+01	8.68%
Panel trim, sold	kg	3.41E+00	0.56%
Lay-up scrap	kg	2.94E+00	0.48%
Tested LVL, used	kg	5.88E+00	0.97%
Resources	**Unit/m^3**	**Value**	
Water, well, in ground	L	1.74E+00	
Materials–fuels	**Unit/m^3**	**Value**	
Wood feedstock, purchased dry veneer, oven-dried	kg	5.85E+02	
PF resin	kg	1.78E+01	
Sodium hydroxide	kg	3.192E+00	
Materials–fuels	**Unit/m^3**	**Value**	
Catalyst	kg	2.453E-01	
Melamine	kg	1.567E+00	
Electricity, at grid	kWh	7.744E+01	
Diesel, combusted in industrial equipment	L	3.509E-01	
Propane, combusted in industrial equipment	L	4.771E-01	
Natural gas, combusted in industrial boiler, direct-fired	m^3	1.28E+01	
Wood fuel, combusted in boiler, self-generated	kg	0.000E+00	
Transport, combination truck, diesel power, wood feedstock	tkm	3.239E+01	6% MC
Transport, combination truck, diesel powered, PF resin	tkm	2.235E+00	60% MC
Transport, combination truck, diesel powered, landfill waste	tkm	1.000E+00	As is
Hydraulic fluid	kg	1.384E-02	
Greases	kg	1.715E-03	
Motor oil	kg	3.398E-02	
Waxes (sealant)	L	3.022E-01	
Paint	L	2.860E-03	
Wrapping material - packaging	kg	4.601E-01	
Strap Protectors - packaging	kg	8.340E-02	
Strapping - packaging	kg	2.002E-01	
Spacers - packaging	kg	4.672E+00	
Emissions to air	**Unit/m^3**	**Value**	
Acetaldehyde	kg	2.846E-03	
Carbon monoxide	kg	1.023E-02	
Formaldehyde	kg	4.487E-03	
Hexane	kg	2.232E-04	
Lead	kg	6.510E-08	
Methanol	kg	1.178E-01	

Nitrogen oxides	kg	1.302E-02	
PM2.5	kg	5.022E-02	
PM10	kg	1.004E-01	
Particulates, unspecified	kg	1.181E-01	
Phenol	kg	4.422E-05	
Propionaldehyde	kg	3.838E-03	
VOCs	kg	4.641E-01	
Waste to treatment	**Unit/m^3**	**Value**	
Waste to inert landfill	kg	8.639E-01	
Waste to recycling	kg	3.954E-01	

[a] Mass allocation approach.

7.5 Material Flows

To evaluate data quality, a weighted-average mass balance of the PNW LVL plants was performed (Table 8). In performing the mass balance for LVL, all unit processes located within the site system boundary were considered. Veneer usage was 585 OD kg for PNW mills, and 23 OD kg of binding agents from the resin system produced 1.0 m^3 (543 OD kg on average) of LVL along with some coproducts (65 OD kg). PF resin made up most of the resin system. Based on the low and similar values calculated for production-weighted coefficient of variation (CoVw) for the final product, LVL shows good consistency between production facilities at 2.9% for the PNW. In addition, the CoVw for total feedstock is 4.1% for the PNW.

Table 8. Mass balance of PNW LVL manufacturing per cubic meter.

	Pacific Northwest		
	Inputs		
	(OD kg)	**Mass (%)**	**CoVw[a] (%)**
Feedstocks			
Purchased veneer	585	96.3	4.1
Total	585	96.3	4.1
Resin system			
PF resin	17.8	2.9	8.3
Sodium hydroxide	3.2	0.5	
Catalyst	0.2	0.0	
Melamine	1.6	0.3	
Total	23	3.7	13.7
Total inputs	608	100	
	Outputs		
	(OD kg)	**Mass (%)**	**CoVw[a] (%)**
Products			
LVL	543	89.3	2.9
Coproducts			
Sawdust, sold	53	8.7	15
Panel trim, sold	3.4	0.5	126
Lay-up scrap	2.9	0.5	–
Tested LVL, used	5.9	1.0	–
Total	65	10.7	46
Total outputs	608	100	

[a] Production weight-averaged coefficient of variation.

7.6 On-Site Energy Inputs

Weighted-average energy inputs consumed at the LVL manufacturing site were developed from survey data (Table 9). Electricity and natural gas were the primary energy inputs at 77.4 kWh and 14.5 m^3 for the PNW per m^3 of LVL. The production-weighted coefficient of variation showed large variation for electricity consumption for the PNW at 61%.

Table 9. Weighted-average on-site energy inputs for PNW LVL manufacturing

	Pacific Northwest		
	Quantity	**Unit**	**CoVw (%)[a]**
Energy inputs			
Electricity	77.4	kWh	61%
Natural gas	12.8	m^3	11%
Diesel	0.35	L	37%
Propane	0.48	L	52%
Gasoline	0	L	

[a] Production-weighted coefficient of variation.

8 LIFE-CYCLE INVENTORY DATA

Cradle-to-gate LCI results for LVL are presented in three life stages, (1) forestry operations, (2) veneer production, and (3) LVL production. The majority of raw material energy consumption occurs during veneer production, followed by LVL production with only a very small portion arising from forestry operations (Table 10). Wood fuel was burned primarily on site at the veneer production facility to generate thermal energy for log conditioning and drying and pressing veneers (Wilson and Dancer 2005; Bergman and Bowe 2011; Puettmann et al 2015). Coal for veneer and LVL at 25.9 and 14.5 kg/m^3 was used primarily to generate electricity. Natural gas was consumed primarily for thermal energy for hot-pressing the LVL billets for setting and curing the resin. For dry veneer production, wood fuel was consumed at a rate of 225 kg/m^3.

Table 10. Raw material primary energy consumption per one cubic meter of cradle-to-gate LVL, PNW, mass allocation.

Fuel	**Unit**	**Total**	**Forestry operations**	**Dry veneer production**	**LVL production**
Wood fuel	OD kg	2.25E+02	0.00E+00	2.24E+02	1.19E+00
Gas, natural, in ground	kg	3.50E+01	1.71E-01	1.32E+01	2.16E+01
Coal, in ground	kg	4.06E+01	1.89E-01	2.59E+01	1.45E+01
Uranium oxide, in ore	kg	8.34E-04	4.44E-06	5.44E-04	2.86E-04
Oil, crude, in ground	kg	1.73E+01	3.23E+00	7.54E+00	6.50E+00

Table 11 shows CPEC for cradle-to-gate production of PNW LVL. Veneer life-cycle stage consumed the most primary energy at 6,750 MJ/m^3 (75.3%). Most of the primary energy was derived from wood fuel at 4.71 GJ/m^3 and natural gas at 1.89 GJ/m^3 with cumulative energy consumption for all three life-cycle stages at 8.97 GJ/m^3. Coal consumption was third at 1.06 GJ/m^3 (11.9%) and came from generating electricity. Adding other renewable energy sources of hydro and wind to wood fuel makes a total of

54.7% of cumulative energy consumption. This study allocates primary energy to LVL and coproducts on mass. Primary energy is energy embodied in the original resources such as crude oil and coal before conversion.

Table 11. Cumulative primary energy consumption per one cubic meter of cradle-to-gate LVL, PNW, mass allocation.

Fuel	Percentage	Total	Forestry operations	Veneer production	LVL production
		MJ/m^3			
Wood fuel	52.5	4.71E+03	0.00E+00	4.68E+03	2.50E+01
Gas, natural, in ground	21.1	1.89E+03	9.31E+00	7.10E+02	1.17E+03
Coal, in ground	11.9	1.06E+03	4.95E+00	6.77E+02	3.81E+02
Oil, crude, in ground	8.8	7.86E+02	1.47E+02	3.43E+02	2.96E+02
Uranium oxide, in ore	3.5	3.18E+02	1.69E+00	2.07E+02	1.09E+02
Hydro	1.8	1.63E+02	3.65E-03	1.07E+02	5.61E+01
Wind	0.2	1.84E+01	0.00E+00	1.21E+01	6.29E+00
Solar	0.0	8.87E-01	0.00E+00	5.84E-01	3.03E-01
Geothermal	0.2	1.41E+01	0.00E+00	9.28E+00	4.81E+00
Total	100.0	8.97E+03	1.63E+02	6.750E+03	2.05E+03
Total, by percent		100%	1.8%	75.3%	22.9%

Wood products typically consume more energy during the manufacturing stage than at any other stage (Puettmann and Wilson 2005; Winistorfer et al 2005; Puettmann et al 2010). One issue found conducting the cradle-to-gate LCA of LVL was the greater cradle-to-gate CPEC in this PNW LVL study. In this study, CPEC of LVL production for the United States was higher than the CPEC from earlier CORRIM studies (Puettmann and Wilson 2005; Wilson and Dancer 2005) as well as from a more recent Canadian LVL LCA (ASMI 2013). To compare with an earlier CORRIM study on making one cubic meter of LVL in the PNW, cumulative allocated energy consumption was 6.64 GJ/m^3 with biomass energy of 46.1% (Puettmann and Wilson 2005; Wilson and Dancer 2005; Puettmann et al 2013). As in this study, Wilson and Dancer (2005) used mass allocation. A similar study in Canada reported cumulative energy consumption for LVL of 4.11 GJ/m^3 with biomass energy of 15.8% (ASMI 2013). For the Canadian LVL LCA, veneer production was embedded into LVL production as a whole. Therefore, there was no discernable way to determine which process, veneer or LVL production, consumed the woody biomass. Additionally, GW impact of 147 kg CO_2-eq/m^3 was estimated (ASMI 2013). Electricity consumed for the Canadian production of LVL was dominated by hydropower. Biomass energy for this study at 52.5% is more consistent with CORRIM Phase I than the later Canadian LCL study.

Two scenario analyses conducted indicated that LVL production itself was a minor contributor to the overall process because veneer production largely outweighed LVL production in terms of energy inputs. As for energy inputs for LVL production itself, one possible explanation is the greater use of ECDs other than baghouses becoming more prevalent because of increased regulatory controls in the United States since the 2000s, which was when Phase I survey data were collected. Kaestner (2015) explored the changes in emission regulations for boilers and heaters (USEPA 2014) and showed that tightened emission regulations paralleled higher consumption of energy sources such as electricity and natural gas. In addition, tightened emission regulation affected the upstream processes such as veneer drying, which had ECDs like RCOs attached to decrease drying emissions.

Air emission data were collected from surveyed mill data that was augmented by secondary resources (Baldwin 1995; USEPA 2002). As mentioned previously, baghouses are the primary collectors of particulate matter with all four surveyed plants using that ECD. LVL manufacturers reported on-site air emissions (Table 7) including particulate $PM_{2.5}$ (<10 µm) and particulate PM_{10} (<10 µm) that are emitted during pressing, sawing, and trimming. Other air emissions include VOCs from pressing. Table 12 lists emissions greater than 10^{-4} and HAPs generated from LVL production along with the ones reported by the mills themselves. Fossil and biogenic CO_2 released in the production of one cubic meter of LVL were 199 and 397 kg, respectively. A complete list of all air emissions for the cradle-to-gate production of LVL can be found in Appendix C.

Table 12. Air emissions released per one cubic meter of LVL, cradle-to-gate, PNW, mass allocation.[a]

Air emissions	Total	Forestry operations	Veneer production	LVL production
	kg/m³			
Acetone	1.06E-02	0.00E+00	1.06E-02	0.00E+00
Acrolein	1.75E-03	5.21E-06	1.73E-03	1.35E-05
Aldehydes, unspecified	6.94E-04	1.31E-04	3.17E-04	2.45E-04
Ammonia	3.12E-03	8.74E-05	2.86E-03	1.70E-04
Benzene	1.97E-02	5.25E-05	1.25E-02	7.13E-03
BTEX[b]	1.19E-02	5.98E-05	4.57E-03	7.29E-03
Carbon dioxide	2.10E+00	2.81E-02	7.37E-02	2.00E+00
Carbon dioxide, biogenic	3.97E+02	8.16E-03	3.95E+02	2.51E+00
Carbon dioxide, fossil	1.97E+02	1.03E+01	1.07E+02	7.96E+01
Carbon monoxide	2.54E-02	3.86E-06	9.73E-03	1.57E-02
Carbon monoxide, biogenic	1.01E+00	0.00E+00	1.01E+00	3.29E-03
Carbon monoxide, fossil	4.03E-01	9.46E-02	1.86E-01	1.22E-01
Cumene	1.10E-02	1.35E-12	5.92E-04	1.04E-02
Dinitrogen monoxide	2.72E-03	1.75E-04	1.56E-03	9.88E-04
Formaldehyde	8.86E-03	6.67E-05	4.63E-03	4.17E-03
HAPs	1.13E-03	0.00E+00	1.13E-03	6.40E-06
Heat, waste	1.21E+01	0.00E+00	1.27E+00	1.09E+01
Hexane	1.99E-04	1.70E-11	4.24E-10	1.99E-04
Hydrocarbons, unspecified	6.77E-03	1.36E-06	1.67E-04	6.60E-03
Hydrogen chloride	2.10E-02	1.06E-04	1.37E-02	7.21E-03
Hydrogen fluoride	2.58E-03	1.24E-05	1.68E-03	8.93E-04
Isoprene	3.43E-02	2.05E-04	2.22E-02	1.18E-02
Magnesium	1.90E-04	9.11E-07	1.23E-04	6.58E-05
Methane	6.24E-01	1.42E-02	2.78E-01	3.32E-01
Methane, biogenic	4.02E-03	0.00E+00	4.00E-03	2.27E-05
Methane, fossil	7.09E-02	1.08E-03	2.81E-02	4.17E-02
Methanol	1.21E-01	0.00E+00	1.26E-02	1.09E-01
Nitrogen oxides	1.13E+00	1.87E-01	7.51E-01	1.94E-01
NMVOC[c]	5.44E-02	6.36E-03	1.81E-02	2.99E-02
Organic substances, unspecified	8.18E-04	5.14E-07	7.65E-04	5.32E-05
Particulates, <10 um	2.53E-01	0.00E+00	1.63E-01	9.02E-02
Particulates, <2.5 um	1.31E-01	0.00E+00	8.60E-02	4.51E-02
Particulates, >10 um	5.97E-04	0.00E+00	4.57E-04	1.39E-04
Particulates, >2.5 um, and <10 um	2.24E-02	5.74E-03	1.07E-02	5.96E-03
Particulates, unspecified	1.70E-01	1.04E-03	3.92E-02	1.29E-01

Phenol	3.36E-04	4.07E-12	2.61E-04	7.42E-05
Propanal	3.44E-03	9.67E-11	9.24E-06	3.43E-03
Propene	4.29E-03	1.45E-04	3.26E-04	3.82E-03
Radionuclides (including radon)	1.19E-03	6.31E-06	7.73E-04	4.07E-04
Sulfur dioxide	1.40E+00	6.82E-03	6.89E-01	7.09E-01
Sulfur monoxide	4.00E-02	1.04E-02	2.65E-02	3.07E-03
Sulfur oxides	1.98E-02	1.33E-04	1.10E-03	1.86E-02
VOC	6.64E-01	5.02E-03	2.21E-01	4.38E-01
Wood (dust)	1.19E-01	0.00E+00	1.18E-01	6.55E-04

[a] Due to large amount of air emissions, emissions greater than 10^{-4} and HAPs generated from LVL production are shown. A complete list of all air emissions can be found in Appendix B.
[b] BTEX (benzene, toluene, ethylbenzene, and xylene), unspecified ratio.
[c] Nonmethane VOCs, unspecified origin.

All waterborne emissions occurred off site (Table 13). LVL plants are zero-discharge facilities. A value of 9.89 kg/m^3 LVL unspecified suspended solids was estimated followed by chloride value of 7.67 kg/m^3. For unspecified suspended solids, most of the emissions came from natural gas extraction and crude oil production followed by sodium hydroxide production, which is used in resin production. Most of the chloride emissions were from the same sources, except the third source was uranium fuel storage instead of sodium hydroxide production.

Table 13. Emissions to water released per one cubic meter of LVL, cradle-to-gate, PNW, mass allocation.[a]

Water emissions	**Total**	**Forestry operations**	**Dry veneer production**	**LVL production**
	kg/m^3			
Aluminium	8.49E-03	1.05E-03	3.71E-03	3.73E-03
Ammonia	3.08E-03	2.28E-04	1.29E-03	1.57E-03
Ammonium, ion	2.17E-04	5.04E-08	2.12E-04	5.30E-06
Barium	1.16E-01	1.43E-02	4.96E-02	5.23E-02
Bentazone	5.77E-12	0.00E+00	0.00E+00	5.77E-12
Benzene	1.83E-02	2.05E-05	1.11E-03	1.72E-02
Benzoic acid	2.15E-04	1.24E-05	8.68E-05	1.16E-04
BOD5	2.08E-01	2.24E-03	2.46E-02	1.81E-01
Boron	6.66E-04	3.84E-05	2.68E-04	3.60E-04
Bromide	4.55E-02	2.62E-03	1.83E-02	2.46E-02
Calcium	6.82E-01	3.93E-02	2.75E-01	3.68E-01
Chloride	7.67E+00	4.42E-01	3.09E+00	4.14E+00
Chromium	1.78E-04	2.79E-05	6.77E-05	8.20E-05
COD[b]	2.39E-01	4.24E-03	3.55E-02	1.99E-01
Cumene	2.63E-02	0.00E+00	1.42E-03	2.49E-02
Detergent, oil	2.02E-04	1.03E-05	8.09E-05	1.11E-04
DOC[b]	4.86E-02	4.03E-13	2.62E-03	4.59E-02
Fluoride	9.66E-04	8.13E-04	1.00E-04	5.28E-05
Iron	2.03E-02	2.09E-03	8.72E-03	9.46E-03
Lithium	1.65E-01	8.38E-04	6.31E-02	1.01E-01
Magnesium	1.33E-01	7.69E-03	5.37E-02	7.20E-02
Manganese	5.17E-04	1.37E-05	2.83E-04	2.20E-04

Metallic ions, unspecified	2.52E-04	6.16E-12	6.68E-10	2.52E-04
Oils, unspecified	4.50E-03	2.82E-04	1.83E-03	2.38E-03
Phosphate	6.33E-04	6.11E-04	0.00E+00	2.17E-05
Propene	9.70E-03	0.00E+00	5.24E-04	9.18E-03
Radioactive species, nuclides, unspecified	1.37E+03	7.32E+00	8.96E+02	4.72E+02
Silver	4.45E-04	2.57E-05	1.79E-04	2.40E-04
Sodium	2.16E+00	1.25E-01	8.71E-01	1.17E+00
Solved solids	3.12E-04	0.00E+00	1.42E-05	2.98E-04
Strontium	1.16E-02	6.68E-04	4.66E-03	6.25E-03
Sulfate	3.48E-02	9.93E-04	1.88E-02	1.50E-02
Sulfur	5.63E-04	3.25E-05	2.27E-04	3.04E-04
Suspended solids, unspecified	9.89E+00	5.78E-01	3.93E+00	5.38E+00
TOC[b]	4.86E-02	0.00E+00	2.62E-03	4.59E-02
Toluene	3.37E-04	1.94E-05	1.36E-04	1.82E-04
Wastewater/m^3	6.87E-04	0.00E+00	0.00E+00	6.87E-04
Xylene	1.76E-04	1.04E-05	7.11E-05	9.48E-05
Zinc	2.13E-04	2.42E-05	9.40E-05	9.44E-05

[a]Due to large amount of water emissions, emissions greater than 10^{-4} and HAPs generated from LVL production are shown. A complete list of all water emissions can be found in Appendix B.
[b]COD, chemical oxygen demand, DOC, dissolved organic carbon; TOC, total organic carbon.

Solid emissions include ash generated at the wood boiler during veneer production and in the upstream processes, primarily fuels and resins, used in LVL production (Table 14). A total of 9.15 kg/m^3 solid waste was generated, of which 0.353 kg/m^3 was recycled (Table 15). Overall, 96% of the solid waste generated was landfilled.

Table 14. Waste to treatment per one cubic meter of LVL, cradle-to-gate, PNW, mass allocation.

Waste to treatment	**Total**	**Forestry operations**	**Veneer production**	**LVL production**
	kg/m^3			
Waste in inert landfill	8.79E+00	0.00E+00	8.02E+00	7.72E-01
Waste to recycling	3.53E-01	0.00E+00	0.00E+00	3.53E-01
Total waste	9.15E+00	0.00E+00	8.02E+00	1.13E+00

9 LIFE-CYCLE IMPACT ASSESSMENT

In addition, energy and material resource consumption values and the waste generated are also provided. Environmental performance results for GW, acidification, eutrophication, ozone depletion, smog, energy consumption from nonrenewables and renewables (wind, hydro, solar, geothermal, and nuclear fuels), renewable and nonrenewable resource consumption, and solid waste are shown in Table 15. Values in Table 15 are the cumulative impact of all upstream processes required for LVL production including those from forestry, production of veneer, plywood, resin, and packaging, and transportation energy required to move these materials to the LVL facility. For example, differences between LVL production data in Table 7 and data in Table 15 are a result of the resources and fuels used in the upstream processes, i.e. fresh water use. In addition, the contribution of major substances to the overall impact from eutrophication, acidification, smog, and global warming categories are provided in Appendix D. A corresponding LCA update for cradle-to-gate LVL in the southeastern United States showed a similar conclusion (Bergman and Alanya-Rosenbaum 2016b).

