

Cradle to Gate Life Cycle Assessment of Laminated Veneer Lumber Production from the Pacific Northwest

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1 Background

CORRIM, the Consortium for Research on Renewable Industrial Materials, has conducted life cycle inventory (LCI) for major wood products and wood production regions in 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 including both structural and nonstructural uses and four major regions: in this report we focus on laminated veneer lumber (LVL) produced in the US Pacific Northwest (PNW) region. The PNW regional data is a representative cross-section of forest growth and manufacturing processes in western Washington and Oregon. This document updates the current wood product LCI's from a gate to gate to a cradle to gate LCI. Updates include the addition of PNW forestry operations, boiler, resin, and electrical grid data that have been developed since the original mill surveys were conducted during 1999 and 2000. The updated LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2 (Simapro version 4.0)(Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare et al. 2011). These updates are necessary for the development of environmental product declarations (EPD) which will be based on this document. This document originates from the CORRIM LCI reports by Wilson and Dancer (2004, 2005) and Johnson et al. (2005). Updates in this report from the original Wilson and Dancer (2004) report include: North American resin data (Wilson 2009), wood combustion boiler updates, and electricity grid updates (Goemans 2010), with results expressed per unit of final product (1 m³ laminated veneer lumber), and an LCIA. Updates to veneer production fall under the "Cradle to gate life cycle assessment of softwood plywood from the Pacific Northwest" report (Puettmann et al. 2012). Updates to the forestry operations report include electricity grid updates and an LCIA using the TRACI method. This report follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011) that will provide the guidance for preparation of North American wood product EPD. This report does not include comparative assertions.

2 Introduction

The goal of this work is to determine energy and material inputs and outputs associated with the production of laminated veneer lumber from the manufacturing base located in the PNW region of North

America. These data are needed for the inclusion of the production process in life-cycle analyses of wood. The data were obtained through a scientifically sound and consistent process established by the Consortium for Research on Renewable Industrial Materials (CORRIM), following ISO14040 standards (ISO 2006).

The scope of this study includes cradle-to-gate LCIs based on primary data for producing laminated veneer lumber from dry veneer using practices and technology common to the PNW region. Veneer production was obtained from the same unit process as developed for softwood plywood (Wilson and Sakimoto 2004, 2005; Puettmann et al. 2012). The logs used for veneer production are obtained from the forest resource base located in western Washington and Oregon as representative of the PNW region. Data for the LCA are based on manufacturing gate to gate LCI's from CORRIM reports (Wilson and Dancer 2004, 2005), the resin LCI's from CORRIM reports (Wilson 2009) and forest resources cradle to gate LCI's specific to the region (Johnson et al. 2005). The report does not consider the impact of how the wood was used which requires a comparison to the impact of substitute products.

3 Description of Product

Laminated veneer lumber is a composite wood material made from sheets of veneer generally 2.54 mm or 3.18 mm (1/10 in. or 1/8 in.) thick that are laminated together with their grain orientation in the same direction and then hot-pressed (Figure 1). LVL was first used in WWII to make airplane propellers and since the 1970s it has been used as a construction product (Neuvonen et al. 1998). LVL can vary in thickness and width but is most commonly produced in the dimensions of 4.45 cm (1 3/4-in.) thick and 121.9 cm (4 ft.) wide, into lengths from 2.44 to 18.29 m (8 to 60 ft.). It is used as an alternative to structural lumber for headers and beams and also as the flange component in wood composite I-joists. According to the APA - The Engineered Wood Association, in the year 2000 the U.S. produced 1.257 million cubic meters (44.4 million cubic feet) of LVL of which 61% was used in the manufacture of I-joists and the other 31% was used as headers or beams (APA 2001). Laminated veneer lumber can be made from any wood species provided its mechanical and physical properties are suitable and it can be properly glued. LVL in the PNW region are made with Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco). Laminated veneer lumber is used as an input into the composite I-joist (Wilson and Dancer 2005; Puettmann et al. 2012) but could also be used as a standalone for headers, beams and joists.



Figure 1 Laminated veneer lumber

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for LVL is one cubic meter (1.0 m³). A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building product cannot be stated (PCR 2011). For conversion of units from the US industry measure, 1.0 cubic foot is equal to 0.02832 m³. All input and output data were allocated to the declared unit of product based on the mass of products and co-products in accordance with International Organization for Standardization (ISO) protocol (ISO 2006). As the analysis does not take the declared unit to the stage of being an installed building product no service life is assigned.