Table 15. Environmental performance of one cubic meter LVL, cradle-to-gate, PNW.

Impact category	Unit	Total	Forestry operations	Veneer production	LVL production
Global warming	kg CO_2e	2.18E+02	1.08E+01	1.16E+02	9.12E+01
Acidification	kg SO_2e	2.29E+00	1.49E-01	1.26E+00	8.75E-01
Eutrophication	kg Ne	7.70E-02	1.03E-02	3.78E-02	2.89E-02
Ozone depletion	kg CFC-11e	4.75E-07	4.87E-10	8.67E-09	4.66E-07
Smog	kg O_3e	3.12E+01	4.67E+00	1.98E+01	6.74E+00
Total primary energy consumption	**Unit**	8.97E+03	1.63E+02	6.75E+03	2.05E+03
Nonrenewable fossil	MJ	3.74E+03	1.61E+02	1.73E+03	1.85E+03
Nonrenewable nuclear	MJ	3.18E+02	1.69E+00	2.07E+02	1.09E+02
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	1.96E+02	3.65E-03	1.29E+02	6.75E+01
Renewable, biomass	MJ	4.71E+03	0.00E+00	4.68E+03	2.50E+01
Material resources consumption (nonfuel resources)	**Unit**	**Total**	**Forestry operations**	**Veneer production**	**LVL production**
Nonrenewable materials	kg	5.11E+00	0.00E+00	5.11E+00	5.47E-05
Renewable materials	kg	8.62E+02	0.00E+00	8.57E+02	4.87E+00
Fresh water	L	1.22E+03	1.03E+01	8.76E+02	3.36E+02
Waste generated	**Unit**	**Total**	**Forestry operations**	**Veneer production**	**LVL production**
Solid waste	kg	9.15E+00	0.00E+00	8.02E+00	1.13E+00

10 COMPARISON OF UPDATED LCI WITH A PREVIOUS STUDY

We compared the energy inputs from the current 2012 study to the earlier CORRIM Phase I study to show how the CPEC for PNW LVL was affected. As expected from the higher CPEC found earlier, the on-site energy inputs were substantially higher than for Phase I (Wilson and Dancer 2005; Puettmann et al 2013). In particular, electricity and natural gas consumption is driving the total impact from energy with changes of 30% and 279%, respectively (Table 16). Therefore, a sensitivity analysis investigating the energy inputs into LVL production was completed in Section 14 to determine their overall impact. However, the apparent statistical differences between the older and current studies could not be adequately addressed because no statistical description of the data from the earlier study was available. However, there was sufficient reason to attempt to quantify the energy impacts associated with LVL production.

Table 16. Production-weighted average PNW on-site energy inputs for manufacturing one cubic meter LVL.

	Pacific Northwest Phase I	Pacific Northwest 2012		
Source	**Quantity**	**Quantity**	**Unit**	**Change (%)**
Electricity	59.5	77.4	kWh	30
Natural gas	3.83	12.8	m^3	234
Diesel	0.169	0.351	L	108
Propane	0.250	0.477	L	91

11 TREATMENT OF BIOGENIC CARBON

Treatment of biogenic carbon is consistent with the Intergovernmental Panel for Climate Change (IPCC 2006) inventory reporting framework in that there is no assumption that biomass combustion is carbon neutral. Instead, net carbon emissions from biomass combustion are accounted for under the Land-Use Change and Forestry (LUCF) Sector and are therefore ignored in energy emissions reporting for product LCAs to prevent double counting. Standards such as ASTM D 7612 (2010), which are used in North America to define legal, responsible, and/or certified sources of wood materials, are in place to provide assurances regarding forest regeneration and sustainable harvest rates that serve as proxies to ensure stable carbon balances in the forest sector. They are outside the accounting framework of this LCA.

This approach to the treatment of biogenic carbon was taken for the Norwegian Solid Wood Product PCR (Aasestad 2008), and the North American PCR (FPInnovations 2013) has adopted an identical approach to ensure comparability and consistency. The North American PCR approach was followed here for GW impact reporting. Therefore, the default TRACI impact assessment method was used. This default method does not count the CO_2 emissions released during the combustion of woody biomass during production. Other emissions associated with wood combustion, e.g. methane or nitrogen oxides, do contribute to and are included in the GW impact category. Bare (2011) provides a complete list of emission factors for the GW impact method used. With this method, total CO_2 emissions of 207.2 kg were released, in the production of one cubic meter of LVL for the PNW (Table 17). That same one cubic meter of LVL stores 959[1] kg CO_2e.

Table 17. Carbon balance per one cubic meter LVL, PNW.

Carbon source	**kg CO_2 equivalent**
Released forestry operations	10.8
Released manufacturing	207.2
CO_2e stored in product	958.7

12 LIFE-CYCLE INTERPRETATION

As defined by ISO (2006), life-cycle interpretation is the phase of the LCA in which the findings of either the LCI or the LCIA, or both, are combined consistent with the defined goal and scope to reach conclusions and recommendations. This phase in the LCA reports the significant issues based on the results presented in the LCI and LCIA of this report. Additional components report an evaluation that considers completeness, sensitivity, and consistency checks of the LCI and LCIA results and conclusions, limitations, and recommendations.

12.1 Identification of Significant Issues

The objective of this element is to structure the results from the LCI or LCIA phases to help determine the significant issues found in the results and presented in previous sections of this report. A contribution analysis was applied for the interpretation phase of this LCA study. Contribution analysis examines the

[1] 543 OD kg of wood in LVL x 0.963 × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO2/kmole/12 kg carbon/kmole) = 958.7 kg CO2 eq.

contribution of life-cycles stages, unit process contributions in a multiunit manufacturing process, or specific substances that contribute to particular impact categories.

12.2 Life-Cycle Phase Contribution Analysis

Allocation was performed using both mass and economic methodologies to investigate the influence of the allocation method on the results. The contribution of five life-cycle stages to the LCA results for mass and economic allocation are provided in Table 18. Overall, the cradle-to-gate environmental impacts from LVL production for the five impact categories taken into consideration were similar, with a difference of about 1% to 10%.

Table 18. Life-cycle stages contribution analysis of one cubic meter LVL, cradle-to-gate.

Mass allocation				
Impact category	**Unit**	**Forestry operations (%)**	**Veneer production (%)**	**LVL production (%)**
Global warming	kg CO_2 eq	5.0	53.2	41.9
Acidification	kg SO_2 eq	6.5	55.2	38.3
Eutrophication	kg N eq	13.3	49.1	37.6
Ozone depletion	kg CFC-11 eq	0.1	1.8	98.1
Smog	kg O_3 eq	15.0	63.4	21.6
Economic allocation				
Total primary energy consumption	**Unit**	**Forestry operations (%)**	**Veneer production (%)**	**LVL production (%)**
Global warming	kg CO_2 eq	4.9	49.0	46.1
Acidification	kg SO_2 eq	6.5	51.1	42.5
Eutrophication	kg N eq	13.3	45.0	41.8
Ozone depletion	kg CFC-11 eq	0.1	0.4	99.5
Smog	kg O_3 eq	15.1	60.5	24.4

12.3 Substance Contribution Analysis

The contribution of substances released to GWP is presented in Table 19. Substance contribution analysis to GW (kg CO_2e) by life-cycle stage (total percentage basis and values).. The major substances that contribute to GWP for the five life-cycle stages of LVL manufacturing include fossil carbon dioxide (CO_2) and methane (CH_3). The results are presented for both mass and economic allocation where CO_2 emissions had the highest contribution.

Table 19. Substance contribution analysis to GW (kg CO_2e) by life-cycle stage (total percentage basis and values).

		Mass allocation				Economic allocation			
Substances	**Compar t-ment type**	**Total (%)**	**Forestry operations**	**Veneer production**	**LVL production**	**Total (%)**	**Forestry operations**	**Veneer production**	**LVL production**
Total of all compartments		**100.00**	1.08E+01	1.16E+02	9.12E+01	**100.00**	1.08E+01	1.08E+02	1.02E+02
Carbon dioxide	Air	91.61	1.04E+01	1.08E+02	8.16E+01	91.51	1.04E+01	1.01E+02	9.12E+01
Methane	Air	8.02	3.81E-01	7.74E+00	9.34E+00	8.12	3.81E-01	7.12E+00	1.04E+01
Other substances	Air	<1	5.22E-02	4.65E-01	2.95E-01	<1%	5.22E-02	4.36E-01	3.30E-01

12.4 Completeness, Sensitivity, and Consistency Checks

Evaluating the LCAs completeness, sensitivity, and consistency offers confidence in and reliability of the LCA results. The completeness check process verifies whether information from the life-cycle phases of an LCA are sufficient for reaching the goals and scope and conclusions of the study and making sound interpretations of the results. Three life-cycle stages (forestry operations, wood material production, and LVL production) were checked for data completeness including all input elements such as raw and ancillary materials input, energy input, transportation scenarios, water consumption, and outputs such as products and coproducts, emissions to air, water, and land, and final waste disposals. All input and output data were found to be complete, and no data gaps were identified.

The consistency check process verifies that the assumptions, methods, and data are consistently applied throughout the study and are in accordance with the goal and scope of the LCA. A comprehensive review process was completed for this LCA to make certain consistency was applied to the assumptions made, methods used, models, data quality including data sources, data accuracy, age, time-related coverage, technology, and geographical coverage.

Sensitivity analysis can be applied to the LCA to determine changes in results caused by variations in assumptions, methods, and data. Sensitivity analysis is a systematic approach for estimating the effects of the choices made concerning methods and data on the outcome of a study. Sensitivity analysis is a key component of data quality analysis and can be applied to quantify the impact of changes in assumptions or input data on study results. A sensitivity analysis was completed per ISO 14040 standards (ISO 2006a, 2006b) to model the effects of natural consumption and electricity consumption for LVL production. Sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors.

12.5 Cumulative Primary Energy Consumption

During LVL manufacturing, natural gas is used for curing resin. Changing the consumption of natural gas may have a significant effect on CPEC and GHG emissions. Lower (-20%) and higher (+20%) natural gas consumptions were selected to compare with the baseline fuel mix developed from the mill survey data. Although the usage changed by 20%, the outcomes changed approximately 2.5% and 1.1% for GHG emissions and CPEC, respectively (Table 20).

Table 20. Key parameters on changing natural gas consumption during LVL production.

Parameter	Unit	Low (-20%)	Surveyed (0%)	High (+20%)
		Values		
GHG emissions	kg CO_2e	212.15	218	223
CPEC	GJ	8.85	8.97	9.05

12.6 Electricity Consumption

During LVL manufacturing, electricity is used for motors including sawing and trimming. However, changing electricity consumption by 20% affects the outcomes less than 4% and 1.6% for GHG emissions and CPEC, respectively (Table 21).

Table 21. Key parameters on changing electricity consumption during LVL production.

Parameter	Unit	Low (-20%)	Surveyed (0%)	High (+20%)
		Values		
GHG emissions	kg CO_2e	210	218	225
CPEC	GJ	8.81	8.97	9.10

Although energy inputs reported for 2012 appear to be higher than CORRIM Phase I, the impacts of this difference in the LVL production process were small compared with energy impacts associated with dry veneer production (Table 11). As shown, neither natural gas nor electrical consumption on site had a substantial impact on the overall process because dry veneer production contributed roughly 75% of cradle-to-gate LVL production CPEC.

13 CONCLUSION, LIMITATIONS, AND RECOMMENDATIONS

The cradle-to-gate LCA for LVL includes (1) the LCI of forest resources, which relies on secondary data, (2) the LCI of dry veneer production, which is used as an input into LVL and relies on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity, and (3) the LVL manufacturing LCI, which relies on primary survey data and secondary data for process inputs such as natural gas, residual fuel oil, diesel, and electricity. The survey results for LVL were representative of the PNW region of the United States. The survey data were representative of LVL sizes and production volumes consistent with trade association production data.

Amount and type of energy has a substantial role during production of building materials such as LVL. Total CPEC for the cradle-to-gate production of PNW LVL was 8.97 GJ/m^3. Renewable biomass, by far the largest renewable energy source, represented 52.5% of the total cumulative energy consumption for all stages of production. Renewable energy consumption was strongly driven by veneer production. Nonrenewable energy for LVL production was strongly driven by fossil fuels. As for the other two life-cycle stages, forestry operations consumed relatively little energy and was exclusively fossil fuels, which came out to about 1.8% of the total cumulative energy consumption. In addition, the veneer production stage consumed slightly less nonrenewable fossil fuel (46%) than the production of LVL itself (49%). Energy consumed during PF resin production along with the additives of the resin system was included in the fossil fuel use for LVL as an upstream process. In summary, to produce one cubic meter of PNW LVL from cradle-to-gate, 52.5% of the cumulative energy was from biomass (wood fuel) and 41.8% from nonrenewable fossil fuels, leaving a small portion of energy needs coming from nuclear (3.5%) and the remaining 1.8% from hydro, wind, solar, and geothermal.

Emissions from the forest resources LCI are small relative to manufacturing emissions (veneer and LVL). At the LVL production facility, emissions originate at the boiler and during hot-pressing and sawing. Boiler emissions released are a function of the fuel burned, whereas other emissions are a function of the unit process and associated ECD. Cradle-to-gate LCI results showed that 199 kg fossil CO_2 were released in the production of one cubic meter of PNW LVL. Carbon content for wood products is assumed to be 50% by mass of OD wood. Excluding the resin system, the carbon stored in the wood portion of one cubic meter of LVL on a production-weighted average is equivalent to 959 kg CO_2 emissions if left to decay.

Data quality was high. A wood mass balance was performed to verify data quality. Inputs and outputs were consistent for the four surveyed mills on a cubic meter basis. Difference for overall wood mass was less than 2% for both regions. Any difference less than 10% would be good. Therefore, tracking of wood mass was excellent for this study.

Specific wood production LCA data such as LVL can be used for several purposes. One purpose is to construct cradle-to-gate LCAs for other products. For example, LVL production LCA data developed in this study can be linked as an input to develop an LCA for I-joist production. Secondly, product production companies can explore potential process improvements in conjunction with new conversion technologies to identify potential environmental hotspots. Thirdly, LCA practitioners can use the data for their studies and product customers can use the data (perhaps in the eventual form of an EPD) to assist in product selection along with building specifiers looking for green building products with documentation. Fourthly, developed wood product LCI data can contribute to product LCAs that are then incorporated into whole-building LCAs in environmental footprint software. Lastly, the gate-to-gate LVL production data can be included or used to update current LCI data found in LCI databases.

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15 APPENDIX A: CONVERSION FACTORS

Table 22. Common conversions from English to SI units.[a]

To convert from	to	multiply by
Cubic feet (ft^3)	Cubic meters (m^3)	0.02831685
Pounds (avdp) (lb)	Kilograms (kg)	0.4535924
Cubic inches (in^3)	Cubic centimeters (cm^3)	16.393
Btu's	Joules (J)	1054
Cubic yards (yd^3)	Cubic meters (m^3)	0.7645549
Feet (ft)	Meters (m)	0.305
Gallons (US) (gal)	Liters (L)	3.785
Kilowatt-hours (kWh)	Megajoules (MJ)	3.6
Miles (mi)	Kilometers (km)	1.609
Ounces (avdp) (oz)	Kilograms (kg)	0.028
Square feet (ft^2)	Square meters (m^2)	0.093
Tons (short)	Kilograms (kg)	907.185
Tons (short)	Metric tons (t)	0.9071847
Pounds (lb)	Metric tons (t)	0.0004
Watts (W)	Joules/second (J/s)	1
Yards (yd)	Meters (m)	0.914
Acres (a)	Hectares (ha)	0.405

[a]Sources: Starr (1971).

Table 23. Electricity grids and dataset name by region and source.

Region	North American grid	Source
Pacific Northwest	Electricity, at grid, WECC, 2008/RNA U	US LCI database

Table 24. Energy contents and densities of various fuels.

Fuel	HHV[a] MJ/kg	Density	Density units
Coal	26.19		
Distillate fuel oil[b]	45.54	0.85	kg/L
Liquid propane gas	54.05	0.49	kg/L
Natural gas	54.45	0.70	kg/m^3
Residual fuel oil	43.45	0.96	kg/L
Wood	20.93		
Uranium	381,000.00		
Gasoline	48.36	0.72	kg/L
Diesel	44.00	0.88	kg/L

[a]HHV: High heating value. Hodgman (1955);Salazar and Meil (2009); Todreas and Kazimi (1990); Used in this study.
[b]Same as for crude oil.

16 APPENDIX B: PACIFIC NORTHWEST LVL LIFE-CYCLE INVENTORY FLOWS — MASS ALLOCATION

Table 25. Mass allocation inventory.

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
1	Calcite	Raw	kg	0.00E+00	0.00E+00	1.09E-03
2	Carbon dioxide, in air	Raw	kg	1.13E+03	8.19E+01	7.93E-01
3	Carbon, organic, in soil or biomass stock	Raw	kg	0.00E+00	0.00E+00	1.00E+03
4	Coal, 26.4 MJ per kg	Raw	kg	1.89E-01	2.59E+01	1.45E+01
5	Coal, 26.4 MJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	7.27E-05
6	Coal, bituminous, 24.8 MJ per kg	Raw	kg	0.00E+00	2.73E-05	8.39E-07
7	Coal, brown	Raw	kg	0.00E+00	2.46E-06	7.55E-08
8	Copper ore	Raw	kg	0.00E+00	0.00E+00	2.20E-03
9	Energy, from biomass	Raw	MJ	0.00E+00	4.54E-06	1.39E-07
10	Energy, from hydro power	Raw	MJ	3.65E-03	1.07E+02	5.61E+01
11	Energy, geothermal	Raw	MJ	0.00E+00	9.28E+00	4.81E+00
12	Energy, kinetic (in wind), converted	Raw	MJ	0.00E+00	1.21E+01	6.29E+00
13	Energy, recovered	Raw	MJ	0.00E+00	3.48E-06	1.07E-07
14	Energy, solar, converted	Raw	MJ	0.00E+00	5.84E-01	3.03E-01
15	Fuel	Raw	m^3	3.36E-03	0.00E+00	0.00E+00
16	Gas, natural, 36.6 MJ per m^3	Raw	m^3	0.00E+00	1.04E-04	3.21E-06
17	Gas, natural, 46.8 MJ per kg	Raw	kg	0.00E+00	1.39E-01	6.26E-06
18	Gas, natural, 46.8 MJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	1.55E-04
19	Gas, natural, in ground	Raw	m^3	0.00E+00	0.00E+00	5.48E-04
20	Gas, natural/m^3	Raw	m^3	2.43E-01	1.85E+01	3.06E+01
21	Iron ore	Raw	kg	0.00E+00	0.00E+00	3.48E-04
22	Limestone	Raw	kg	0.00E+00	5.11E+00	5.47E-05
23	Limestone, in ground	Raw	kg	0.00E+00	0.00E+00	2.68E-02
24	Nitrogen	Raw	kg	0.00E+00	0.00E+00	1.18E-02
25	Nitrogen, in air	Raw	kg	5.29E-02	0.00E+00	0.00E+00
26	Occupation, arable, conservation tillage	Raw	m^{2a}	0.00E+00	0.00E+00	3.46E-04
27	Occupation, arable, conventional tillage	Raw	m^{2a}	0.00E+00	0.00E+00	3.79E-04
28	Occupation, arable, reduced tillage	Raw	m^{2a}	0.00E+00	0.00E+00	2.32E-04
29	Oil, crude	Raw	kg	3.23E+00	7.54E+00	6.50E+00
30	Oil, crude, 42 MJ per kg	Raw	kg	0.00E+00	6.28E-01	2.81E-06
31	Oil, crude, 42 MJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	6.23E-04
32	Oil, crude, 42.7 MJ per kg	Raw	kg	0.00E+00	5.45E-05	1.68E-06
33	Oil, crude, in ground	Raw	kg	0.00E+00	0.00E+00	2.48E-03
34	Oxygen	Raw	kg	0.00E+00	1.34E-04	7.96E-06
35	Oxygen, in air	Raw	kg	0.00E+00	7.90E-02	1.39E+00
36	Pesticides	Raw	kg	0.00E+00	0.00E+00	2.28E-07
37	Phosphate ore, in ground	Raw	kg	0.00E+00	0.00E+00	2.17E-05
38	Phosphorus, in ground	Raw	kg	8.96E-03	0.00E+00	0.00E+00
39	Sand, quartz, in ground	Raw	kg	0.00E+00	0.00E+00	2.53E-06
40	Scrap, external	Raw	kg	0.00E+00	0.00E+00	8.87E-02
41	Seed corn	Raw	kg	0.00E+00	0.00E+00	1.22E-06
42	Sodium carbonate, in ground	Raw	kg	0.00E+00	0.00E+00	2.95E-04
43	Sodium chloride	Raw	kg	0.00E+00	4.93E-02	3.73E+00
44	Sodium chloride, in ground	Raw	kg	0.00E+00	0.00E+00	2.89E-04
45	Sodium sulfate	Raw	kg	0.00E+00	0.00E+00	6.91E-04
46	Sodium sulphate, various forms, in ground	Raw	kg	0.00E+00	0.00E+00	9.12E-04
47	Sulfur, in ground	Raw	kg	0.00E+00	0.00E+00	8.64E-05
48	Sylvinite, in ground	Raw	kg	0.00E+00	0.00E+00	1.07E-05
49	Uranium	Raw	kg	0.00E+00	0.00E+00	1.78E-03
50	Uranium oxide, 332 GJ per kg, in ore	Raw	kg	4.44E-06	5.44E-04	2.86E-04
51	Uranium, 2291 GJ per kg	Raw	kg	0.00E+00	2.11E-06	2.07E-11
52	Uranium, 2291 GJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	2.09E-09
53	Uranium, in ground	Raw	kg	0.00E+00	0.00E+00	8.32E-09
54	Water, cooling, unspecified natural origin/kg	Raw	kg	0.00E+00	1.45E-02	2.54E-01
55	Water, cooling, unspecified natural origin/m^3	Raw	m^3	0.00E+00	1.74E-01	2.18E-01