System Boundaries

The system boundary begins with regeneration of forest in the PNW (Johnson et al. 2005) and ends with LVL packaged to leave the mill gate (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which included site preparation, thinning, and fertilization on a subset of hectares, and final harvest. The transportation of logs from the woods to the mill is accounted for with the LVL manufacturing (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. For veneer production logs are transported to plywood manufacturing facilities and after manufacturing is complete, dry veneer sheets are transported to LVL plants (Figure 2). In the PNW region, in addition to using individual dry veneer sheets, LVL can be produced using pre-glued veneers called parallel laminated veneer¹. The system boundary includes the production and transportation of resins to the LVL plant. The LVL production process was modeled as a single unit process (Figure 2). Outputs to the system boundary include 1 m³ of LVL ready to be shipped, air and water emissions, solid waste and small volumes of co-products (chips and sawdust). The co-products are no longer tracked once they leave the system boundary.

¹ A product in which the veneers have been laminated with their grains parallel to one another.,

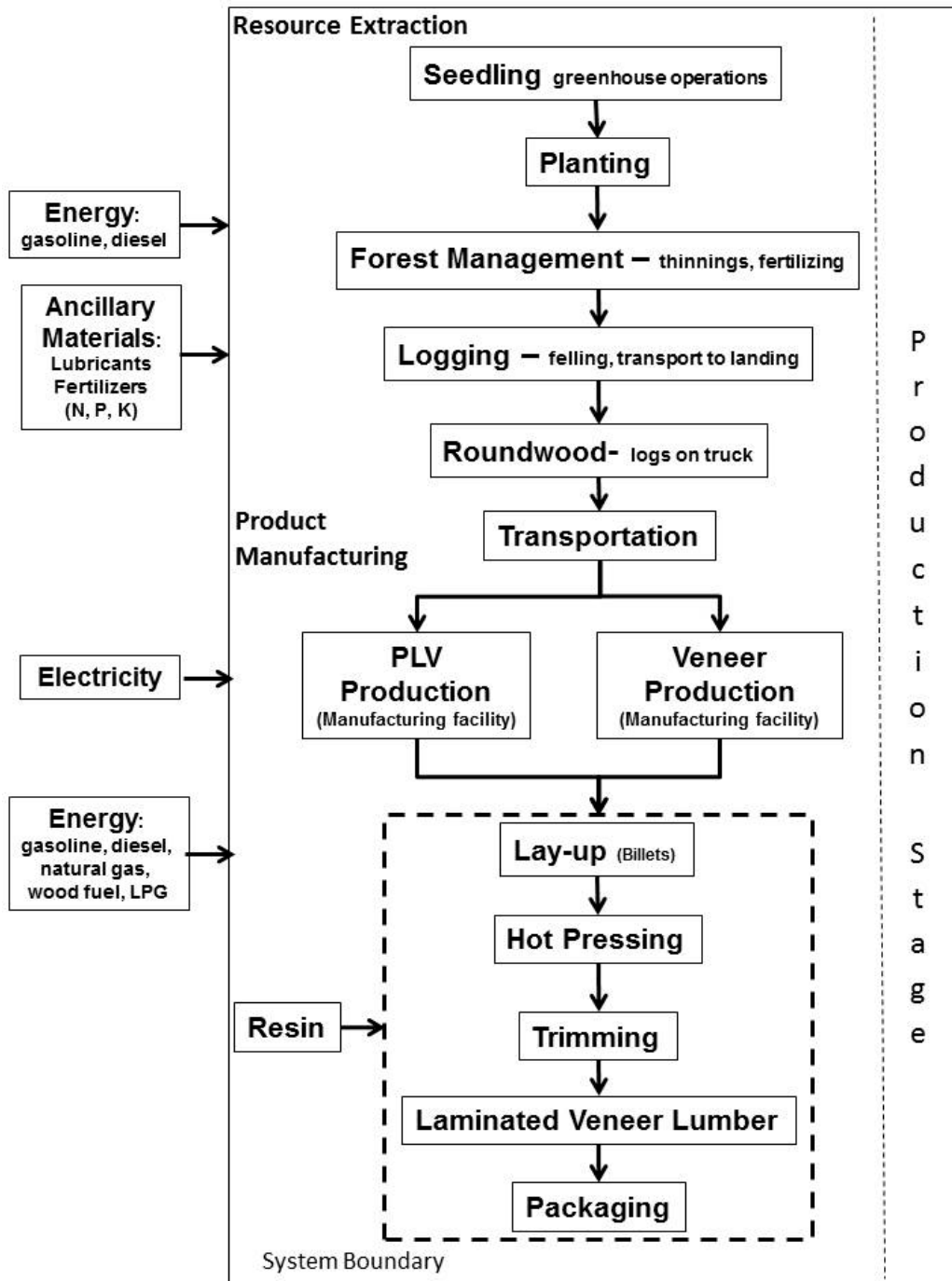


Figure 2 Cradle to gate life cycle stages for Laminated Veneer Lumber, PNW.

3.2 Description of data/ Process Description

3.2.1 Forestry Operations

Forestry operations include growing seedlings, planting, thinning, fertilization (where applicable) and final harvest. The specific processes involved are reforestation: which includes seedling production, site preparation, planting, pre-commercial thinning, and fertilization, and harvesting: which includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. 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, and the fuel and lubricants needed to power and maintain equipment for thinning, and harvest operations. The primary output product for this analysis is a log destined for the plywood mill where the first step of LVL manufacturing occurs. The co-product, non-merchantable slash, is generally left at a landing. Slash disposal was not modeled as it was assumed to decay in-situ.

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 (Figure 2). This group of activities is collectively referred to as forest resource management. The forest resource management life cycle stages includes the efforts required to establish a forest stand, to treat that stand through to maturity, and to harvest the merchantable logs from the stand. Stand establishment involves planting seedlings. Intermediate stand treatments enhance growth and productivity while the stand is growing and can involve thinning, fertilization, or both. Only 12% of stands in the PNW have fertilizer applications, while 58% have thinning operations.

In the PNW most harvested volume comes from forest operations on private lands where investment in timber is the precursor to harvest. For all non-federal land managers in the 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. 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.