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
56	Water, process, surface	Raw	kg	0.00E+00	1.98E+02	2.95E+00
57	Water, process, unspecified natural origin/kg	Raw	kg	0.00E+00	2.69E-01	4.71E+00
58	Water, process, unspecified natural origin/m^3	Raw	m^3	0.00E+00	4.38E-05	1.35E-06
59	Water, process, well	Raw	kg	0.00E+00	8.62E+01	6.53E-01
60	Water, process, well, in ground	Raw	kg	0.00E+00	3.35E-02	5.87E-01
61	Water, river	Raw	m^3	0.00E+00	0.00E+00	3.88E-06
62	Water, unspecified natural origin, RoW	Raw	m^3	0.00E+00	2.83E-04	1.61E-06
63	Water, unspecified natural origin, US	Raw	m^3	0.00E+00	4.09E-01	0.00E+00
64	Water, unspecified natural origin/m^3	Raw	m^3	1.03E-02	6.20E-03	1.09E-01
65	Water, well, in ground	Raw	m^3	0.00E+00	0.00E+00	2.24E-05
66	Water, well, in ground, US	Raw	m^3	0.00E+00	2.89E-03	0.00E+00
67	Wood and wood waste, 20.9 MJ per kg, ovendry basis	Raw	kg	0.00E+00	2.24E+02	1.19E+00
68	Wood and wood waste, 9.5 MJ per kg	Raw	kg	0.00E+00	0.00E+00	8.73E-02
69	Wood for fiber, feedstock	Raw	kg	0.00E+00	0.00E+00	1.87E-01
70	Wood, feedstock	Raw	kg	0.00E+00	0.00E+00	1.99E-01
71	Wood, soft, standing	Raw	m^3	0.00E+00	1.62E+00	9.72E-03
72	Wood, unspecified, standing/kg	Raw	kg	0.00E+00	0.00E+00	1.57E-02
73	2-chloroacetophenone	Air	kg	1.78E-12	4.43E-11	6.96E-10
74	2-methyl-4-chlorophenoxyacetic acid	Air	kg	0.00E+00	0.00E+00	2.28E-11
75	2,4-D	Air	kg	0.00E+00	0.00E+00	1.22E-09
76	5-methyl chrysene	Air	kg	1.82E-12	2.46E-10	1.32E-10
77	Acenaphthene	Air	kg	4.22E-11	5.70E-09	3.05E-09
78	Acenaphthylene	Air	kg	2.07E-11	2.79E-09	1.50E-09
79	Acetaldehyde	Air	kg	4.30E-05	9.60E-03	2.74E-03
80	Acetochlor	Air	kg	0.00E+00	0.00E+00	1.69E-08
81	Acetone	Air	kg	0.00E+00	1.06E-02	0.00E+00
82	Acetophenone	Air	kg	3.82E-12	9.50E-11	1.49E-09
83	Acrolein	Air	kg	5.21E-06	1.73E-03	1.35E-05
84	Alachlor	Air	kg	0.00E+00	0.00E+00	1.67E-09
85	Aldehydes, unspecified	Air	kg	1.31E-04	3.17E-04	2.45E-04
86	Ammonia	Air	kg	8.74E-05	2.86E-03	1.70E-04
87	Ammonium chloride	Air	kg	2.36E-07	2.88E-05	1.52E-05
88	Anthracene	Air	kg	1.74E-11	2.35E-09	1.26E-09
89	Antimony	Air	kg	1.49E-09	2.01E-07	1.14E-07
90	Arsenic	Air	kg	4.72E-08	4.69E-06	2.62E-06
91	Atrazine	Air	kg	0.00E+00	0.00E+00	3.30E-08
92	Barium	Air	kg	0.00E+00	0.00E+00	1.91E-07
93	Bentazone	Air	kg	0.00E+00	0.00E+00	1.35E-10
94	Benzene	Air	kg	5.25E-05	1.25E-02	7.13E-03
95	Benzene, chloro-	Air	kg	5.60E-12	1.39E-10	2.19E-09
96	Benzene, ethyl-	Air	kg	2.39E-11	7.05E-07	1.25E-07
97	Benzo(a)anthracene	Air	kg	6.63E-12	8.94E-10	4.78E-10
98	Benzo(a)pyrene	Air	kg	3.15E-12	4.25E-10	2.27E-10
99	Benzo(b,j,k)fluoranthene	Air	kg	9.11E-12	1.23E-09	6.58E-10
100	Benzo(g,h,i)perylene	Air	kg	2.24E-12	3.02E-10	1.61E-10
101	Benzo(ghi)perylene	Air	kg	0.00E+00	0.00E+00	6.92E-18
102	Benzyl chloride	Air	kg	1.78E-10	4.43E-09	6.96E-08
103	Beryllium	Air	kg	2.32E-09	2.50E-07	1.56E-07
104	Biphenyl	Air	kg	1.41E-10	1.90E-08	1.02E-08
105	Bromoform	Air	kg	9.92E-12	2.47E-10	3.88E-09
106	Bromoxynil	Air	kg	0.00E+00	0.00E+00	2.95E-10
107	BTEX (benzene, toluene, ethylbenzene, and xylene), unspecified ratio	Air	kg	5.98E-05	4.57E-03	7.29E-03
108	Butadiene	Air	kg	2.19E-06	1.65E-06	2.56E-08
109	Cadmium	Air	kg	1.15E-08	8.79E-07	7.48E-07
110	Carbofuran	Air	kg	0.00E+00	0.00E+00	2.52E-10
111	Carbon dioxide	Air	kg	2.81E-02	7.37E-02	2.00E+00
112	Carbon dioxide, biogenic	Air	kg	8.16E-03	3.95E+02	2.51E+00
113	Carbon dioxide, fossil	Air	kg	1.03E+01	1.07E+02	7.96E+01
114	Carbon disulfide	Air	kg	3.31E-11	8.24E-10	1.29E-08
115	Carbon monoxide	Air	kg	3.86E-06	9.73E-03	1.57E-02
116	Carbon monoxide, biogenic	Air	kg	0.00E+00	1.01E+00	3.29E-03

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
117	Carbon monoxide, fossil	Air	kg	9.46E-02	1.86E-01	1.22E-01
118	Chloride	Air	kg	6.25E-12	6.78E-10	3.62E-10
119	Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	Air	kg	0.00E+00	8.45E-09	5.99E-07
120	Chlorine	Air	kg	0.00E+00	1.01E-07	5.97E-06
121	Chloroform	Air	kg	1.50E-11	3.74E-10	5.87E-09
122	Chlorpyrifos	Air	kg	0.00E+00	0.00E+00	1.94E-09
123	Chromium	Air	kg	3.39E-08	3.31E-06	2.13E-06
124	Chromium VI	Air	kg	6.54E-09	8.83E-07	4.72E-07
125	Chrysene	Air	kg	8.28E-12	1.12E-09	5.98E-10
126	Cobalt	Air	kg	6.47E-08	1.35E-06	8.87E-07
127	Copper	Air	kg	5.81E-10	2.28E-08	5.02E-08
128	Cumene	Air	kg	1.35E-12	5.92E-04	1.04E-02
129	Cyanazine	Air	kg	0.00E+00	0.00E+00	2.91E-10
130	Cyanide	Air	kg	6.36E-10	1.58E-08	2.49E-07
131	Dicamba	Air	kg	0.00E+00	0.00E+00	1.72E-09
132	Dimethenamid	Air	kg	0.00E+00	0.00E+00	4.05E-09
133	Dimethyl ether	Air	kg	0.00E+00	4.28E-06	7.50E-05
134	Dinitrogen monoxide	Air	kg	1.75E-04	1.56E-03	9.88E-04
135	Dioxin, 2,3,7,8 tetrachlorodibenzo-p-	Air	kg	2.09E-13	9.55E-12	1.31E-09
136	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	kg	0.00E+00	0.00E+00	3.18E-19
137	Dipropylthiocarbamic acid S-ethyl ester	Air	kg	0.00E+00	0.00E+00	2.77E-09
138	Ethane, 1,1,1-trichloro-, HCFC-140	Air	kg	3.08E-10	8.34E-10	2.54E-09
139	Ethane, 1,2-dibromo-	Air	kg	3.05E-13	7.83E-12	1.19E-10
140	Ethane, 1,2-dichloro-	Air	kg	1.02E-11	2.53E-10	3.98E-09
141	Ethane, chloro-	Air	kg	1.07E-11	2.66E-10	4.18E-09
142	Ethene, tetrachloro-	Air	kg	4.27E-09	4.85E-07	2.65E-07
143	Ethene, trichloro-	Air	kg	0.00E+00	0.00E+00	2.25E-13
144	Ethylene oxide	Air	kg	0.00E+00	1.44E-08	4.43E-10
145	Fluoranthene	Air	kg	5.88E-11	7.93E-09	4.25E-09
146	Fluorene	Air	kg	7.54E-11	1.02E-08	5.44E-09
147	Fluoride	Air	kg	3.36E-07	9.37E-07	4.78E-06
148	Formaldehyde	Air	kg	6.67E-05	4.63E-03	4.17E-03
149	Furan	Air	kg	3.79E-13	5.49E-11	2.88E-11
150	Glyphosate	Air	kg	0.00E+00	0.00E+00	3.64E-09
151	HAPs	Air	kg	0.00E+00	1.13E-03	6.40E-06
152	HAPs, unspecified	Air	kg	0.00E+00	0.00E+00	1.02E-07
153	Heat, waste	Air	MJ	0.00E+00	1.27E+00	1.09E+01
154	Hexane	Air	kg	1.70E-11	4.24E-10	1.99E-04
155	Hydrazine, methyl-	Air	kg	4.33E-11	1.08E-09	1.69E-08
156	Hydrocarbons, unspecified	Air	kg	1.36E-06	1.67E-04	6.60E-03
157	Hydrogen	Air	kg	0.00E+00	3.08E-07	5.51E-06
158	Hydrogen chloride	Air	kg	1.06E-04	1.37E-02	7.21E-03
159	Hydrogen fluoride	Air	kg	1.24E-05	1.68E-03	8.93E-04
160	Hydrogen sulfide	Air	kg	2.02E-13	2.19E-11	1.17E-11
161	Indeno(1,2,3-cd)pyrene	Air	kg	5.05E-12	6.82E-10	3.65E-10
162	Iron	Air	kg	0.00E+00	0.00E+00	1.91E-07
163	Isophorone	Air	kg	1.48E-10	3.67E-09	5.77E-08
164	Isoprene	Air	kg	2.05E-04	2.22E-02	1.18E-02
165	Kerosene	Air	kg	1.13E-07	1.38E-05	7.27E-06
166	Lead	Air	kg	5.24E-08	3.63E-05	3.47E-06
167	Magnesium	Air	kg	9.11E-07	1.23E-04	6.58E-05
168	Manganese	Air	kg	7.02E-08	5.70E-06	4.87E-06
169	Mercaptans, unspecified	Air	kg	5.47E-08	1.36E-06	2.16E-05
170	Mercury	Air	kg	9.31E-09	1.36E-06	1.83E-06
171	Metals, unspecified	Air	kg	2.32E-14	2.51E-12	3.34E-05
172	Methane	Air	kg	1.42E-02	2.78E-01	3.32E-01
173	Methane, biogenic	Air	kg	0.00E+00	4.00E-03	2.27E-05
174	Methane, bromo-, Halon 1001	Air	kg	4.07E-11	1.01E-09	1.59E-08
175	Methane, chlorodifluoro-, HCFC-22	Air	kg	0.00E+00	1.20E-13	3.69E-15
176	Methane, chlorotrifluoro-, CFC-13	Air	kg	0.00E+00	1.14E-12	3.50E-14
177	Methane, dichloro-, HCC-30	Air	kg	7.21E-08	3.53E-06	2.43E-06

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
178	Methane, dichlorodifluoro-, CFC-12	Air	kg	3.75E-10	8.76E-10	6.81E-10
179	Methane, fossil	Air	kg	1.08E-03	2.81E-02	4.17E-02
180	Methane, monochloro-, R-40	Air	kg	1.35E-10	3.36E-09	5.27E-08
181	Methane, tetrachloro-, CFC-10	Air	kg	3.75E-11	8.92E-09	6.11E-07
182	Methanol	Air	kg	0.00E+00	1.26E-02	1.09E-01
183	Methyl ethyl ketone	Air	kg	9.92E-11	2.47E-09	3.88E-08
184	Methyl methacrylate	Air	kg	5.09E-12	1.27E-10	1.99E-09
185	Metolachlor	Air	kg	0.00E+00	0.00E+00	1.34E-08
186	Metribuzin	Air	kg	0.00E+00	0.00E+00	6.21E-11
187	N-nitrodimethylamine	Air	kg	0.00E+00	0.00E+00	5.02E-14
188	Naphthalene	Air	kg	1.34E-08	1.07E-05	5.87E-07
189	Nickel	Air	kg	8.18E-07	6.59E-06	6.06E-06
190	Nitrogen oxides	Air	kg	1.87E-01	7.51E-01	1.94E-01
191	Nitrogen, total	Air	kg	6.36E-06	0.00E+00	1.64E-09
192	NMVOC, nonmethane volatile organic compounds, unspecified origin	Air	kg	6.36E-03	1.81E-02	2.99E-02
193	Organic acids	Air	kg	8.66E-10	1.06E-07	5.58E-08
194	Organic substances, unspecified	Air	kg	5.14E-07	7.65E-04	5.32E-05
195	Other organic	Air	kg	0.00E+00	3.80E-05	2.16E-07
196	PAH, polycyclic aromatic hydrocarbons	Air	kg	9.42E-06	7.04E-06	2.25E-05
197	Paraquat	Air	kg	0.00E+00	0.00E+00	2.71E-10
198	Parathion, methyl	Air	kg	0.00E+00	0.00E+00	2.05E-10
199	Particulates	Air	kg	0.00E+00	2.09E-06	3.66E-05
200	Particulates, <10 um	Air	kg	0.00E+00	1.63E-01	9.02E-02
201	Particulates, <2.5 um	Air	kg	0.00E+00	8.60E-02	4.51E-02
202	Particulates, >10 um	Air	kg	0.00E+00	4.57E-04	1.39E-04
203	Particulates, >2.5 um, and <10 um	Air	kg	5.74E-03	1.07E-02	5.96E-03
204	Particulates, unspecified	Air	kg	1.04E-03	3.92E-02	1.29E-01
205	Pendimethalin	Air	kg	0.00E+00	0.00E+00	1.39E-09
206	Permethrin	Air	kg	0.00E+00	0.00E+00	1.25E-10
207	Phenanthrene	Air	kg	2.24E-10	3.02E-08	1.61E-08
208	Phenol	Air	kg	4.07E-12	2.61E-04	7.42E-05
209	Phenols, unspecified	Air	kg	3.76E-08	3.95E-07	4.91E-07
210	Phorate	Air	kg	0.00E+00	0.00E+00	6.42E-11
211	Phosphate	Air	kg	1.46E-07	0.00E+00	0.00E+00
212	Phthalate, dioctyl-	Air	kg	1.86E-11	4.62E-10	7.26E-09
213	Polycyclic organic matter, unspecified	Air	kg	0.00E+00	2.90E-12	8.90E-14
214	Potassium	Air	kg	0.00E+00	0.00E+00	3.38E-05
215	Propanal	Air	kg	9.67E-11	9.24E-06	3.43E-03
216	Propene	Air	kg	1.45E-04	3.26E-04	3.82E-03
217	Propylene oxide	Air	kg	0.00E+00	6.36E-07	1.05E-07
218	Pyrene	Air	kg	2.73E-11	3.69E-09	1.97E-09
219	Radioactive species, unspecified	Air	Bq	4.68E+03	6.32E+05	3.33E+05
220	Radionuclides (including radon)	Air	kg	6.31E-06	7.73E-04	4.07E-04
221	Selenium	Air	kg	1.16E-07	1.46E-05	7.94E-06
222	Simazine	Air	kg	0.00E+00	0.00E+00	8.79E-10
223	Sodium	Air	kg	0.00E+00	0.00E+00	7.81E-07
224	Styrene	Air	kg	6.36E-12	1.58E-10	2.49E-09
225	Sulfur	Air	kg	0.00E+00	0.00E+00	4.11E-06
226	Sulfur dioxide	Air	kg	6.82E-03	6.89E-01	7.09E-01
227	Sulfur monoxide	Air	kg	1.04E-02	2.65E-02	3.07E-03
228	Sulfur oxides	Air	kg	1.33E-04	1.10E-03	1.86E-02
229	Sulfur, total reduced	Air	kg	0.00E+00	0.00E+00	2.41E-06
230	Sulfuric acid, dimethyl ester	Air	kg	1.22E-11	3.04E-10	4.78E-09
231	t-butyl methyl ether	Air	kg	8.91E-12	2.22E-10	3.48E-09
232	Tar	Air	kg	7.03E-12	7.63E-10	4.07E-10
233	Terbufos	Air	kg	0.00E+00	0.00E+00	2.19E-09
234	TOC, total organic carbon	Air	kg	0.00E+00	0.00E+00	3.19E-06
235	Toluene	Air	kg	2.29E-05	2.00E-05	7.47E-07
236	Toluene, 2,4-dinitro-	Air	kg	7.12E-14	1.77E-12	2.79E-11
237	Vinyl acetate	Air	kg	1.93E-12	4.81E-11	7.56E-10
238	VOC	Air	kg	5.02E-03	2.21E-01	4.38E-01
239	Wood (dust)	Air	kg	0.00E+00	1.18E-01	6.55E-04