The forest resource management LCI was structured from three general combinations of management intensity and site productivity (Table 1). Management intensities ranged from little intervention on low site productivity lands to higher management intensities involving combinations of fertilization and thinning on high productivity lands. Associated with each combination of management intensity and site productivity is an estimated yield of biomass based on forest growth and yield generated using the Forest Vegetation Simulator (FVS) growth and yield model (Wykoff 1986). FVS is developed from empirical data on forest growth and provides a reasonable estimate of standing and harvested biomass along with other stand attributes through time from seedling establishment to final harvest of the forest stand at rotation age.

3.2.1.1 Regeneration (seedling production and planting process)

Environmental burdens associated with the production of seedlings including fertilizer used in greenhouses or fields, and the electrical energy required to operate forest nursery pumps and to keep seedlings cool for planting were included as inputs to the regeneration process (Table 1). Greenhouse operations data for the PNW were developed from personal communication with forest nursery managers (Wenny 2003) and published documentation of greenhouse operations for containerized seedlings (Schlosser et al. 2003). All seedlings in the PNW were planted by hand. The only energy inputs associated with planting were related to travel to and from the planting site.

Stand treatment operations were based on growth and yield modeling and management scenarios developed at the University of Washington (Lippke and Connick 2002). Based on that input, fertilization occurred once seedlings were planted in the forest for the subset of hectares that were in higher management intensities. Fertilization was done in years 20, 30, and 40 on acres in the high-intensity management class and the environmental burdens associated with these efforts are included as part of the reforestation process. The fertilizer mixture included nitrogen, potassium, and phosphorus.

Table 1 Inputs to the regeneration phase and mid-rotation fertilization per hectare (ha) of forest.

		Low intensity	Medium intensity	High intensity	Weighted Average
Reforesting 1 ha					
Diesel and Gasoline	L	12	12	12	12
Seedlings, at greenhouse	p ¹	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	-	-	-	-

¹p = individual seedling

3.2.1.2 Equipment

Timber harvesting activities include four components: felling (severing the standing tree from the stump), processing (bucking, limbing and/or topping) which involves removal of non-merchantable limbs and tops and cutting of the tree into merchantable and transportable log lengths, secondary transportation (called skidding on gentle slopes and yarding on steep slopes), which is a transportation step that moves trees or logs from the point of felling to a loading point near a haul road, loading (moving logs from the ground to haul vehicles). Although all functions are required to remove logs from the woods, the specific order and location of the operations will vary by harvesting system as cable yarding systems used in steep terrain have the processing step occur prior to the secondary transport step. A fifth step, primary transportation, includes hauling logs from the woods to a manufacturing location and it is included in the LCI for the primary manufacturing facility.

Although harvesting operations in the PNW can be found on both gentle and steep terrain, they are more likely to involve steep slope conditions that dictate the use of manual felling and cable yarding harvest systems, therefore that system is modeled for the PNW region. Cable yarding systems rely on manual felling and transporting the logs up the hill using a long cable attached to a large woods tractor with a tall boom (a cable yarder). Most final harvest operations in the PNW use clearcut harvests with retention of a minimum number of trees to meet statutory green tree retention requirements. Operations under these conditions are modeled using production rates for clearcut systems.

Variations in harvest equipment size affect machine productivity and therefore emissions per m³ of logs produced. Harvest equipment operational efficiencies vary between thinning and final harvest (clearcut), which also affects machine productivity and therefore emissions per m³ of logs produced. To account for these inherent variations, equipment usage was allocated between thinning operations and final harvest for those management regimes that use thinning (Table 2).

Table 2 Equipment allocation by treatment and management intensity

Management Intensity	Thinning	Final Harvest (usage per final volume harvested)
Low intensity site		
Chain saw	NA	100%
Cable yarder, large	NA	100%
Loader	NA	100%
Medium intensity		
Chain saw	19.6%	80.4%
Cable yard, medium	19.6%	
Cable yarder, large		80.4%
Loader	19.6%	80.4%
High intensity		
Chain saw	12.6%	87.5%
Cable yard, medium	12.6%	
Cable yarder, large		87.5%
Loader	12.6%	87.5%

3.2.1.3 Thinning and Final Harvest Process

A single estimate of the average volume harvested per unit area was developed by weighting three combinations of site productivity and management intensity (Table 3) based on the relative percentage of the land base they occupy. Site productivity as measured by site index, the height of dominant trees at 50 years, and ownership class was obtained from the U.S. Forest Service Resource Planning Assessment database (USDA 2000, Mills 2001). A combination of these data and expert opinion was used to categorize the number of private forest hectares into a management intensity classes. The management intensity and site productivity classes used in the Forest Service analysis were associated with, and were represented by three general management intensity combinations. Specific assumptions associated with these three scenarios are outlined in Table 3. In the PNW, 42% of the lands were classified in the lowest productivity/ management intensity class, 46% in the middle class, and 12% in the highest management intensity class. The allocation of forested area to management intensity/site productivity class produces the log volume recovered from the forest resource as shown in Table 3. Allocating per ha values from Table 1 to the total yield of 501 m³/ha is used to carry forward the environmental burdens of the reforestation effort on a per m³ basis.

Table 3 Input assumptions for three levels of management intensity in the PNW.

Management intensity class prescription	Low Intensity	Medium Intensity	High Intensity	Weighted Average
	per hectare			
Rotation age (yr)	45	45	45	
Planting density (trees per hectare)	988	1,482	1,482	1,275
Fertilization	None	None	Years 20, 30, 40	
Pre-commercial thinning	None	Year 15	Year 15	
Final thinned density (Trees per hectare)	0	740	680	
Commercial thinning—m ³	0	81	81	47
<i>at year</i>		30	25	
Final harvest— m ³	433	409	701	454
<i>at year</i>	45	45	45	
Total yield/hectare— m ³	433	490	782	501
Percent sawlogs	100%	100%	100%	
Percent area in class	42%	46%	12%	

Fuel consumption and energy use for forest resource management processes were averaged by the percent area in each class to develop weighted average values for the PNW region by major process (Table 4).

Table 4 Fuel consumption for PNW forest resource management processes (regeneration, thinning, and harvest).