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
240	Xylene	Air	kg	1.60E-05	1.34E-05	4.11E-07
241	Zinc	Air	kg	1.18E-07	1.52E-08	2.24E-07
242	2-hexanone	Water	kg	8.00E-08	5.58E-07	7.48E-07
243	2-methyl-4-chlorophenoxyacetic acid	Water	kg	0.00E+00	0.00E+00	9.77E-13
244	2-propanol	Water	kg	0.00E+00	0.00E+00	2.27E-09
245	2,4-D	Water	kg	0.00E+00	0.00E+00	5.24E-11
246	4-methyl-2-pentanone	Water	kg	5.15E-08	3.59E-07	4.81E-07
247	Acetaldehyde	Water	kg	0.00E+00	1.52E-08	4.67E-10
248	Acetochlor	Water	kg	0.00E+00	0.00E+00	7.26E-10
249	Acetone	Water	kg	1.22E-07	8.55E-07	1.15E-06
250	Acidity, unspecified	Water	kg	0.00E+00	0.00E+00	8.12E-15
251	Acids, unspecified	Water	kg	1.31E-10	1.42E-08	3.23E-06
252	Alachlor	Water	kg	0.00E+00	0.00E+00	7.15E-11
253	Aluminium	Water	kg	1.05E-03	3.71E-03	3.73E-03
254	Aluminum	Water	kg	0.00E+00	0.00E+00	9.16E-06
255	Ammonia	Water	kg	2.28E-04	1.29E-03	1.57E-03
256	Ammonia, as N	Water	kg	6.60E-11	7.15E-09	3.81E-09
257	Ammonium, ion	Water	kg	5.04E-08	2.12E-04	5.30E-06
258	Antimony	Water	kg	6.52E-07	2.16E-06	2.22E-06
259	Arsenic	Water	kg	3.62E-06	2.06E-05	2.66E-05
260	Arsenic, ion	Water	kg	0.00E+00	0.00E+00	1.12E-11
261	Atrazine	Water	kg	0.00E+00	0.00E+00	1.42E-09
262	Barium	Water	kg	1.43E-02	4.96E-02	5.23E-02
263	Bentazone	Water	kg	0.00E+00	0.00E+00	5.77E-12
264	Benzene	Water	kg	2.05E-05	1.11E-03	1.72E-02
265	Benzene, 1-methyl-4-(1-methylethyl)-	Water	kg	1.22E-09	8.55E-09	1.14E-08
266	Benzene, ethyl-	Water	kg	1.16E-06	8.07E-06	1.08E-05
267	Benzene, pentamethyl-	Water	kg	9.18E-10	6.41E-09	8.59E-09
268	Benzenes, alkylated, unspecified	Water	kg	5.72E-07	1.90E-06	1.95E-06
269	Benzo(a)pyrene	Water	kg	0.00E+00	0.00E+00	2.36E-10
270	Benzoic acid	Water	kg	1.24E-05	8.68E-05	1.16E-04
271	Beryllium	Water	kg	1.86E-07	1.00E-06	1.26E-06
272	Biphenyl	Water	kg	3.70E-08	1.23E-07	1.26E-07
273	BOD5, biological oxygen demand	Water	kg	2.24E-03	2.46E-02	1.81E-01
274	Boron	Water	kg	3.84E-05	2.68E-04	3.60E-04
275	Bromide	Water	kg	2.62E-03	1.83E-02	2.46E-02
276	Bromoxynil	Water	kg	0.00E+00	0.00E+00	7.64E-12
277	Cadmium	Water	kg	5.85E-07	3.08E-06	9.52E-06
278	Cadmium, ion	Water	kg	0.00E+00	0.00E+00	2.72E-11
279	Calcium	Water	kg	3.93E-02	2.75E-01	3.68E-01
280	Calcium, ion	Water	kg	0.00E+00	0.00E+00	1.32E-07
281	Carbofuran	Water	kg	0.00E+00	0.00E+00	1.08E-11
282	CFCs, unspecified	Water	kg	0.00E+00	0.00E+00	2.27E-09
283	Chloride	Water	kg	4.42E-01	3.09E+00	4.14E+00
284	Chlorpyrifos	Water	kg	0.00E+00	0.00E+00	8.33E-11
285	Chromate	Water	kg	0.00E+00	0.00E+00	4.59E-13
286	Chromium	Water	kg	2.79E-05	6.77E-05	8.20E-05
287	Chromium III	Water	kg	2.14E-06	3.04E-05	1.86E-05
288	Chromium VI	Water	kg	1.16E-07	2.70E-07	2.10E-07
289	Chromium, ion	Water	kg	0.00E+00	0.00E+00	7.02E-12
290	Cobalt	Water	kg	2.71E-07	1.89E-06	2.54E-06
291	COD, chemical oxygen demand	Water	kg	4.24E-03	3.55E-02	1.99E-01
292	Copper	Water	kg	3.65E-06	2.17E-05	2.23E-05
293	Copper, ion	Water	kg	0.00E+00	0.00E+00	1.17E-11
294	Cumene	Water	kg	0.00E+00	1.42E-03	2.49E-02
295	Cyanazine	Water	kg	0.00E+00	0.00E+00	1.25E-11
296	Cyanide	Water	kg	8.84E-10	6.22E-09	3.52E-08
297	Decane	Water	kg	3.57E-07	2.49E-06	3.34E-06
298	Detergent, oil	Water	kg	1.03E-05	8.09E-05	1.11E-04
299	Dibenzofuran	Water	kg	2.33E-09	1.63E-08	2.18E-08
300	Dibenzothiophene	Water	kg	2.00E-09	1.36E-08	1.80E-08
301	Dicamba	Water	kg	0.00E+00	0.00E+00	7.35E-11
302	Dimethenamid	Water	kg	0.00E+00	0.00E+00	1.74E-10

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
303	Dipropylthiocarbamic acid S-ethyl ester	Water	kg	0.00E+00	0.00E+00	7.18E-11
304	Disulfoton	Water	kg	0.00E+00	0.00E+00	4.28E-12
305	Diuron	Water	kg	0.00E+00	0.00E+00	1.20E-12
306	DOC, dissolved organic carbon	Water	kg	4.03E-13	2.62E-03	4.59E-02
307	Docosane	Water	kg	1.31E-08	9.15E-08	1.23E-07
308	Dodecane	Water	kg	6.77E-07	4.73E-06	6.34E-06
309	Eicosane	Water	kg	1.87E-07	1.30E-06	1.74E-06
310	Fluorene	Water	kg	0.00E+00	2.84E-13	8.72E-15
311	Fluorene, 1-methyl-	Water	kg	1.39E-09	9.73E-09	1.30E-08
312	Fluorenes, alkylated, unspecified	Water	kg	3.31E-08	1.10E-07	1.13E-07
313	Fluoride	Water	kg	8.13E-04	1.00E-04	5.28E-05
314	Fluorine	Water	kg	1.64E-08	5.81E-08	6.20E-08
315	Furan	Water	kg	0.00E+00	0.00E+00	8.33E-11
316	Glyphosate	Water	kg	0.00E+00	0.00E+00	1.56E-10
317	Hexadecane	Water	kg	7.39E-07	5.16E-06	6.92E-06
318	Hexanoic acid	Water	kg	2.57E-06	1.80E-05	2.41E-05
319	Hydrocarbons, unspecified	Water	kg	5.05E-13	5.47E-11	8.13E-05
320	Iron	Water	kg	2.09E-03	8.72E-03	9.46E-03
321	Lead	Water	kg	7.14E-06	3.52E-05	4.25E-05
322	Lead-210/kg	Water	kg	1.27E-15	8.89E-15	1.19E-14
323	Lithium	Water	kg	8.38E-04	6.31E-02	1.01E-01
324	Lithium, ion	Water	kg	0.00E+00	0.00E+00	2.10E-09
325	m-xylene	Water	kg	3.71E-07	2.59E-06	3.47E-06
326	Magnesium	Water	kg	7.69E-03	5.37E-02	7.20E-02
327	Manganese	Water	kg	1.37E-05	2.83E-04	2.20E-04
328	Mercury	Water	kg	1.56E-08	4.59E-08	7.05E-06
329	Metallic ions, unspecified	Water	kg	6.16E-12	6.68E-10	2.52E-04
330	Methane, monochloro-, R-40	Water	kg	4.93E-10	3.44E-09	4.61E-09
331	Methyl ethyl ketone	Water	kg	9.86E-10	6.89E-09	9.22E-09
332	Metolachlor	Water	kg	0.00E+00	0.00E+00	5.74E-10
333	Metribuzin	Water	kg	0.00E+00	0.00E+00	2.66E-12
334	Molybdenum	Water	kg	2.82E-07	1.97E-06	2.63E-06
335	n-hexacosane	Water	kg	8.18E-09	5.71E-08	7.65E-08
336	Naphthalene	Water	kg	2.23E-07	1.55E-06	2.08E-06
337	Naphthalene, 2-methyl-	Water	kg	1.94E-07	1.35E-06	1.81E-06
338	Naphthalenes, alkylated, unspecified	Water	kg	9.37E-09	3.11E-08	3.19E-08
339	Nickel	Water	kg	3.43E-06	1.76E-05	2.21E-05
340	Nickel, ion	Water	kg	0.00E+00	0.00E+00	2.63E-13
341	Nitrate	Water	kg	4.42E-14	4.79E-12	2.70E-07
342	Nitrate compounds	Water	kg	1.78E-12	1.93E-10	1.03E-10
343	Nitric acid	Water	kg	3.99E-09	4.33E-07	2.31E-07
344	Nitrogen, total	Water	kg	1.25E-07	1.54E-05	3.01E-05
345	o-cresol	Water	kg	3.52E-07	2.46E-06	3.30E-06
346	o-xylene	Water	kg	0.00E+00	6.03E-13	1.85E-14
347	Octadecane	Water	kg	1.83E-07	1.28E-06	1.71E-06
348	Oils, unspecified	Water	kg	2.82E-04	1.83E-03	2.38E-03
349	Organic substances, unspecified	Water	kg	0.00E+00	0.00E+00	2.22E-09
350	p-cresol	Water	kg	3.80E-07	2.65E-06	3.56E-06
351	p-xylene	Water	kg	0.00E+00	6.03E-13	1.85E-14
352	Paraquat	Water	kg	0.00E+00	0.00E+00	1.16E-11
353	Parathion, methyl	Water	kg	0.00E+00	0.00E+00	8.77E-12
354	Pendimethalin	Water	kg	0.00E+00	0.00E+00	5.97E-11
355	Permethrin	Water	kg	0.00E+00	0.00E+00	5.36E-12
356	Phenanthrene	Water	kg	3.37E-09	1.52E-08	1.80E-08
357	Phenanthrenes, alkylated, unspecified	Water	kg	3.89E-09	1.29E-08	1.32E-08
358	Phenol	Water	kg	5.11E-06	1.19E-05	9.61E-06
359	Phenol, 2,4-dimethyl-	Water	kg	3.43E-07	2.40E-06	3.21E-06
360	Phenols, unspecified	Water	kg	1.06E-06	2.80E-05	4.36E-05
361	Phorate	Water	kg	0.00E+00	0.00E+00	1.66E-12
362	Phosphate	Water	kg	6.11E-04	0.00E+00	2.17E-05
363	Phosphorus	Water	kg	0.00E+00	0.00E+00	4.65E-06
364	Phosphorus compounds, unspecified	Water	kg	0.00E+00	0.00E+00	3.08E-08
365	Phosphorus, total	Water	kg	0.00E+00	0.00E+00	2.75E-06

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
366	Process solvents, unspecified	Water	kg	0.00E+00	0.00E+00	8.33E-09
367	Propene	Water	kg	0.00E+00	5.24E-04	9.18E-03
368	Radioactive species, nuclides, unspecified	Water	Bq	7.32E+00	8.96E+02	4.72E+02
369	Radium-226/kg	Water	kg	4.43E-13	3.09E-12	4.14E-12
370	Radium-228/kg	Water	kg	2.26E-15	1.58E-14	2.12E-14
371	Selenium	Water	kg	1.44E-07	2.58E-06	1.57E-06
372	Silver	Water	kg	2.57E-05	1.79E-04	2.40E-04
373	Simazine	Water	kg	0.00E+00	0.00E+00	3.77E-11
374	Sodium	Water	kg	1.25E-01	8.71E-01	1.17E+00
375	Sodium, ion	Water	kg	0.00E+00	0.00E+00	4.17E-07
376	Solids, inorganic	Water	kg	1.02E-11	1.10E-09	5.87E-10
377	Solved solids	Water	kg	0.00E+00	1.42E-05	2.98E-04
378	Strontium	Water	kg	6.68E-04	4.66E-03	6.25E-03
379	Styrene	Water	kg	0.00E+00	1.78E-11	3.21E-10
380	Sulfate	Water	kg	9.93E-04	1.88E-02	1.50E-02
381	Sulfide	Water	kg	5.93E-07	1.59E-06	3.10E-05
382	Sulfur	Water	kg	3.25E-05	2.27E-04	3.04E-04
383	Sulfuric acid	Water	kg	0.00E+00	0.00E+00	1.95E-10
384	Surfactants	Water	kg	0.00E+00	2.79E-11	8.59E-13
385	Suspended solids, unspecified	Water	kg	5.78E-01	3.93E+00	5.38E+00
386	Tar	Water	kg	1.01E-13	1.09E-11	5.82E-12
387	Terbufos	Water	kg	0.00E+00	0.00E+00	5.66E-11
388	Tetradecane	Water	kg	2.97E-07	2.07E-06	2.78E-06
389	Thallium	Water	kg	1.37E-07	4.56E-07	4.69E-07
390	Tin	Water	kg	2.67E-06	1.25E-05	1.50E-05
391	Titanium	Water	kg	1.00E-05	3.32E-05	3.41E-05
392	Titanium, ion	Water	kg	0.00E+00	0.00E+00	3.39E-11
393	TOC, total organic carbon	Water	kg	0.00E+00	2.62E-03	4.59E-02
394	Toluene	Water	kg	1.94E-05	1.36E-04	1.82E-04
395	Vanadium	Water	kg	3.33E-07	2.32E-06	3.11E-06
396	Wastewater/m^3	Water	m^3	0.00E+00	0.00E+00	6.87E-04
397	Xylene	Water	kg	1.04E-05	7.11E-05	9.48E-05
398	Yttrium	Water	kg	8.25E-08	5.76E-07	7.72E-07
399	Zinc	Water	kg	2.42E-05	9.40E-05	9.44E-05
400	Zinc, ion	Water	kg	0.00E+00	0.00E+00	3.67E-07
401	Waste in inert landfill	Waste	kg	0.00E+00	0.00E+00	7.72E-01
402	Waste to recycling	Waste	kg	0.00E+00	0.00E+00	3.53E-01
403	Waste, solid	Waste	kg	0.00E+00	0.00E+00	9.81E-03

17 APPENDIX C: PACIFIC NORTHWEST LVL LIFE-CYCLE IMPACT ASSESSMENT — ECONOMIC ALLOCATION

Cradle-to-gate LCI and impact assessment results of economic allocation are shown in this section. The results for NW LVL analyses were for three life-cycle stages: (1) forestry operations, (2) veneer production, and (3) LVL production. The difference between the raw material energy consumption obtained for the two different allocation methods, i.e. mass and economic, was about 1% to 7%. Similarly, no notable difference was observed in the overall cumulative energy consumption, which was about 3%. Although the impact assessment results did not differ much when economic allocation was used (about 1% to 2% difference), ozone depletion impact category of the veneer production stage was four times lower compared with mass allocation results. This resulted in a 10% increase in overall ozone depletion impact. In addition, using economic allocation led to a slight decrease in contribution of veneer production to the overall energy consumption, whereas the share from LVL production increased from 23% to 26%. The difference in CPEC of veneer production between the mass and economic allocations was about 7%. The impact assessment results for the categories taken into consideration were similar, with a difference of about 6% to 8% for both allocation methods. The majority of the ozone depletion impact at the veneer production stage is assigned to the wood boiler used in veneer drying. The fuel used in the wood boiler is a mixture of coproducts coming from a downstream process of plywood production. The lower ozone depletion for economic allocation is a result of lower emissions allocated to coproducts because of their low economic value.

Table 26. Raw material primary energy consumption per one cubic meter of cradle-to-gate LVL, PNW, economic allocation.

Fuel	Unit	Total	Forestry operations	Dry veneer production	LVL production
Wood fuel	OD kg	2.10E+02	0.00E+00	2.09E+02	1.33E+00
Gas, natural, in ground	kg	3.62E+01	1.71E-01	1.19E+01	2.41E+01
Coal, in ground	kg	4.05E+01	1.89E-01	2.41E+01	1.63E+01
Uranium oxide, in ore	kg	8.30E-04	4.44E-06	5.06E-04	3.20E-04
Oil, crude, in ground	kg	1.76E+01	3.23E+00	7.09E+00	7.28E+00

Table 27. Cumulative primary energy consumption per one cubic meter of cradle-to-gate LVL, PNW, economic allocation.

Fuel	Percentage	Total	Forestry operations	Veneer production	LVL production
		MJ/m^3			
Wood fuel	50.3	4.39E+03	0.00E+00	4.37E+03	2.77E+01
Gas, natural, in ground	22.5	1.97E+03	9.31E+00	6.47E+02	1.31E+03
Coal, in ground	12.1	1.06E+03	4.95E+00	6.31E+02	4.26E+02
Oil, crude, in ground	9.2	8.00E+02	1.47E+02	3.22E+02	3.31E+02
Uranium oxide, in ore	3.6	3.16E+02	1.69E+00	1.93E+02	1.22E+02
Hydro	1.9	1.64E+02	3.65E-03	1.02E+02	6.27E+01
Wind	0.2	1.86E+01	0.00E+00	1.15E+01	7.03E+00
Solar	0.0	8.94E-01	0.00E+00	5.56E-01	3.39E-01
Geothermal	0.2	1.42E+01	0.00E+00	8.83E+00	5.38E+00
Total	100.0	8.74E+03	1.63E+02	6.28E+03	2.29E+03
Total, %		100	1.9	71.9	26.3

Table 28. Air emissions released per one cubic meter of LVL, cradle-to-gate, PNW, economic allocation.[a]

Air emissions	Total	Forestry operations	Veneer production	LVL production
	kg/m^3			
Acetone	9.82E-03	0.00E+00	9.82E-03	0.00E+00
Acrolein	1.57E-03	5.21E-06	1.55E-03	1.50E-05
Aldehydes, unspecified	7.04E-04	1.31E-04	2.98E-04	2.75E-04
Ammonia	2.95E-03	8.74E-05	2.67E-03	1.90E-04
Benzene	1.94E-02	5.25E-05	1.14E-02	7.96E-03
BTEX[b]	1.24E-02	5.98E-05	4.16E-03	8.15E-03
Carbon dioxide	2.33E+00	2.81E-02	6.31E-02	2.23E+00
Carbon dioxide, biogenic	3.72E+02	8.16E-03	3.69E+02	2.79E+00
Carbon dioxide, fossil	2.00E+02	1.03E+01	1.01E+02	8.90E+01
Carbon monoxide	2.66E-02	3.86E-06	9.06E-03	1.75E-02
Carbon monoxide, biogenic	9.46E-01	0.00E+00	9.42E-01	3.65E-03
Carbon monoxide, fossil	4.08E-01	9.46E-02	1.77E-01	1.36E-01
Cumene	1.16E-02	1.35E-12	2.34E-05	1.16E-02
Dinitrogen monoxide	2.74E-03	1.75E-04	1.46E-03	1.10E-03
Formaldehyde	8.87E-03	6.67E-05	4.14E-03	4.66E-03
HAPs	1.06E-03	0.00E+00	1.05E-03	7.09E-06
Heat, waste	1.28E+01	0.00E+00	6.31E-01	1.21E+01
Hexane	2.23E-04	1.70E-11	3.38E-10	2.23E-04
Hydrocarbons, unspecified	7.53E-03	1.36E-06	1.55E-04	7.37E-03
Hydrogen chloride	2.09E-02	1.06E-04	1.27E-02	8.06E-03
Hydrogen fluoride	2.57E-03	1.24E-05	1.56E-03	9.98E-04
Isoprene	3.42E-02	2.05E-04	2.07E-02	1.33E-02
Magnesium	1.89E-04	9.11E-07	1.14E-04	7.36E-05
Methane	6.41E-01	1.42E-02	2.56E-01	3.71E-01
Methane, biogenic	3.75E-03	0.00E+00	3.73E-03	2.52E-05
Methane, fossil	7.34E-02	1.08E-03	2.57E-02	4.66E-02
Methanol	1.32E-01	0.00E+00	9.99E-03	1.22E-01
Nitrogen oxides	1.12E+00	1.87E-01	7.11E-01	2.17E-01
NMVOC[c]	5.59E-02	6.36E-03	1.61E-02	3.35E-02
Organic substances, unspecified	7.72E-04	5.14E-07	7.12E-04	5.94E-05
Particulates, <10 um	2.47E-01	0.00E+00	1.47E-01	1.01E-01
Particulates, <2.5 um	1.27E-01	0.00E+00	7.63E-02	5.04E-02
Particulates, >10 um	6.21E-04	0.00E+00	4.26E-04	1.94E-04
Particulates, >2.5 um, and < 10 um	2.26E-02	5.74E-03	1.02E-02	6.67E-03
Particulates, unspecified	1.82E-01	1.04E-03	3.65E-02	1.45E-01
Phenol	3.03E-04	4.07E-12	2.20E-04	8.29E-05
Propanal	3.84E-03	9.67E-11	8.61E-06	3.83E-03
Propene	4.53E-03	1.45E-04	1.15E-04	4.27E-03
Radioactive species, unspecified	9.65E+05	4.68E+03	5.88E+05	3.72E+05
Radionuclides (including radon)	1.18E-03	6.31E-06	7.19E-04	4.55E-04
Sulfur dioxide	1.43E+00	6.82E-03	6.35E-01	7.93E-01
Sulfur monoxide	3.94E-02	1.04E-02	2.55E-02	3.44E-03
Sulfur oxides	2.13E-02	1.33E-04	3.64E-04	2.08E-02

[a] Because of a large amount of air emissions, emissions greater than 10^{-4} and HAPs generated from LVL production are shown. A complete list of all air emissions can be found in Appendix E.
[b] BTEX (benzene, toluene, ethylbenzene, and xylene), unspecified ratio.
[c] Nonmethane volatile organic compounds, unspecified origin.

Table 29. Emissions to water released per cubic meter of LVL, cradle-to-gate, PNW, economic allocation.[a]

Water emissions	Total	Forestry operations	Dry veneer production	LVL production
	kg/m^3			
Aluminium	8.68E-03	1.05E-03	3.45E-03	4.18E-03
Ammonia	3.17E-03	2.28E-04	1.19E-03	1.75E-03
Ammonium, ion	2.03E-04	5.04E-08	1.98E-04	5.68E-06
Barium	1.19E-01	1.43E-02	4.61E-02	5.85E-02
Benzene	1.94E-02	2.05E-05	1.70E-04	1.92E-02
Benzoic acid	2.22E-04	1.24E-05	7.98E-05	1.30E-04
BOD5, biological oxygen demand	2.19E-01	2.24E-03	1.47E-02	2.02E-01
Boron	6.87E-04	3.84E-05	2.47E-04	4.02E-04
Bromide	4.69E-02	2.62E-03	1.69E-02	2.75E-02
Calcium	7.04E-01	3.93E-02	2.53E-01	4.12E-01
Chloride	7.91E+00	4.42E-01	2.84E+00	4.63E+00
Chromium	1.83E-04	2.79E-05	6.30E-05	9.18E-05
COD, chemical oxygen demand	2.52E-01	4.24E-03	2.47E-02	2.23E-01
Cumene	2.79E-02	0.00E+00	5.62E-05	2.78E-02
Detergent, oil	2.08E-04	1.03E-05	7.43E-05	1.24E-04
DOC, dissolved organic carbon	5.14E-02	4.03E-13	1.04E-04	5.13E-02
Fluoride	9.65E-04	8.13E-04	9.34E-05	5.91E-05
Iron	2.08E-02	2.09E-03	8.09E-03	1.06E-02
Lithium	1.71E-01	8.38E-04	5.74E-02	1.12E-01
Magnesium	1.38E-01	7.69E-03	4.94E-02	8.05E-02
Manganese	5.23E-04	1.37E-05	2.62E-04	2.46E-04
Metallic ions, unspecified	2.82E-04	6.16E-12	6.23E-10	2.82E-04
Oils, unspecified	4.63E-03	2.82E-04	1.69E-03	2.66E-03
Phosphate	6.35E-04	6.11E-04	0.00E+00	2.43E-05
Propene	1.03E-02	0.00E+00	2.07E-05	1.03E-02
Radioactive species, nuclides, unspecified	1.37E+03	7.32E+00	8.34E+02	5.27E+02
Silver	4.59E-04	2.57E-05	1.65E-04	2.69E-04
Sodium	2.23E+00	1.25E-01	8.01E-01	1.31E+00
Solved solids	3.33E-04	0.00E+00	5.60E-07	3.33E-04
Strontium	1.19E-02	6.68E-04	4.29E-03	6.98E-03
Sulfate	3.52E-02	9.93E-04	1.74E-02	1.68E-02
Sulfur	5.80E-04	3.25E-05	2.08E-04	3.39E-04
Suspended solids, unspecified	1.02E+01	5.78E-01	3.61E+00	6.02E+00
TOC, total organic carbon	5.14E-02	0.00E+00	1.04E-04	5.13E-02
Toluene	3.47E-04	1.94E-05	1.25E-04	2.03E-04
Wastewater/m^3	7.67E-04	0.00E+00	0.00E+00	7.67E-04
Xylene	1.82E-04	1.04E-05	6.54E-05	1.06E-04
Zinc	2.17E-04	2.42E-05	8.74E-05	1.06E-04

[a] Because of large amount of air emissions, emissions greater than 10^{-4} and HAPs generated from LVL production are shown. A complete list of all air emissions can be found in Appendix E.

Table 30. Waste to treatment per one cubic meter of LVL, cradle-to-gate, PNW, economic allocation.

Waste to treatment	Total	Forestry operations	Veneer production	LVL production
	kg/m^3			
Waste in inert landfill	8.88E+00	0.00E+00	8.02E+00	8.63E-01
Waste to recycling	3.95E-01	0.00E+00	0.00E+00	3.95E-01

Table 31. Environmental performance of one cubic meter LVL, cradle-to-gate, PNW, economic allocation.

Impact category	Unit	Total	Forestry operations	Veneer production	LVL production
Global warming	kg CO_2e	2.21E+02	1.08E+01	1.08E+02	1.02E+02
Acidification	kg SO_2e	2.30E+00	1.49E-01	1.18E+00	9.78E-01
Eutrophication	kg Ne	7.75E-02	1.03E-02	3.48E-02	3.24E-02
Ozone depletion	kg CFC-11e	5.23E-07	4.87E-10	2.18E-09	5.21E-07
Smog	kg O_3e	3.09E+01	4.67E+00	1.87E+01	7.55E+00
Total primary energy consumption	**MJ**	**8.74E+03**	**1.63E+02**	**6.28E+03**	**2.29E+03**
Nonrenewable fossil	MJ	3.83E+03	1.61E+02	1.60E+03	2.07E+03
Nonrenewable nuclear	MJ	3.16E+02	1.69E+00	1.93E+02	1.22E+02
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	1.98E+02	3.65E-03	1.23E+02	7.55E+01
Renewable, biomass	MJ	4.39E+03	0.00E+00	4.37E+03	2.77E+01
Material resources consumption (nonfuel resources)	**Unit**	**Total**	**Forestry operations**	**Veneer production**	**LVL production**
Nonrenewable materials	kg	4.76E+00	0.00E+00	4.76E+00	6.49E-05
Renewable materials	kg	8.62E+02	0.00E+00	8.57E+02	4.87E+00
Fresh water	L	1.19E+03	1.03E+01	8.04E+02	3.76E+02
Waste generated	**Unit**	**Total**	**Forestry operations**	**Veneer production**	**LVL production**
Solid waste	kg	9.28E+00	0.00E+00	8.02E+00	1.26E+00

18 APPENDIX D: SUBSTANCE CONTRIBUTION ANALYSIS

Table 32. Substance contribution analysis to acidification (kg SO_2e) by life-cycle stage (total percentage basis and values).

		Mass allocation				Economic allocation			
Substances	**Compartment type**	**Total (%)**	**Forestry operations**	**Veneer production**	**LVL production**	**Total (%)**	**Forestry operations**	**Veneer production**	**LVL production**
Total of all compartments		**100.00**	1.49E-01	1.26E+00	8.75E-01	**100.00**	1.49E-01	1.18E+00	9.78E-01
Sulfur dioxide	Air	61.46	6.82E-03	6.89E-01	7.09E-01	62.27	6.82E-03	6.35E-01	7.93E-01
Nitrogen oxides	Air	34.68	1.31E-01	5.26E-01	1.36E-01	33.88	1.31E-01	4.97E-01	1.52E-01
Sulfur monoxide	Air	1.75	1.04E-02	2.65E-02	3.07E-03	1.71	1.04E-02	2.55E-02	3.44E-03
Other substances	Air	<1	4.11E-04	2.12E-02	2.67E-02	<1	4.11E-04	1.91E-02	2.98E-02

Table 33. Substance contribution analysis to eutrophication (kg Ne) by life-cycle stage (total percentage basis and values).

		Mass Allocation				Economic Allocation			
Substances	**Compartment type**	**TOTAL**	**Forestry Operations**	**Veneer Production**	**LVL production**	**TOTAL**	**Forestry Operations**	**Veneer Production**	**LVL production**
Total of all compartments		**100.00%**	1.03E-02	3.78E-02	2.89E-02	**100.00%**	1.03E-02	3.48E-02	3.24E-02
Nitrogen oxides	Air	65.14%	8.30E-03	3.33E-02	8.59E-03	63.74%	8.30E-03	3.15E-02	9.62E-03
COD, Chemical Oxygen Demand	Water	15.53%	2.12E-04	1.78E-03	9.97E-03	16.24%	2.12E-04	1.24E-03	1.11E-02
BOD5, Biological Oxygen Demand	Water	13.51%	1.12E-04	1.23E-03	9.06E-03	14.16%	1.78E-04	9.28E-04	1.36E-03
Ammonia	Water	3.12%	1.78E-04	1.01E-03	1.22E-03	3.19%	1.03E-02	3.48E-02	3.24E-02
Phosphate	Water	1.96%	1.45E-03	0.00E+00	5.17E-05	1.95%	1.45E-03	0.00E+00	5.77E-05
Other substances	Air	<1%	1.05E-05	5.05E-04	6.70E-05	<1%	9.35E-08	1.54E-04	5.22E-05

Table 34. Substance contribution analysis to smog potential (kg O_3e) by life-cycle stage (total percentage basis and values).

		Mass allocation				Economic allocation			
Substances	**Compartment type**	**Total (%)**	**Forestry operations**	**Veneer production**	**LVL production**	**Total (%)**	**Forestry operations**	**Veneer production**	**LVL production**
Total of all compartments		**100.00**	4.67E+00	1.98E+01	6.74E+00	**100.00**	4.67E+00	1.87E+01	7.55E+00
Nitrogen oxides	Air	89.93	4.65E+00	1.86E+01	4.81E+00	89.44	4.65E+00	1.76E+01	5.38E+00
VOC, volatile organic compounds	Air	7.65	1.81E-02	7.94E-01	1.58E+00	8.09	1.81E-02	7.23E-01	1.76E+00
Isoprene	Air	1.16	2.20E-03	2.36E-01	1.26E-01	1.17	2.20E-03	2.20E-01	1.41E-01
Other substances	Air	<1	3.12E-03	1.52E-01	2.37E-01	<1	3.12E-03	1.33E-01	2.65E-01

19 APPENDIX E: PACIFIC NORTHWEST LVL LIFE-CYCLE INVENTORY FLOWS — ECONOMIC ALLOCATION

Table 35. Economic allocation inventory.

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
1	Calcite	Raw	kg	0.00E+00	0.00E+00	1.22E-03
2	Carbon dioxide, in air	Raw	kg	1.13E+03	7.63E+01	8.86E-01
3	Carbon, organic, in soil or biomass stock	Raw	kg	0.00E+00	0.00E+00	1.12E+03
4	Coal, 26.4 MJ per kg	Raw	kg	1.89E-01	2.41E+01	1.63E+01
5	Coal, 26.4 MJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	8.12E-05
6	Coal, bituminous, 24.8 MJ per kg	Raw	kg	0.00E+00	2.55E-05	1.13E-06
7	Coal, brown	Raw	kg	0.00E+00	2.29E-06	1.02E-07
8	Copper ore	Raw	kg	0.00E+00	0.00E+00	2.46E-03
9	Energy, from biomass	Raw	MJ	0.00E+00	4.23E-06	1.88E-07
10	Energy, from hydro power	Raw	MJ	3.65E-03	1.02E+02	6.27E+01
11	Energy, geothermal	Raw	MJ	0.00E+00	8.83E+00	5.38E+00
12	Energy, kinetic (in wind), converted	Raw	MJ	0.00E+00	1.15E+01	7.03E+00
13	Energy, recovered	Raw	MJ	0.00E+00	3.24E-06	1.44E-07
14	Energy, solar, converted	Raw	MJ	0.00E+00	5.56E-01	3.39E-01
15	Fuel	Raw	m^3	3.36E-03	0.00E+00	0.00E+00
16	Gas, natural, 36.6 MJ per m^3	Raw	m^3	0.00E+00	9.72E-05	4.32E-06
17	Gas, natural, 46.8 MJ per kg	Raw	kg	0.00E+00	1.30E-01	9.13E-06
18	Gas, natural, 46.8 MJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	1.73E-04
19	Gas, natural, in ground	Raw	m^3	0.00E+00	0.00E+00	6.13E-04
20	Gas, natural/m^3	Raw	m^3	2.43E-01	1.69E+01	3.43E+01
21	Iron ore	Raw	kg	0.00E+00	0.00E+00	4.13E-04
22	Limestone	Raw	kg	0.00E+00	4.76E+00	6.49E-05
23	Limestone, in ground	Raw	kg	0.00E+00	0.00E+00	2.99E-02
24	Nitrogen	Raw	kg	0.00E+00	0.00E+00	1.31E-02
25	Nitrogen, in air	Raw	kg	5.29E-02	0.00E+00	0.00E+00
26	Occupation, arable, conservation tillage	Raw	m^{2a}	0.00E+00	0.00E+00	3.86E-04
27	Occupation, arable, conventional tillage	Raw	m^{2a}	0.00E+00	0.00E+00	4.23E-04
28	Occupation, arable, reduced tillage	Raw	m^{2a}	0.00E+00	0.00E+00	2.59E-04
29	Oil, crude	Raw	kg	3.23E+00	7.09E+00	7.28E+00
30	Oil, crude, 42 MJ per kg	Raw	kg	0.00E+00	5.85E-01	4.41E-06
31	Oil, crude, 42 MJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	6.97E-04
32	Oil, crude, 42.7 MJ per kg	Raw	kg	0.00E+00	5.08E-05	2.26E-06
33	Oil, crude, in ground	Raw	kg	0.00E+00	0.00E+00	2.77E-03
34	Oxygen	Raw	kg	0.00E+00	1.25E-04	1.16E-05
35	Oxygen, in air	Raw	kg	0.00E+00	3.12E-03	1.55E+00
36	Pesticides	Raw	kg	0.00E+00	0.00E+00	2.55E-07
37	Phosphate ore, in ground	Raw	kg	0.00E+00	0.00E+00	2.43E-05
38	Phosphorus, in ground	Raw	kg	8.96E-03	0.00E+00	0.00E+00
39	Sand, quartz, in ground	Raw	kg	0.00E+00	0.00E+00	2.83E-06
40	Scrap, external	Raw	kg	0.00E+00	0.00E+00	9.91E-02
41	Seed corn	Raw	kg	0.00E+00	0.00E+00	1.37E-06
42	Sodium carbonate, in ground	Raw	kg	0.00E+00	0.00E+00	3.30E-04
43	Sodium chloride	Raw	kg	0.00E+00	1.95E-03	4.17E+00
44	Sodium chloride, in ground	Raw	kg	0.00E+00	0.00E+00	3.23E-04
45	Sodium sulfate	Raw	kg	0.00E+00	0.00E+00	7.72E-04
46	Sodium sulphate, various forms, in ground	Raw	kg	0.00E+00	0.00E+00	1.02E-03
47	Sulfur, in ground	Raw	kg	0.00E+00	0.00E+00	9.65E-05
48	Sylvinite, in ground	Raw	kg	0.00E+00	0.00E+00	1.19E-05
49	Uranium	Raw	kg	0.00E+00	0.00E+00	1.99E-03
50	Uranium oxide, 332 GJ per kg, in ore	Raw	kg	4.44E-06	5.06E-04	3.20E-04
51	Uranium, 2291 GJ per kg	Raw	kg	0.00E+00	1.97E-06	3.26E-11
52	Uranium, 2291 GJ per kg, in ground	Raw	kg	0.00E+00	0.00E+00	2.33E-09
53	Uranium, in ground	Raw	kg	0.00E+00	0.00E+00	9.30E-09
54	Water, cooling, unspecified natural origin/kg	Raw	kg	0.00E+00	5.72E-04	2.84E-01

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
55	Water, cooling, unspecified natural origin/m^3	Raw	m^3	0.00E+00	1.51E-01	2.44E-01
56	Water, process, surface	Raw	kg	0.00E+00	1.84E+02	3.39E+00
57	Water, process, unspecified natural origin/kg	Raw	kg	0.00E+00	1.06E-02	5.26E+00
58	Water, process, unspecified natural origin/m^3	Raw	m^3	0.00E+00	4.08E-05	1.81E-06
59	Water, process, well	Raw	kg	0.00E+00	8.04E+01	7.64E-01
60	Water, process, well, in ground	Raw	kg	0.00E+00	1.32E-03	6.56E-01
61	Water, river	Raw	m^3	0.00E+00	0.00E+00	4.33E-06
62	Water, unspecified natural origin, RoW	Raw	m^3	0.00E+00	2.64E-04	1.78E-06
63	Water, unspecified natural origin, US	Raw	m^3	0.00E+00	3.85E-01	0.00E+00
64	Water, unspecified natural origin/m^3	Raw	m^3	1.03E-02	2.45E-04	1.21E-01
65	Water, well, in ground	Raw	m^3	0.00E+00	0.00E+00	2.51E-05
66	Water, well, in ground, US	Raw	m^3	0.00E+00	2.72E-03	0.00E+00
67	Wood and wood waste, 20.9 MJ per kg, ovendry basis	Raw	kg	0.00E+00	2.09E+02	1.33E+00
68	Wood and wood waste, 9.5 MJ per kg	Raw	kg	0.00E+00	0.00E+00	9.75E-02
69	Wood for fiber, feedstock	Raw	kg	0.00E+00	0.00E+00	2.09E-01
70	Wood, feedstock	Raw	kg	0.00E+00	0.00E+00	2.22E-01
71	Wood, soft, standing	Raw	m^3	0.00E+00	1.60E+00	1.53E-02
72	Wood, unspecified, standing/kg	Raw	kg	0.00E+00	0.00E+00	1.75E-02
73	2-chloroacetophenone	Air	kg	1.78E-12	3.53E-11	7.78E-10
74	2-methyl-4-chlorophenoxyacetic acid	Air	kg	0.00E+00	0.00E+00	2.55E-11
75	2,4-D	Air	kg	0.00E+00	0.00E+00	1.37E-09
76	5-methyl chrysene	Air	kg	1.82E-12	2.29E-10	1.47E-10
77	Acenaphthene	Air	kg	4.22E-11	5.31E-09	3.41E-09
78	Acenaphthylene	Air	kg	2.07E-11	2.60E-09	1.67E-09
79	Acetaldehyde	Air	kg	4.30E-05	8.70E-03	3.05E-03
80	Acetochlor	Air	kg	0.00E+00	0.00E+00	1.89E-08
81	Acetone	Air	kg	0.00E+00	9.82E-03	0.00E+00
82	Acetophenone	Air	kg	3.82E-12	7.56E-11	1.67E-09
83	Acrolein	Air	kg	5.21E-06	1.55E-03	1.50E-05
84	Alachlor	Air	kg	0.00E+00	0.00E+00	1.86E-09
85	Aldehydes, unspecified	Air	kg	1.31E-04	2.98E-04	2.75E-04
86	Ammonia	Air	kg	8.74E-05	2.67E-03	1.90E-04
87	Ammonium chloride	Air	kg	2.36E-07	2.68E-05	1.70E-05
88	Anthracene	Air	kg	1.74E-11	2.18E-09	1.40E-09
89	Antimony	Air	kg	1.49E-09	1.87E-07	1.27E-07
90	Arsenic	Air	kg	4.72E-08	4.37E-06	2.93E-06
91	Atrazine	Air	kg	0.00E+00	0.00E+00	3.69E-08
92	Barium	Air	kg	0.00E+00	0.00E+00	2.13E-07
93	Bentazone	Air	kg	0.00E+00	0.00E+00	1.51E-10
94	Benzene	Air	kg	5.25E-05	1.14E-02	7.96E-03
95	Benzene, chloro-	Air	kg	5.60E-12	1.11E-10	2.45E-09
96	Benzene, ethyl-	Air	kg	2.39E-11	6.57E-07	1.40E-07
97	Benzo(a)anthracene	Air	kg	6.63E-12	8.32E-10	5.35E-10
98	Benzo(a)pyrene	Air	kg	3.15E-12	3.95E-10	2.54E-10
99	Benzo(b,j,k)fluoranthene	Air	kg	9.11E-12	1.14E-09	7.36E-10
100	Benzo(g,h,i)perylene	Air	kg	2.24E-12	2.81E-10	1.81E-10
101	Benzo(ghi)perylene	Air	kg	0.00E+00	0.00E+00	7.74E-18
102	Benzyl chloride	Air	kg	1.78E-10	3.53E-09	7.78E-08
103	Beryllium	Air	kg	2.32E-09	2.33E-07	1.75E-07
104	Biphenyl	Air	kg	1.41E-10	1.77E-08	1.14E-08
105	Bromoform	Air	kg	9.92E-12	1.97E-10	4.34E-09
106	Bromoxynil	Air	kg	0.00E+00	0.00E+00	3.30E-10
107	BTEX (benzene, toluene, ethylbenzene, and xylene), unspecified ratio	Air	kg	5.98E-05	4.16E-03	8.15E-03
108	Butadiene	Air	kg	2.19E-06	1.63E-06	3.01E-08
109	Cadmium	Air	kg	1.15E-08	8.17E-07	8.36E-07
110	Carbofuran	Air	kg	0.00E+00	0.00E+00	2.82E-10
111	Carbon dioxide	Air	kg	2.81E-02	6.31E-02	2.23E+00
112	Carbon dioxide, biogenic	Air	kg	8.16E-03	3.69E+02	2.79E+00

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
113	Carbon dioxide, fossil	Air	kg	1.03E+01	1.01E+02	8.90E+01
114	Carbon disulfide	Air	kg	3.31E-11	6.55E-10	1.45E-08
115	Carbon monoxide	Air	kg	3.86E-06	9.06E-03	1.75E-02
116	Carbon monoxide, biogenic	Air	kg	0.00E+00	9.42E-01	3.65E-03
117	Carbon monoxide, fossil	Air	kg	9.46E-02	1.77E-01	1.36E-01
118	Chloride	Air	kg	6.25E-12	6.33E-10	4.04E-10
119	Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	Air	kg	0.00E+00	3.34E-10	6.69E-07
120	Chlorine	Air	kg	0.00E+00	3.99E-09	6.67E-06
121	Chloroform	Air	kg	1.50E-11	2.97E-10	6.56E-09
122	Chlorpyrifos	Air	kg	0.00E+00	0.00E+00	2.17E-09
123	Chromium	Air	kg	3.39E-08	3.08E-06	2.38E-06
124	Chromium VI	Air	kg	6.54E-09	8.22E-07	5.28E-07
125	Chrysene	Air	kg	8.28E-12	1.04E-09	6.69E-10
126	Cobalt	Air	kg	6.47E-08	1.25E-06	9.91E-07
127	Copper	Air	kg	5.81E-10	2.11E-08	5.61E-08
128	Cumene	Air	kg	1.35E-12	2.34E-05	1.16E-02
129	Cyanazine	Air	kg	0.00E+00	0.00E+00	3.25E-10
130	Cyanide	Air	kg	6.36E-10	1.26E-08	2.78E-07
131	Dicamba	Air	kg	0.00E+00	0.00E+00	1.92E-09
132	Dimethenamid	Air	kg	0.00E+00	0.00E+00	4.53E-09
133	Dimethyl ether	Air	kg	0.00E+00	1.69E-07	8.38E-05
134	Dinitrogen monoxide	Air	kg	1.75E-04	1.46E-03	1.10E-03
135	Dioxin, 2,3,7,8 tetrachlorodibenzo-p-	Air	kg	2.09E-13	8.88E-12	1.46E-09
136	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	kg	0.00E+00	0.00E+00	3.56E-19
137	Dipropylthiocarbamic acid S-ethyl ester	Air	kg	0.00E+00	0.00E+00	3.10E-09
138	Ethane, 1,1,1-trichloro-, HCFC-140	Air	kg	3.08E-10	7.65E-10	2.84E-09
139	Ethane, 1,2-dibromo-	Air	kg	3.05E-13	6.26E-12	1.33E-10
140	Ethane, 1,2-dichloro-	Air	kg	1.02E-11	2.02E-10	4.45E-09
141	Ethane, chloro-	Air	kg	1.07E-11	2.12E-10	4.67E-09
142	Ethene, tetrachloro-	Air	kg	4.27E-09	4.52E-07	2.96E-07
143	Ethene, trichloro-	Air	kg	0.00E+00	0.00E+00	3.29E-13
144	Ethylene oxide	Air	kg	0.00E+00	1.34E-08	5.98E-10
145	Fluoranthene	Air	kg	5.88E-11	7.39E-09	4.75E-09
146	Fluorene	Air	kg	7.54E-11	9.47E-09	6.09E-09
147	Fluoride	Air	kg	3.36E-07	8.34E-07	5.34E-06
148	Formaldehyde	Air	kg	6.67E-05	4.14E-03	4.66E-03
149	Furan	Air	kg	3.79E-13	5.11E-11	3.22E-11
150	Glyphosate	Air	kg	0.00E+00	0.00E+00	4.07E-09
151	HAPs	Air	kg	0.00E+00	1.05E-03	7.09E-06
152	HAPs, unspecified	Air	kg	0.00E+00	0.00E+00	8.28E-08
153	Heat, waste	Air	MJ	0.00E+00	6.31E-01	1.21E+01
154	Hexane	Air	kg	1.70E-11	3.38E-10	2.23E-04
155	Hydrazine, methyl-	Air	kg	4.33E-11	8.57E-10	1.89E-08
156	Hydrocarbons, unspecified	Air	kg	1.36E-06	1.55E-04	7.37E-03
157	Hydrogen	Air	kg	0.00E+00	1.26E-08	6.15E-06
158	Hydrogen chloride	Air	kg	1.06E-04	1.27E-02	8.06E-03
159	Hydrogen fluoride	Air	kg	1.24E-05	1.56E-03	9.98E-04
160	Hydrogen sulfide	Air	kg	2.02E-13	2.04E-11	1.31E-11
161	Indeno(1,2,3-cd)pyrene	Air	kg	5.05E-12	6.35E-10	4.08E-10
162	Iron	Air	kg	0.00E+00	0.00E+00	2.13E-07
163	Isophorone	Air	kg	1.48E-10	2.92E-09	6.45E-08
164	Isoprene	Air	kg	2.05E-04	2.07E-02	1.33E-02
165	Kerosene	Air	kg	1.13E-07	1.29E-05	8.13E-06
166	Lead	Air	kg	5.24E-08	3.38E-05	3.88E-06
167	Magnesium	Air	kg	9.11E-07	1.14E-04	7.36E-05
168	Manganese	Air	kg	7.02E-08	5.30E-06	5.44E-06
169	Mercaptans, unspecified	Air	kg	5.47E-08	1.08E-06	2.41E-05
170	Mercury	Air	kg	9.31E-09	1.25E-06	2.04E-06
171	Metals, unspecified	Air	kg	2.32E-14	2.35E-12	3.73E-05
172	Methane	Air	kg	1.42E-02	2.56E-01	3.71E-01
173	Methane, biogenic	Air	kg	0.00E+00	3.73E-03	2.52E-05

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
174	Methane, bromo-, Halon 1001	Air	kg	4.07E-11	8.07E-10	1.78E-08
175	Methane, chlorodifluoro-, HCFC-22	Air	kg	0.00E+00	1.12E-13	4.97E-15
176	Methane, chlorotrifluoro-, CFC-13	Air	kg	0.00E+00	1.06E-12	4.72E-14
177	Methane, dichloro-, HCC-30	Air	kg	7.21E-08	3.28E-06	2.72E-06
178	Methane, dichlorodifluoro-, CFC-12	Air	kg	3.75E-10	8.22E-10	7.63E-10
179	Methane, fossil	Air	kg	1.08E-03	2.57E-02	4.66E-02
180	Methane, monochloro-, R-40	Air	kg	1.35E-10	2.67E-09	5.89E-08
181	Methane, tetrachloro-, CFC-10	Air	kg	3.75E-11	4.31E-10	6.83E-07
182	Methanol	Air	kg	0.00E+00	9.99E-03	1.22E-01
183	Methyl ethyl ketone	Air	kg	9.92E-11	1.97E-09	4.34E-08
184	Methyl methacrylate	Air	kg	5.09E-12	1.01E-10	2.22E-09
185	Metolachlor	Air	kg	0.00E+00	0.00E+00	1.50E-08
186	Metribuzin	Air	kg	0.00E+00	0.00E+00	6.93E-11
187	N-nitrodimethylamine	Air	kg	0.00E+00	0.00E+00	7.34E-14
188	Naphthalene	Air	kg	1.34E-08	1.00E-05	6.56E-07
189	Nickel	Air	kg	8.18E-07	6.08E-06	6.78E-06
190	Nitrogen oxides	Air	kg	1.87E-01	7.11E-01	2.17E-01
191	Nitrogen, total	Air	kg	6.36E-06	0.00E+00	1.83E-09
192	NMVOC, nonmethane volatile organic compounds, unspecified origin	Air	kg	6.36E-03	1.61E-02	3.35E-02
193	Organic acids	Air	kg	8.66E-10	9.86E-08	6.24E-08
194	Organic substances, unspecified	Air	kg	5.14E-07	7.12E-04	5.94E-05
195	Other organic	Air	kg	0.00E+00	3.54E-05	2.39E-07
196	PAH, polycyclic aromatic hydrocarbons	Air	kg	9.42E-06	6.94E-06	2.51E-05
197	Paraquat	Air	kg	0.00E+00	0.00E+00	3.03E-10
198	Parathion, methyl	Air	kg	0.00E+00	0.00E+00	2.29E-10
199	Particulates	Air	kg	0.00E+00	8.26E-08	4.09E-05
200	Particulates, <10 um	Air	kg	0.00E+00	1.47E-01	1.01E-01
201	Particulates, <2.5 um	Air	kg	0.00E+00	7.63E-02	5.04E-02
202	Particulates, >10 um	Air	kg	0.00E+00	4.26E-04	1.94E-04
203	Particulates, >2.5 um, and < 10 um	Air	kg	5.74E-03	1.02E-02	6.67E-03
204	Particulates, unspecified	Air	kg	1.04E-03	3.65E-02	1.45E-01
205	Pendimethalin	Air	kg	0.00E+00	0.00E+00	1.56E-09
206	Permethrin	Air	kg	0.00E+00	0.00E+00	1.40E-10
207	Phenanthrene	Air	kg	2.24E-10	2.81E-08	1.81E-08
208	Phenol	Air	kg	4.07E-12	2.20E-04	8.29E-05
209	Phenols, unspecified	Air	kg	3.76E-08	3.65E-07	5.49E-07
210	Phorate	Air	kg	0.00E+00	0.00E+00	7.17E-11
211	Phosphate	Air	kg	1.46E-07	0.00E+00	0.00E+00
212	Phthalate, dioctyl-	Air	kg	1.86E-11	3.68E-10	8.12E-09
213	Polycyclic organic matter, unspecified	Air	kg	0.00E+00	2.70E-12	1.20E-13
214	Potassium	Air	kg	0.00E+00	0.00E+00	3.78E-05
215	Propanal	Air	kg	9.67E-11	8.61E-06	3.83E-03
216	Propene	Air	kg	1.45E-04	1.15E-04	4.27E-03
217	Propylene oxide	Air	kg	0.00E+00	5.94E-07	1.18E-07
218	Pyrene	Air	kg	2.73E-11	3.43E-09	2.21E-09
219	Radioactive species, unspecified	Air	Bq	4.68E+03	5.88E+05	3.72E+05
220	Radionuclides (including radon)	Air	kg	6.31E-06	7.19E-04	4.55E-04
221	Selenium	Air	kg	1.16E-07	1.36E-05	8.88E-06
222	Simazine	Air	kg	0.00E+00	0.00E+00	9.83E-10
223	Sodium	Air	kg	0.00E+00	0.00E+00	8.73E-07
224	Styrene	Air	kg	6.36E-12	1.26E-10	2.78E-09
225	Sulfur	Air	kg	0.00E+00	0.00E+00	4.60E-06
226	Sulfur dioxide	Air	kg	6.82E-03	6.35E-01	7.93E-01
227	Sulfur monoxide	Air	kg	1.04E-02	2.55E-02	3.44E-03
228	Sulfur oxides	Air	kg	1.33E-04	3.64E-04	2.08E-02
229	Sulfur, total reduced	Air	kg	0.00E+00	0.00E+00	2.70E-06
230	Sulfuric acid, dimethyl ester	Air	kg	1.22E-11	2.42E-10	5.34E-09
231	t-butyl methyl ether	Air	kg	8.91E-12	1.76E-10	3.89E-09
232	Tar	Air	kg	7.03E-12	7.11E-10	4.55E-10
233	Terbufos	Air	kg	0.00E+00	0.00E+00	2.45E-09
234	TOC, total organic carbon	Air	kg	0.00E+00	0.00E+00	3.57E-06
235	Toluene	Air	kg	2.29E-05	1.96E-05	8.51E-07

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
236	Toluene, 2,4-dinitro-	Air	kg	7.12E-14	1.41E-12	3.11E-11
237	Vinyl acetate	Air	kg	1.93E-12	3.83E-11	8.45E-10
238	VOC, volatile organic compounds	Air	kg	5.02E-03	2.01E-01	4.90E-01
239	Wood (dust)	Air	kg	0.00E+00	1.05E-01	7.64E-04
240	Xylene	Air	kg	1.60E-05	1.31E-05	4.71E-07
241	Zinc	Air	kg	1.18E-07	1.41E-08	2.51E-07
242	2-hexanone	Water	kg	8.00E-08	5.14E-07	8.36E-07
243	2-methyl-4-chlorophenoxyacetic acid	Water	kg	0.00E+00	0.00E+00	1.09E-12
244	2-propanol	Water	kg	0.00E+00	0.00E+00	2.54E-09
245	2,4-D	Water	kg	0.00E+00	0.00E+00	5.86E-11
246	4-methyl-2-pentanone	Water	kg	5.15E-08	3.31E-07	5.38E-07
247	Acetaldehyde	Water	kg	0.00E+00	1.42E-08	6.29E-10
248	Acetochlor	Water	kg	0.00E+00	0.00E+00	8.11E-10
249	Acetone	Water	kg	1.22E-07	7.87E-07	1.28E-06
250	Acidity, unspecified	Water	kg	0.00E+00	0.00E+00	1.05E-14
251	Acids, unspecified	Water	kg	1.31E-10	1.33E-08	3.61E-06
252	Alachlor	Water	kg	0.00E+00	0.00E+00	7.99E-11
253	Aluminium	Water	kg	1.05E-03	3.45E-03	4.18E-03
254	Aluminum	Water	kg	0.00E+00	0.00E+00	1.02E-05
255	Ammonia	Water	kg	2.28E-04	1.19E-03	1.75E-03
256	Ammonia, as N	Water	kg	6.60E-11	6.67E-09	4.26E-09
257	Ammonium, ion	Water	kg	5.04E-08	1.98E-04	5.68E-06
258	Antimony	Water	kg	6.52E-07	2.01E-06	2.49E-06
259	Arsenic	Water	kg	3.62E-06	1.90E-05	2.97E-05
260	Arsenic, ion	Water	kg	0.00E+00	0.00E+00	1.25E-11
261	Atrazine	Water	kg	0.00E+00	0.00E+00	1.58E-09
262	Barium	Water	kg	1.43E-02	4.61E-02	5.85E-02
263	Bentazone	Water	kg	0.00E+00	0.00E+00	6.45E-12
264	Benzene	Water	kg	2.05E-05	1.70E-04	1.92E-02
265	Benzene, 1-methyl-4-(1-methylethyl)-	Water	kg	1.22E-09	7.86E-09	1.28E-08
266	Benzene, ethyl-	Water	kg	1.16E-06	7.42E-06	1.21E-05
267	Benzene, pentamethyl-	Water	kg	9.18E-10	5.90E-09	9.60E-09
268	Benzenes, alkylated, unspecified	Water	kg	5.72E-07	1.76E-06	2.18E-06
269	Benzo(a)pyrene	Water	kg	0.00E+00	0.00E+00	3.71E-10
270	Benzoic acid	Water	kg	1.24E-05	7.98E-05	1.30E-04
271	Beryllium	Water	kg	1.86E-07	9.27E-07	1.41E-06
272	Biphenyl	Water	kg	3.70E-08	1.14E-07	1.41E-07
273	BOD5, biological oxygen demand	Water	kg	2.24E-03	1.47E-02	2.02E-01
274	Boron	Water	kg	3.84E-05	2.47E-04	4.02E-04
275	Bromide	Water	kg	2.62E-03	1.69E-02	2.75E-02
276	Bromoxynil	Water	kg	0.00E+00	0.00E+00	8.54E-12
277	Cadmium	Water	kg	5.85E-07	2.84E-06	1.06E-05
278	Cadmium, ion	Water	kg	0.00E+00	0.00E+00	3.04E-11
279	Calcium	Water	kg	3.93E-02	2.53E-01	4.12E-01
280	Calcium, ion	Water	kg	0.00E+00	0.00E+00	1.47E-07
281	Carbofuran	Water	kg	0.00E+00	0.00E+00	1.21E-11
282	CFCs, unspecified	Water	kg	0.00E+00	0.00E+00	2.54E-09
283	Chloride	Water	kg	4.42E-01	2.84E+00	4.63E+00
284	Chlorpyrifos	Water	kg	0.00E+00	0.00E+00	9.30E-11
285	Chromate	Water	kg	0.00E+00	0.00E+00	5.84E-13
286	Chromium	Water	kg	2.79E-05	6.30E-05	9.18E-05
287	Chromium III	Water	kg	2.14E-06	2.83E-05	2.08E-05
288	Chromium VI	Water	kg	1.16E-07	2.54E-07	2.35E-07
289	Chromium, ion	Water	kg	0.00E+00	0.00E+00	7.85E-12
290	Cobalt	Water	kg	2.71E-07	1.74E-06	2.84E-06
291	COD, chemical oxygen demand	Water	kg	4.24E-03	2.47E-02	2.23E-01
292	Copper	Water	kg	3.65E-06	2.01E-05	2.49E-05
293	Copper, ion	Water	kg	0.00E+00	0.00E+00	1.30E-11
294	Cumene	Water	kg	0.00E+00	5.62E-05	2.78E-02
295	Cyanazine	Water	kg	0.00E+00	0.00E+00	1.39E-11
296	Cyanide	Water	kg	8.84E-10	5.72E-09	5.17E-08
297	Decane	Water	kg	3.57E-07	2.29E-06	3.73E-06
298	Detergent, oil	Water	kg	1.03E-05	7.43E-05	1.24E-04

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
299	Dibenzofuran	Water	kg	2.33E-09	1.50E-08	2.44E-08
300	Dibenzothiophene	Water	kg	2.00E-09	1.25E-08	2.02E-08
301	Dicamba	Water	kg	0.00E+00	0.00E+00	8.22E-11
302	Dimethenamid	Water	kg	0.00E+00	0.00E+00	1.94E-10
303	Dipropylthiocarbamic acid S-ethyl ester	Water	kg	0.00E+00	0.00E+00	8.02E-11
304	Disulfoton	Water	kg	0.00E+00	0.00E+00	4.79E-12
305	Diuron	Water	kg	0.00E+00	0.00E+00	1.35E-12
306	DOC, dissolved organic carbon	Water	kg	4.03E-13	1.04E-04	5.13E-02
307	Docosane	Water	kg	1.31E-08	8.42E-08	1.37E-07
308	Dodecane	Water	kg	6.77E-07	4.35E-06	7.09E-06
309	Eicosane	Water	kg	1.87E-07	1.20E-06	1.95E-06
310	Fluorene	Water	kg	0.00E+00	2.65E-13	1.18E-14
311	Fluorene, 1-methyl-	Water	kg	1.39E-09	8.95E-09	1.46E-08
312	Fluorenes, alkylated, unspecified	Water	kg	3.31E-08	1.02E-07	1.26E-07
313	Fluoride	Water	kg	8.13E-04	9.34E-05	5.91E-05
314	Fluorine	Water	kg	1.64E-08	5.40E-08	6.93E-08
315	Furan	Water	kg	0.00E+00	0.00E+00	9.30E-11
316	Glyphosate	Water	kg	0.00E+00	0.00E+00	1.74E-10
317	Hexadecane	Water	kg	7.39E-07	4.75E-06	7.73E-06
318	Hexanoic acid	Water	kg	2.57E-06	1.65E-05	2.69E-05
319	Hydrocarbons, unspecified	Water	kg	5.05E-13	5.11E-11	9.08E-05
320	Iron	Water	kg	2.09E-03	8.09E-03	1.06E-02
321	Lead	Water	kg	7.14E-06	3.25E-05	4.75E-05
322	Lead-210/kg	Water	kg	1.27E-15	8.17E-15	1.33E-14
323	Lithium	Water	kg	8.38E-04	5.74E-02	1.12E-01
324	Lithium, ion	Water	kg	0.00E+00	0.00E+00	2.34E-09
325	m-xylene	Water	kg	3.71E-07	2.38E-06	3.88E-06
326	Magnesium	Water	kg	7.69E-03	4.94E-02	8.05E-02
327	Manganese	Water	kg	1.37E-05	2.62E-04	2.46E-04
328	Mercury	Water	kg	1.56E-08	4.27E-08	7.87E-06
329	Metallic ions, unspecified	Water	kg	6.16E-12	6.23E-10	2.82E-04
330	Methane, monochloro-, R-40	Water	kg	4.93E-10	3.17E-09	5.16E-09
331	Methyl ethyl ketone	Water	kg	9.86E-10	6.33E-09	1.03E-08
332	Metolachlor	Water	kg	0.00E+00	0.00E+00	6.41E-10
333	Metribuzin	Water	kg	0.00E+00	0.00E+00	2.97E-12
334	Molybdenum	Water	kg	2.82E-07	1.81E-06	2.94E-06
335	n-hexacosane	Water	kg	8.18E-09	5.25E-08	8.55E-08
336	Naphthalene	Water	kg	2.23E-07	1.43E-06	2.33E-06
337	Naphthalene, 2-methyl-	Water	kg	1.94E-07	1.25E-06	2.03E-06
338	Naphthalenes, alkylated, unspecified	Water	kg	9.37E-09	2.89E-08	3.57E-08
339	Nickel	Water	kg	3.43E-06	1.63E-05	2.48E-05
340	Nickel, ion	Water	kg	0.00E+00	0.00E+00	2.94E-13
341	Nitrate	Water	kg	4.42E-14	4.47E-12	3.02E-07
342	Nitrate compounds	Water	kg	1.78E-12	1.80E-10	1.15E-10
343	Nitric acid	Water	kg	3.99E-09	4.04E-07	2.58E-07
344	Nitrogen, total	Water	kg	1.25E-07	1.43E-05	3.37E-05
345	o-cresol	Water	kg	3.52E-07	2.26E-06	3.69E-06
346	o-xylene	Water	kg	0.00E+00	5.63E-13	2.50E-14
347	Octadecane	Water	kg	1.83E-07	1.17E-06	1.91E-06
348	Oils, unspecified	Water	kg	2.82E-04	1.69E-03	2.66E-03
349	Organic substances, unspecified	Water	kg	0.00E+00	0.00E+00	2.73E-09
350	p-cresol	Water	kg	3.80E-07	2.44E-06	3.98E-06
351	p-xylene	Water	kg	0.00E+00	5.63E-13	2.50E-14
352	Paraquat	Water	kg	0.00E+00	0.00E+00	1.30E-11
353	Parathion, methyl	Water	kg	0.00E+00	0.00E+00	9.81E-12
354	Pendimethalin	Water	kg	0.00E+00	0.00E+00	6.67E-11
355	Permethrin	Water	kg	0.00E+00	0.00E+00	6.00E-12
356	Phenanthrene	Water	kg	3.37E-09	1.40E-08	2.01E-08
357	Phenanthrenes, alkylated, unspecified	Water	kg	3.89E-09	1.20E-08	1.48E-08
358	Phenol	Water	kg	5.11E-06	1.12E-05	1.08E-05
359	Phenol, 2,4-dimethyl-	Water	kg	3.43E-07	2.20E-06	3.59E-06
360	Phenols, unspecified	Water	kg	1.06E-06	2.55E-05	4.87E-05
361	Phorate	Water	kg	0.00E+00	0.00E+00	1.85E-12

No	Substance	Type	Unit	Forest operations	Dry veneer production	LVL production
362	Phosphate	Water	kg	6.11E-04	0.00E+00	2.43E-05
363	Phosphorus	Water	kg	0.00E+00	0.00E+00	5.20E-06
364	Phosphorus compounds, unspecified	Water	kg	0.00E+00	0.00E+00	3.44E-08
365	Phosphorus, total	Water	kg	0.00E+00	0.00E+00	3.07E-06
366	Process solvents, unspecified	Water	kg	0.00E+00	0.00E+00	9.30E-09
367	Propene	Water	kg	0.00E+00	2.07E-05	1.03E-02
368	Radioactive species, nuclides, unspecified	Water	Bq	7.32E+00	8.34E+02	5.27E+02
369	Radium-226/kg	Water	kg	4.43E-13	2.84E-12	4.63E-12
370	Radium-228/kg	Water	kg	2.26E-15	1.45E-14	2.37E-14
371	Selenium	Water	kg	1.44E-07	2.40E-06	1.76E-06
372	Silver	Water	kg	2.57E-05	1.65E-04	2.69E-04
373	Simazine	Water	kg	0.00E+00	0.00E+00	4.21E-11
374	Sodium	Water	kg	1.25E-01	8.01E-01	1.31E+00
375	Sodium, ion	Water	kg	0.00E+00	0.00E+00	4.66E-07
376	Solids, inorganic	Water	kg	1.02E-11	1.03E-09	6.56E-10
377	Solved solids	Water	kg	0.00E+00	5.60E-07	3.33E-04
378	Strontium	Water	kg	6.68E-04	4.29E-03	6.98E-03
379	Styrene	Water	kg	0.00E+00	8.11E-13	3.58E-10
380	Sulfate	Water	kg	9.93E-04	1.74E-02	1.68E-02
381	Sulfide	Water	kg	5.93E-07	1.31E-06	3.47E-05
382	Sulfur	Water	kg	3.25E-05	2.08E-04	3.39E-04
383	Sulfuric acid	Water	kg	0.00E+00	0.00E+00	2.73E-10
384	Surfactants	Water	kg	0.00E+00	2.60E-11	1.16E-12
385	Suspended solids, unspecified	Water	kg	5.78E-01	3.61E+00	6.02E+00
386	Tar	Water	kg	1.01E-13	1.02E-11	6.50E-12
387	Terbufos	Water	kg	0.00E+00	0.00E+00	6.33E-11
388	Tetradecane	Water	kg	2.97E-07	1.91E-06	3.11E-06
389	Thallium	Water	kg	1.37E-07	4.24E-07	5.25E-07
390	Tin	Water	kg	2.67E-06	1.16E-05	1.68E-05
391	Titanium	Water	kg	1.00E-05	3.09E-05	3.82E-05
392	Titanium, ion	Water	kg	0.00E+00	0.00E+00	3.79E-11
393	TOC, total organic carbon	Water	kg	0.00E+00	1.04E-04	5.13E-02
394	Toluene	Water	kg	1.94E-05	1.25E-04	2.03E-04
395	Vanadium	Water	kg	3.33E-07	2.14E-06	3.48E-06
396	Wastewater/m^3	Water	m^3	0.00E+00	0.00E+00	7.67E-04
397	Xylene	Water	kg	1.04E-05	6.54E-05	1.06E-04
398	Yttrium	Water	kg	8.25E-08	5.30E-07	8.63E-07
399	Zinc	Water	kg	2.42E-05	8.74E-05	1.06E-04
400	Zinc, ion	Water	kg	0.00E+00	0.00E+00	4.10E-07
401	Waste in inert landfill	Waste	kg	0.00E+00	0.00E+00	8.63E-01
402	Waste to recycling	Waste	kg	0.00E+00	0.00E+00	3.95E-01
403	Waste, solid	Waste	kg	0.00E+00	0.00E+00	1.10E-02

20 APPENDIX F: PRODUCTION FACILITY SURVEY QUESTIONNAIRES

CORRIM SURVEY

The Consortium for Research on Renewable Industrial Materials (CORRIM)

Laminated Veneer Lumber (LVL) and Composite I-Joist Plants

2014

The information from this survey will be used in a project by CORRIM, a consortium of universities, industry, and government groups. In collaboration with the USDA Forest Service Forest Products Laboratory, APA-The Engineered Wood Association, and the American Wood Council, CORRIM is updating life-cycle assessment data that describes environmental impacts of building materials. This CORRIM survey is designed specifically for LVL and composite I-joist plants. There are three sections for this survey. The three sections are the LVL plant (pg. 3-11), the veneer mill (pg. 12-19), and the I-joist plant (pg. 20-29). Please complete the section(s) that apply to your facilities. Emission data are requested for each section.

Questions will be concentrated on **annual production**, electricity production and usage, fuel consumption, material flows, and environmental emissions. We realize that you may not have all the information requested, especially when it comes to specific equipment/processing groups or what we call 'machine centers'. The data you are able to provide will be appreciated.

Your data will be confidential; only weight-averaged values based on production for the industry will be reported.

Company: ______________________________

Facility Site (city, state): ______________________________

Should we have a follow-up question about the data, please provide the name and the following information for the contact in your company.

Name: ____________________ Title: ____________________

Telephone: ____________________ Email: ____________________

Please send the complete survey to the following email or address by March 3rd. If you have questions about the survey, contact:

Rick Bergman
Research Forest Products Technologist,
USDA Forest Service Forest Products Laboratory
One Gifford Pinchot Dr,
Madison, WI 53726-2398
(608) 231-9477 (ph) / (608) 231-9508 (fax)
rbergman@fs.fed.us

General Plant Information

Yes	No	Equipment in mill
O	O	Veneer dryer (for redry)
O	O	conventional steam, #: _________
O	O	high temp (>212F) steam # _____
O	O	direct fire, # ___________
O	O	continuous, # ___________
O	O	other:___________________
O	O	Hot pressing
O	O	Hot press(es), #_____________
		year built or updated:_______
O	O	heating system
O	O	hot oil (fired by nat. gas)
O	O	microwave
O	O	radio-frequency
		pressure (psig) ________
		temperature (°F) ________
		press time (min:sec) ________
O	O	Precipitator
O	O	Bag house
O	O	Other pollution controls?
O	O	Layup of LVL billets
O	O	Resin
O	O	phenol-formaldehyde
O	O	other ___________
O	O	other ___________
		Inputs
O	O	PLV
O	O	veneer
O	O	Sawing/trimming of LVL
O	O	Resaw
O	O	Rip saw
O	O	In-line moisture meter
O	O	Automatic grading (visual grades)
O	O	Manual grading (visual grades)
O	O	Machine grading (MSR grades)
O	O	End Trim
O	O	Wrap LVL, material ____________
O	O	Steel strapping
O	O	Plastic strapping
O	O	Cardboard corners
O	O	other:___________________
O	O	other:___________________
O	O	other:___________________
O	O	Bag house
O	O	Other pollution control

Yes	No	Equipment in mill (continued)
O	O	Boiler / cogen
O	O	wood boiler(s), #_______
O	O	gas boiler(s), #_________
O	O	oil boiler(s), #_________
O	O	propane boiler(s), #_________
O	O	Cogeneration unit
O	O	Bag house
O	O	Other pollution control?
O	O	Precipitator
O	O	other:_____________
O	O	other:___________________
O	O	other:___________________
O	O	Buy steam
O	O	Sell electricity
O	O	Routing/shaping of web and flanges
O	O	Router(s), # ___________
		Flanges
O	O	LSL
O	O	LVL
O	O	Lumber
O	O	Lumber (finger-jointed)
O	O	Assembly of I-joist
O	O	Resin
O	O	phenol-resorcinol-formaldehyde
O	O	emulsified polyurethane
O	O	other ______________________
		% MC (dry basis) ___________
O	O	Sawing/curing of I-joists
O	O	Ripsaw
O	O	Oven(s), # ___________
		Fuel source_______________
O	O	Wrap LVL, material ____________
O	O	Steel strapping
O	O	Plastic strapping
O	O	Cardboard corners
O	O	other:___________________
O	O	Bag house
O	O	Other pollution control

LVL Plant Annual Wood Production Data

Reporting year __________ Starting month ___________ Ending month ______________

LVL Annual Production			
(Please provide units of measurement if different than stated)			Total Production
1.	Annual LVL production, 2012	ft^3	
	Annual LVL production, 2012	MSF 3/8 in. basis	
	Annual LVL production, 2012	Tons (%MC)	
2.	Veneer		
	a. Produced Veneer:		
	i. Used in Mill	MSF 3/8 in. basis	
	ii. Sold	MSF 3/8 in. basis	
	b. Purchased Veneer:		
	i. Dry	MSF 3/8 in. basis	
	ii. Green	MSF 3/8 in. basis	
	c. Sold Veneer		
	i. Dry	MSF 3/8 in. basis	
	ii. Green	MSF 3/8 in. basis	
	d. Purchased Parallel Laminated Veneer (PLV)	MSF 3/8 in. basis	

Transportation method(s) and average delivery distance for purchased veneer				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for purchased PLV				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		

3. If you either peel/dry or dry veneer on-site, please be sure to complete the next section on veneer mills.

LVL Plant Annual Power and Fuel Consumption

If you have completed a 2012 Annual Fuel and Energy Survey for AF&PA, you may want to attach the survey and skip to the next section entitled "Other Annual Production." The first section refers to energy generation (non-transport fuel). (Please provide units of measurement if different)

Fuel	**Unit**	**Quantity**
Purchased electricity	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	1000 ft^3	
Kerosene (fuel oil #1)	Gallons	
Fuel oil #2	Gallons	
Residual fuel oil #6 (Bunker C)	Gallons	
Diesel	Gallons	
Gasoline	Gallons	
Liquid Propane Gas	Gallons	
Total electricity for LVL plant	kWh	

If your facility produces any of the following for use on-site or for sale, please fill out the table. Enter N/A if not applicable.

Energy	**Unit**	**Quantity (used on-site)**	**Quantity (sold off-site)**
Electricity	kWh		
Steam	lbs (°F)		

If your facility has a boiler, please provide the following. Otherwise, enter N/A as applicable.

Boiler	**Boiler size (million BTU/hr)**	**Boiler fuel**	**Boiler fuel unit**	**Quantity**	**Electricity to operate boiler (kWh)**
#1					
#2					
#3					
#4					

LVL Plant Annual Transportation Fuel Use On-site

(includes all fuels for yard equipment, forklifts, and carriers)

Type	Total Quantity	Percent of total by unit process (percentage or volume)						Units
		Veneer / PLV prep	Layup	Boiler	Hot press	Saw/ trimmer	Support vehicles	
Off-road diesel								Gallons
On-road diesel								Gallons
Propane								Gallons
Gasoline								Gallons
Electricity								kWh
Other								

Other LVL Plant Annual Use Data

Formulation and usage of resin, fillers, and other components		
Component Type	Percent of Solid by Weight (range is ok)	Total annual use (lbs.)
Phenol formaldehyde		
Extender and filler		
Catalyst (NaOH)		
Water		
Other (please specify)		
Other (please specify)		

Transportation method and distance for resin			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation method and distance for extender and filler			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation method and distance for catalysts			
Truck (% of total)		Average delivery miles	

Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Source of Heat for Press: direct or in-direct (circle one)			
Thermal Fluid (Hot Oil) heated by	Units		
Natural Gas	1000 ft^3		
Electricity	kWh		
Steam	lbs		
Radio Frequency	kWh		
Microwave Frequency	kWh		
Other	?		

LVL Plant Annual Wood Residue Production

Wood residues are any wood material produced in conjunction with making LVL and are called co-products in this survey. For each of the co-products produced at your plant, please indicate the weight (tons) of **annual** wood residue production for the reporting period that are shipped to other users, used internally as fuel or for the production of another co-product at your facility, stockpiled for future use or land filled (estimates are acceptable). If zero, enter a dash (-). Please state units if other than tons like cubic yards. The final column (Total Quantity) should equal the sum of the individual rows.

Estimate amount of wood residue produced per Msf of LVL ___________tons/Msf LVL

Wood residue	Moisture Content (wet basis)	Sold (Shipped)	Used Internally (as fuel)	Used Internally (other uses)	Landfill	Inventory	Total Quantity
	(%)	tons	tons	tons	tons	tons	Tons
Veneer loss							
PLV loss							
Lay-up scrap							
Panel trim							
Sawdust (sawing and trimming)							
Sawdust (rip saw)							
Tested LVL, used							
Other							

LVL Plant Ancillary Material Inputs

Ancillary Material	Used		Amount	How amount was found? Mark one[1]		Where the ancillary material is emitted as a percent (estimation is ok)					
	Yes	No		M	E	Veneer / PLV prep	Layup	Boiler	Hot press	Saw/ trimmer	Comments
Hydraulic fluids	O	O	lb/yr	O	O	%	%	%	%	%	
Greases	O	O	lb/yr	O	O	%	%	%	%	%	
Motor Oil	O	O	lb/yr	O	O	%	%	%	%	%	
Plastic wrapping	O	O	lb/yr	O	O	%	%	%	%	%	
Cardboard packaging	O	O	lb/yr	O	O	%	%	%	%	%	
Steel strapping	O	O	lb/yr	O	O	%	%	%	%	%	
Plastic strapping	O	O	lb/yr	O	O	%	%	%	%	%	
Potable water	O	O	gal/yr	O	O	%	%	%	%	%	
Paints	O	O	lb/yr	O	O	%	%	%	%	%	
Waxes	O	O	lb/yr	O	O	%	%	%	%	%	
Other: ____________	O	O	lb/yr	O	O	%	%	%	%	%	
Other: ____________	O	O	lb/yr	O	O	%	%	%	%	%	
Other: ____________	O	O	lb/yr	O	O	%	%	%	%	%	

[1] Estimated (E) / Measured (M)

LVL Plant Air Emissions

If air emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached ☐

Substance	Emit		Amount	How amount was found?[1]			Sampling method or source[2]	Where the substance is emitted as a percent (estimation is ok)				
	Yes	No		M	E	PV		Veneer / PLV prep	Layup	Boiler	Hot press	Saw/ trimmer
Dust	O	O	lb/yr	O	O	O		%	%	%	%	%
Particulate	O	O	lb/yr	O	O	O		%	%	%	%	%
Particulate, PM10[3]	O	O	lb/yr	O	O	O		%	%	%	%	%
Particulate, PM2.5[4]	O	O	lb/yr	O	O	O		%	%	%	%	%
VOC	O	O	lb/yr	O	O	O		%	%	%	%	%
Sulfur dioxide	O	O	lb/yr	O	O	O		%	%	%	%	%
Carbon monoxide	O	O	lb/yr	O	O	O		%	%	%	%	%
Nitrous oxide	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Total	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Methanol	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Formaldehyde	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Acetaldehyde	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Propionaldehyde	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Acrolein	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Phenol	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: Acetone	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: ____________	O	O	lb/yr	O	O	O		%	%	%	%	%
HAP: ____________	O	O	lb/yr	O	O	O		%	%	%	%	%
Other organic[5]: _______	O	O	lb/yr	O	O	O		%	%	%	%	%
Other inorganic[6]: ____	O	O	lb/yr	O	O	O		%	%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement

[2] Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other source.

[3] PM10 is particulate matter up to 10 micrometers in size

[4] PM2.5 is particulate matter up to 2.5 micrometers in size

[5] Non-HAP organics that are not included in VOC value.

[6] Inorganics such as chlorine, mercury sulfur.

LVL Plant Water Emissions

If water emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached ☐

Substance	Emit		Amount[2]	How amount was found Mark one[3]			Sampling method or source[1]	Where the substance is emitted as a percent (estimation is ok)				
	Yes	No		M	E	PV		Veneer / PLV prep	Layup	Boiler	Hot press	Saw/ trimmer
Suspended solids	O	O	lb/yr	O	O	O		%	%	%	%	%
BOD	O	O	lb/yr	O	O	O		%	%	%	%	%
COD	O	O	lb/yr	O	O	O		%	%	%	%	%
Oil and grease	O	O	lb/yr	O	O	O		%	%	%	%	%
HAPs	O	O	lb/yr	O	O	O		%	%	%	%	%
Chemicals in boiler blowdown (if not included above)	O	O	lb/yr	O	O	O		%	%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%	%

[1] Sampling methods is type of water test or how estimate was obtained.

[2] Report the mass of material, not the mass of material and water.

[3] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.

LVL Plant Solid Waste Production

If annual solid waste summary is available, please provide as an alternative to the following table. Check here if summary is attached □

Material	Amount[2] (lb/yr)	Where material is going? Landfill (L) or recycled (R) Mark one	How amount was found? Mark one[1]			Where the solid waste is emitted as a percent (estimation is ok)				
			M	E	PV	Veneer / LVL prep	Layup	Boiler	Hot press	Saw/ trimmer
Discarded Wood		L / R	O	O	O	%	%	%	%	%
Discarded Bark		L / R	O	O	O	%	%	%	%	%
Dirt and rocks		L / R	O	O	O	%	%	%	%	%
Ash		L / R	O	O	O	%	%	%	%	%
Plastic wrap		L / R	O	O	O	%	%	%	%	%
Metal strapping		L / R	O	O	O	%	%	%	%	%
Plastic strapping		L / R	O	O	O	%	%	%	%	%
Other metals		L / R	O	O	O	%	%	%	%	%
Other organics		L / R	O	O	O	%	%	%	%	%
Other non-organics		L / R	O	O	O	%	%	%	%	%
Other: ___________		L / R	O	O	O	%	%	%	%	%
Other: ___________		L / R	O	O	O	%	%	%	%	%
Other: ___________		L / R	O	O	O	%	%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.

[2] Report the mass of material, for example, report wood separately from dirt and rocks.

LVL Plant Annual Water Use

Type	Total Quantity	Percent of total by unit process (percentage or volume; estimation is ok)					Units
		Veneer / LVL prep	Layup	Boiler	Hot press	Saw/ trimmer	
Input							
Surface water							Gallons
Groundwater							Gallons
Municipal water							Gallons
Output							
Water discharged							Gallons
Water recycled							Gallons

Recycling rate of water helps reduce the water footprint.

What percent of water is recycled?		%
Was water measured or estimated?		

LVL Plant Emission Control Device (ECD)

The following is a chart of emission control devices. Please fill in all information related to the control devices.

Emission Control Device (ECD)- Type, Electricity, Fuel Usage					
	ECD 1	ECD 2	ECD 3	ECD 4	ECD 5
Equipment controlled (i.e., boiler, press, dryer, etc.)					
Type					
Model					
Year Installed					
Electricity used to operate ECD; either kWh or % of total plant use					
Natural Gas used to operate ECD; either $ft.^3$ or % of total plant use					

Machine Center Breakdown for Electricity and Fuel Use

Fill in all that apply and for which you have data. If you **do not** have given machines center such as the co-generator, either draw **a line** through that row and **write N/A**.

	Model/Type	**Annual electricity**	**Fuel Usage**
Machine Center	**Year Installed**	**kWh or % of the total use for mill**	**% of total use for mill**
Co-generator			
Lay-up			
Press(es)			
#1			
#2			
#3			
#4			
Billet Cuts			
Rip Saw			

If you do not peel or dry veneer or produce I-joists, congratulations you have completed the survey! However, if you do, please complete the following pages.

Veneer Mill Annual Wood Production Data

Please fill in all the information that pertains just to your plant.

Type of veneer dryer: Longitudinal, Cross flow, Jet, Rotary (circle one)

Log scale: Dolye, International, Scribner, Weight base (circle one)

Total volume of incoming softwood logs	________	thousand BF/year
Total volume of incoming green veneer	________	thousand ft^2 3/8” basis/year
Total volume of veneer produced on-site	________	thousand ft^2 3/8” basis/year
Total volume of veneer produced on-site used on-site	________	thousand ft^2 3/8” basis/year

Please complete the following table showing the breakdown of the ***individual tree species*** and approximate ***sizes*** processed by your mill by species and the average log diameter. If less than 2% of total, use category labeled “Other”.

Species	% of total log input into veneer mill	Log Diameter* (in)
Total	100%	

*Please provide individual log diameters if known otherwise please state the average or range of logs processed at your facility in bottom row under Log Diameter

Wood species processed into veneer and approximate percentage of total:			
Species	Volume (Msf 3/8")	%MC (wet basis)	Percent
Total			100%

MILEAGE: Over the Road _______% By Rail_______%

Total number of log deliveries made to this facility annually ____________ # per year
Average one-way mileage travel to this facility to deliver logs ____________ miles

Veneer Mill Annual Transportation Fuel Use On-site

(includes all fuels for yard equipment, forklifts, and carriers)

Type	Total Quantity	Percent of total by unit process (percentage or volume)					Units
		Bucking & Debarking	Block Conditioning	Peeling & Clipping	Drying	Support Vehicle	
Off-road diesel							Gallons
On-road diesel							Gallons
Propane							Gallons
Gasoline							Gallons
Electricity							kWh
Other							

Veneer Mill Annual (Non-Transportation) Fuel Use

(boilers, cogeneration units, etc.)

Fuel	Unit	Quantity
Total electricity for veneer mill	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	1000 ft^3	
Kerosene (fuel oil #1)	Gallons	
Fuel oil #2	Gallons	
Residual fuel oil #6 (Bunker C)	Gallons	
Diesel	Gallons	
Gasoline	Gallons	
Liquid Propane Gas	Gallons	

If your facility has a boiler, please provide the following. Otherwise, enter N/A as applicable.

Boiler	Boiler size (million BTU/hr)	Boiler Fuel	Boiler Fuel Unit	Quantity	Electricity to operate boiler (kWh)
#1					
#2					
#3					
#4					

Veneer Mill Machine Center Breakdown

Fill in all that apply and for which you have data. If you do not have a given machine center, draw a line through that row and write None. Please provide units.

Machine Center	Model/Type Year Installed	Annual Electricity Usage kWh or % of total electricity use for mill **(Estimation is ok)**	Fuel Usage % of total use for mill **(Estimation is ok)**
Bucking & Debarking			
Log Conditioning			
Peeling & Clipping			
Drying			
Energy Generation			
Emissions control			
Total veneer mill			

Veneer Mill Annual Wood Residue Production

This is a general material flow survey for veneer mills. Wood residues are any wood material produced in conjunction with making LVL and are called co-products in this survey. This survey is designed to trace all wood components generated during production.

Estimate amount of wood residue produced per Msf of veneer ____________tons/Msf veneer

Wood residue	Moisture Content (wet basis) (%)	Sold (Shipped) tons	Used Internally (as fuel) tons	Used Internally (other uses) tons	Landfill tons	Total Quantity Tons
Bark, green						
Roundup wood, green						
Peeler core, green						
Clippings, green						
Veneer downfall						
Trim , green						
Chips, green						
Hogged material						
Waste gate material						
Clippings, green						
Other						

For dryer(s), check heat source and give the annual fuel consumption: indirect or direct (circle one)		
Heat source		
☐ Steam	lbs	
☐ Natural gas direct-fired	ft^3	
☐ Wood fuel	Tons (%MC)	/
☐ Other		

Veneer moisture content information		
Average moisture content into dryer	% ovendry basis	
Average moisture content out of dryer	% ovendry basis	
Redry rate	%	

Transportation method and distance for veneer logs			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Veneer Mill Ancillary Material Inputs

Ancillary Material	Used		Amount	How amount was found? Mark one[1]		Where the ancillary material is emitted as a percent (estimation is ok)				
	Yes	No		M	E	Bucking & Debarking	Block Conditioning	Peeling & Clipping	Drying	Comments
Hydraulic fluids	O	O	lb/yr	O	O	%	%	%	%	
Greases	O	O	lb/yr	O	O	%	%	%	%	
Motor Oil	O	O	lb/yr	O	O	%	%	%	%	
Plastic wrapping	O	O	lb/yr	O	O	%	%	%	%	
Cardboard packaging	O	O	lb/yr	O	O	%	%	%	%	
Steel strapping	O	O	lb/yr	O	O	%	%	%	%	
Plastic strapping	O	O	lb/yr	O	O	%	%	%	%	
Potable water	O	O	gal/yr	O	O	%	%	%	%	
Paints	O	O	lb/yr	O	O	%	%	%	%	
Waxes	O	O	lb/yr	O	O	%	%	%	%	
Runners	O	O	lb/yr	O	O	%	%	%	%	
Boiler chemicals	O	O	lb/yr	O	O	%	%	%	%	
Other: ____________	O	O	lb/yr	O	O	%	%	%	%	
Other: ____________	O	O	lb/yr	O	O	%	%	%	%	
Other: ____________	O	O	lb/yr	O	O	%	%	%	%	

[1] Estimated (E) / Measured (M)

Veneer Mill Air Emissions

If air emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached □

Substance	Emit		Amount	How amount was found? Mark one[1]			Sampling method or source[2]	Where the substance is emitted as a percent (estimation is ok)			
	Yes	No		M	E	PV		Bucking & Debarking	Block Conditioning	Peeling & Clipping	Drying
Dust	O	O	lb/yr	O	O	O		%	%	%	%
Particulate	O	O	lb/yr	O	O	O		%	%	%	%
Particulate, PM10[3]	O	O	lb/yr	O	O	O		%	%	%	%
Particulate, PM2.5[4]	O	O	lb/yr	O	O	O		%	%	%	%
VOC	O	O	lb/yr	O	O	O		%	%	%	%
Sulfur dioxide	O	O	lb/yr	O	O	O		%	%	%	%
Carbon monoxide	O	O	lb/yr	O	O	O		%	%	%	%
Nitrous oxide	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Total	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Methanol	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Formaldehyde	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Acetaldehyde	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Propionaldehyde	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Acrolein	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Phenol	O	O	lb/yr	O	O	O		%	%	%	%
HAP: Acetone	O	O	lb/yr	O	O	O		%	%	%	%
HAP: ____________	O	O	lb/yr	O	O	O		%	%	%	%
Other organic[5]: _______	O	O	lb/yr	O	O	O		%	%	%	%
Other inorganic[6]: _____	O	O	lb/yr	O	O	O		%	%	%	%
Other: __________	O	O	lb/yr	O	O	O		%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement
[2] Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other source.
[3] PM10 is particulate matter up to 10 micrometers in size
[4] PM2.5 is particulate matter up to 2.5 micrometers in size
[5] Non-HAP organics that are not included in VOC value.
[6] Inorganics such as chlorine, mercury sulfur.

Veneer Mill Water Emissions

If water emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached ☐

Substance	Emit		Amount[2]	How amount was found? Mark one[3]			Sampling method or source[1]	Where the substance is emitted as a percent (Estimation is ok)			
	Yes	No		M	E	PV		Bucking & Debarking	Block Conditioning	Peeling & Clipping	Drying
Suspended solids	O	O	lb/yr	O	O	O		%	%	%	%
BOD	O	O	lb/yr	O	O	O		%	%	%	%
COD	O	O	lb/yr	O	O	O		%	%	%	%
Oil and grease	O	O	lb/yr	O	O	O		%	%	%	%
HAPs	O	O	lb/yr	O	O	O		%	%	%	%
Chemicals in boiler blowdown (if not included above)	O	O	lb/yr	O	O	O		%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%
Other: ______________	O	O	lb/yr	O	O	O		%	%	%	%

[1] Sampling methods is type of water test or how estimate was obtained.

[2] Report the mass of material, not the mass of material and water.

[3] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.

Veneer Mill Solid waste

If annual solid waste summary is available, please provide as an alternative to the following table.
Check here if summary is attached □

Material	Amount[2] (lb/yr)	Where material is going? Landfill (L) or recycled (R)	How amount was found? Mark one[1]	Where the solid waste is emitted as a percent (estimation is ok)			
				Bucking & Debarking	Block Conditioning	Peeling & Clipping	Drying
Discarded Wood		L / R	M / E / PV	%	%	%	%
Discarded Bark		L / R	M / E / PV	%	%	%	%
Dirt and rocks		L / R	M / E / PV	%	%	%	%
Ash		L / R	M / E / PV	%	%	%	%
Plastic wrap		L / R	M / E / PV	%	%	%	%
Plastic strapping		L / R	M / E / PV	%	%	%	%
Metal strapping		L / R	M / E / PV	%	%	%	%
Plastic bags		L / R	M / E / PV	%	%	%	%
Other metals		L / R	M / E / PV	%	%	%	%
Other organics		L / R	M / E / PV	%	%	%	%
Other non organics		L / R	M / E / PV	%	%	%	%
Other: ___________		L / R	M / E / PV	%	%	%	%
Other: ___________		L / R	M / E / PV	%	%	%	%
Other: ___________		L / R	M / E / PV	%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.
[2] Report the mass of material, for example, report wood separately from dirt and rocks.

Veneer Mill Annual Water Use

Type	Total Quantity	Percent of total by unit process (percentage or volume)				Units
		Bucking & Debarking	Block Conditioning	Peeling & Clipping	Drying	
Input						
Surface water						Gallons
Groundwater						Gallons
Municipal water						Gallons
Output						
Water discharged						Gallons
Water recycled						Gallons

Recycling rate of water helps reduce the water footprint.

What percent of water is recycled?		%
Was water measured or estimated?		

2012 Composite I-joists Annual Production Plant Data

Please fill in all information relevant to producing I-joists. Please provide the data on an annual basis for the year which the data is reported.

Annual I-Joists Production for 2012			
Product (Series)	Amount (lin.ft.)	Joist Depth (in.)	Flange dim. (in. x in.)

I-joists Construction-Web		
Material	Percent of total	Annual consumption (MSF 3/8”)
OSB		
Plywood		
Total	100%	

Transportation Method and Delivery Distance for OSB			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation Method and Delivery Distance for plywood			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Estimate amount of wood residue produced per Msf of I-joist ___________tons/Msf I-joist

Wood residue	Moisture Content (wet basis)	Sold (Shipped)	Used Internally (as fuel)	Used Internally (other uses)	Landfill	Inventory	Total Quantity
	(%)	tons	tons	tons	tons	tons	Tons
Sawdust, dry							
Other							
Other							

I-joists Construction-Flange

Material	Percent of total	Annual consumption (MSF 3/8")
LVL		
LSL		
Lumber (finger-jointed)		
Total	100%	

Transportation Method and Delivery Distance for LVL

Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation Method and Delivery Distance for LSL

Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation Method and Delivery Distance for lumber (finger-jointed)

Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Annual Resin Consumption Data

Resin consumption is comprised of three different scenarios: 1) web-joint, 2) flange finger-joint, and 3) I-joist (web to flange)

1. Web-joint resin consumption	
Resin type	
Percent water	

Transportation Method and Delivery Distance for web-joint resin			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

- Please include the amount of resin used in the web-joints of the I-joist in this section. Please state whether weight is given as wet or dry weight.
- If you use the same resin for the web-joint, finger-joint, and web to flange-joint, complete the following table with total resin use and check this box ☐ ☐
- Otherwise, fill in resin use for web-joint only and then proceed to fill out resin data for flange finger-joints and I-joist (web to flange).

Formulation and usage of web-joint resin, fillers, and other components			
Component Type	Range % of Solid by Weight	Total Annual Use (lbs.)	Circle one
Resin			Wet or dry
Extender and filler			Wet or dry
Catalyst (NaOH)			Wet or dry
Water			
Other (please specify)			Wet or dry
Resin loss (lbs)			Wet or dry

2. Flange finger-joint resin consumption	
Resin type	
Percent water	

Transportation Method and Delivery Distance for flange finger-joint resin			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Formulation and usage of flange finger-joint resin, fillers, and other components			
Component Type	Range % of Solid by Weight	Total Annual Use (lbs.)	Circle one
Resin			Wet or dry
Extender and filler			Wet or dry
Catalyst (NaOH)			Wet or dry
Water			
Other (please specify)			Wet or dry
Resin loss (lbs)			Wet or dry

3. I-joist (web-to-flange) resin consumption	
Resin type	
Percent water	

Transportation Method and Delivery Distance for I-joist (web-to-flange) resin			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Formulation and usage of I-joist (web-to-flange) resin, fillers, and other components			
Component Type	Range % of Solid by Weight	Total Annual Use (lbs.)	Circle one
Resin			Wet or dry
Extender and filler			Wet or dry
Catalyst (NaOH)			Wet or dry
Water			
Other (please specify)			Wet or dry
Resin loss (lbs)			Wet or dry

I-joist Plant Annual (Non-Transportation) Fuel Use

(boilers, cogeneration units, etc.)

Fuel	Unit	Quantity
Total electricity for I-joist plant	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	1000 ft^3	
Kerosene (fuel oil #1)	Gallons	
Fuel oil #2	Gallons	
Residual fuel oil #6 (Bunker C)	Gallons	
Diesel	Gallons	
Gasoline	Gallons	
Liquid Propane Gas	Gallons	

If your facility has a boiler, please provide the following. Otherwise, enter N/A as applicable.

Boiler	Boiler size (million BTU/hr)	Boiler Fuel	Boiler Fuel Unit	Quantity	Electricity to operate boiler (kWh)
#1					
#2					
#3					

For oven(s), check heat source and give the annual fuel consumption: **indirect or direct (circle one)**		
Heat source		
☐ Steam	lbs	
☐ Natural gas direct-fired	ft^3	
☐ Wood fuel	Tons (%MC)	/
☐ Other		

I-Joist Plant Annual Transportation Fuel Use On-site

(includes all fuels for yard equipment, forklifts, and carriers)

Type	Total Quantity	Percent of total by unit process (percentage or volume)					Units
		Routing / shaping	Assembly	Sawing	Curing	Support vehicles	
Off-road diesel							Gallons
On-road diesel							Gallons
Propane							Gallons
Gasoline							Gallons
Electricity							kWh
Other							

Machine Center Breakdown for Electricity and Fuel Use

Fill in all that apply and for which you have data. If you **do not** have a given machine center that is listed here, either **draw a line** through that row and **write N/A**.

Machine Center	**Model/Type** **Year Installed**	**Annual Electricity** **kWh or % of the Total Use for Mill**	**Fuel Usage** **% of Total Use for Mill**
OSB/Plywood saws			
LVL/FJ lumber saws			
Web joint shaper/router			
I-joist assembler			
I-joist saw			
Other (please specify)			
Curing Oven			
Steam			
Electricity			
Natural Gas			

I-joist Plant Ancillary Material Inputs

Ancillary Material	Used		Amount	How amount was found? Circle one[1]	Where the ancillary material is emitted as a percent (estimation is ok)				
	Yes	No			Routing / shaping	Assembly	Sawing	Curing	Comments
Hydraulic fluids	O	O	lb/yr	M / E	%	%	%	%	
Greases	O	O	lb/yr	M / E	%	%	%	%	
Motor Oil	O	O	lb/yr	M / E	%	%	%	%	
Plastic wrapping	O	O	lb/yr	M / E	%	%	%	%	
Cardboard packaging	O	O	lb/yr	M / E	%	%	%	%	
Steel strapping	O	O	lb/yr	M / E	%	%	%	%	
Plastic strapping	O	O	lb/yr	M / E	%	%	%	%	
Potable water	O	O	gal/yr	M / E	%	%	%	%	
Paints	O	O	lb/yr	M / E	%	%	%	%	
Waxes	O	O	lb/yr	M / E	%	%	%	%	
Plastic strapping	O	O	lb/yr	M / E	%	%	%	%	
Runners	O	O	lb/yr	M / E	%	%	%	%	
Boiler chemicals	O	O	lb/yr	M / E	%	%	%	%	
Other: ______________	O	O	lb/yr	M / E	%	%	%	%	
Other: ______________	O	O	lb/yr	M / E	%	%	%	%	
Other: ______________	O	O	lb/yr	M / E	%	%	%	%	

[1] Estimated (E) / Measured (M)

I-joist Plant Air Emissions

If air emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached □

Substance	Emit		Amount	How amount was found? Circle one[1]	Sampling method or source[2]	Where the substance is emitted as a percent (estimation is ok)			
	Yes	No				Routing / shaping	Assembly	Sawing	Curing
Dust	O	O	lb/yr	M / E / PV		%	%	%	%
Particulate	O	O	lb/yr	M / E / PV		%	%	%	%
Particulate, PM10[3]	O	O	lb/yr	M / E / PV		%	%	%	%
Particulate, PM2.5[4]	O	O	lb/yr	M / E / PV		%	%	%	%
VOC	O	O	lb/yr	M / E / PV		%	%	%	%
Sulfur dioxide	O	O	lb/yr	M / E / PV		%	%	%	%
Carbon monoxide	O	O	lb/yr	M / E / PV		%	%	%	%
Nitrous oxide	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Total	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Methanol	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Formaldehyde	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Acetaldehyde	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Propionaldehyde	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Acrolein	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Phenol	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: Acetone	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: ___________	O	O	lb/yr	M / E / PV		%	%	%	%
HAP: ___________	O	O	lb/yr	M / E / PV		%	%	%	%
Other organic[5]: ______	O	O	lb/yr	M / E / PV		%	%	%	%
Other inorganic[6]: ____	O	O	lb/yr	M / E / PV		%	%	%	%
Other: _____________	O	O	lb/yr	M / E / PV		%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement
[2] Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other source.
[3] PM10 is particulate matter up to 10 micrometers in size
[4] PM2.5 is particulate matter up to 2.5 micrometers in size
[5] Non-HAP organics that are not included in VOC value.
[6] Inorganics such as chlorine, mercury sulfur.

I-joist Plant Water Emissions

If water emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached □

Substance	Emit		Amount[2]	How amount was found? Circle one[3]	Sampling method or source[1]	Where the substance is emitted as a percent (estimation is ok)			
	Yes	No				Routing / shaping	Assembly	Sawing	Curing
Suspended solids	O	O	lb/yr	M / E / PV		%	%	%	%
BOD	O	O	lb/yr	M / E / PV		%	%	%	%
COD	O	O	lb/yr	M / E / PV		%	%	%	%
Oil and grease	O	O	lb/yr	M / E / PV		%	%	%	%
HAPs	O	O	lb/yr	M / E / PV		%	%	%	%
Chemicals in boiler blowdown (if not included above)	O	O	lb/yr	M / E / PV		%	%	%	%
Other: ______________	O	O	lb/yr	M / E / PV		%	%	%	%
Other: ______________	O	O	lb/yr	M / E / PV		%	%	%	%
Other: ______________	O	O	lb/yr	M / E / PV		%	%	%	%
Other: ______________	O	O	lb/yr	M / E / PV		%	%	%	%
Other: ______________	O	O	lb/yr	M / E / PV		%	%	%	%

[1] Sampling methods is type of water test or how estimate was obtained.

[2] Report the mass of material, not the mass of material and water.

[3] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.

I-joist Plant Solid waste

If annual solid waste summary is available, please provide as an alternative to the following table. Check here if summary is attached □

Material	Amount[2] (lb/yr)	Where material is going? Landfill (L) or recycled (R)	How amount was found? Circle one[1]	Where the solid waste is emitted as a percent (estimation is ok)			
				Routing / shaping	Assembly	Sawing	Curing
Discarded Wood		L / R	M / E / PV	%	%	%	%
Discarded Bark		L / R	M / E / PV	%	%	%	%
Dirt and rocks		L / R	M / E / PV	%	%	%	%
Ash		L / R	M / E / PV	%	%	%	%
Plastic wrap		L / R	M / E / PV	%	%	%	%
Metal strapping		L / R	M / E / PV	%	%	%	%
Cardboard packaging		L / R	M / E / PV	%	%	%	%
Plastic bags		L / R	M / E / PV	%	%	%	%
Other metals		L / R	M / E / PV	%	%	%	%
Other organics		L / R	M / E / PV	%	%	%	%
Other non organics		L / R	M / E / PV	%	%	%	%
Other: ____________		L / R	M / E / PV	%	%	%	%
Other: ____________		L / R	M / E / PV	%	%	%	%
Other: ____________		L / R	M / E / PV	%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.

[2] Report the mass of material, for example, report wood separately from dirt and rocks.

I-joist Plant Annual Water Use

Type	Total Quantity	Percent of total by unit process (percentage or volume)				Units
		Routing / shaping	Assembly	Sawing	Curing	
Input						
Surface water						Gallons
Groundwater						Gallons
Municipal water						Gallons
Output						
Water discharged						Gallons
Water recycled						Gallons

Recycling rate of water helps reduce the water footprint.

What percent of water is recycled?		%
Was water measured or estimated? M/E		

Annual Emission Control Device and Environmental Emission

The following is a chart of emission control devices and a listing of chemical compounds that are observed and/or permitted. Please fill in all information related to the control devices. Then list all compounds that are collected and known for the mill for all control device sources. If you recently applied for air permit, use those numbers. Fill in all that apply and for which you have data.

Annual Emission Control Device (ECD)- Electricity and Fuel Usage					
	ECD 1	ECD 2	ECD 3	ECD 4	ECD 5
Equipment controlled (i.e., boiler, press, dryer, etc.)					
Type					
Model					
Year Installed					
Electricity used to operate ECD; either kWh or % of total plant use					
Natural gas used to operate ECD; either ft^3 or % of total plant use					