	Unit	Fuel Consumption per m ³
Seedling, Site Prep, Plant, Pre-commercial Thinning		
Diesel and gasoline	L	0.088
Lubricants	L	0.002
Electricity	kWh	0.107
Commercial Thinning and Final Harvest		
Diesel	L	2.850
Lubricants	L	0.051
Total Forest Extraction Process		
Gasoline and Diesel	L	2.938
Lubricants	L	0.053
Electricity	kWh	0.107

3.2.2 Product Manufacturing

3.2.2.1 Transportation Process

Transportation is the first process of product manufacturing (Figure 2). Logs are transported by truck to plywood or veneer facilities for veneer production (Table 5). Average haul distance in the PNW was 97 km from forest landing to veneer production. Dry veneer, PLV, and resin were delivered to the LVL mill requiring an additional 121 km, 6 km, and 67 km, respectively. All flow analyses of wood processes were determined on an oven-dry weight specific gravity² of 0.48 and 0.49 for veneer and PLV, respectively.

Table 5 Average delivery distance (one-way) for materials to produce Laminated Veneer Lumber in the PNW.

Material delivered to mill	Delivery Distance (km)	
	kilometers	miles
Logs with bark to veneer production	97	60
Dry veneer to LVL	121	75
PLV to LVL	6	4
Phenol-formaldehyde resin	167	122

3.2.2.2 Parallel Laminated Veneer Production (PLV)

PLV is produced using the same manufacturing process as plywood production except the veneers are all oriented in the same direction. PLV is produced at plywood facilities and therefore the environmental burdens associated with its production are assumed to be equivalent to plywood production. For that reason the LCI processes for producing dry PLV used appropriate plywood unit process developed by Wilson and Sakimoto (2004, 2005). PNW LVL production uses both PLV and plywood veneers. The PLV is neither as thick nor as long as LVL therefore it must be face and finger-jointed, glued and pressed to make large LVL billets.

3.2.2.3 Veneer Production

Veneers are usually produced during plywood production. Veneers are dried to a moisture content of 3-6% (oven-dry basis). For detailed description of veneer production for LVL see Wilson and Sakimoto (2004, 2005).

3.2.2.4 Phenol-formaldehyde resin

The life cycle inventory for the production of phenol-formaldehyde (PF) resin covers its cycle from in-ground resources through the production and delivery of input chemicals and fuels, through to the manufacturing of a resin as shipped to the customer (Wilson 2009). It examines the use of all resources, fuels and electricity and all emissions to air, water and land; it also includes feedstock of natural gas and crude oil used to produce the chemicals. The PF resin survey data were from 13 plants in U.S. that represented 62% of total production for the year 2005 (Wilson 2009). Total annual production was 779,063,000 kg (1,717,500,000 lb) of neat phenol-formaldehyde (PF) resin at 47.4% non-volatile solids content. 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 emissions control equipment. Natural gas is used for boiler fuel and emission control equipment, and propane fuel is used in forklifts.

² specific gravity uses oven dry mass and dry volume of the wood resource.

3.2.2.5 Phenol resorcinol formaldehyde resin

The phenol-resorcinol-formaldehyde (PRF) resin data is from 8 plants in U.S. that represented 63% of total production for the year 2005 (Wilson 2009). Total annual production was 15,513,000 kg (34,166,667 lb) of neat resin at 60% non-volatile solids content. PRF production is small in comparison to that for PF resin at approximately 2% of PF annual production. PRF resins differ somewhat from the other resins in that to assist curing when producing wood composites they require a hardener. That hardener is predominately paraformaldehyde for manufacturing glue laminated timbers and oxazolidine for manufacturing I-joists. As a group, 60% of PRF adhesive use paraformaldehyde and 40% use oxazolidine. PFR resin can be cold or hot cured, and can be radio-frequency cured.

3.2.2.6 Energy generation

Energy production 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 the purpose of generating heat for the presses in the LVL plants. The diesel is used for equipment, which transports materials outside of the plant, and the LPG is used in forklift trucks, which are operated inside the plant. Other types of fuels are used to generate energy in the plywood plants that produce dry veneer and PLV. These energy sources are not analyzed in this report, but the burdens that are created are carried over into the LVL final product. For information on the energy consumption for producing dry veneer and PLV see Wilson and Sakimoto (2004, 2005).

3.2.2.7 Laminated Veneer Production

The steps for producing LVL include the lay-up of billets, pressing, and trimming. A billet is produced by aligning dry veneers so their grain direction is parallel. They are then coated with resin in preparation for pressing. Outputs from this process include billets and waste veneer. During pressing the billets are heated under pressure (320-350°F and approximately 250 lb/in²) which cures the resin thereby bonding the veneers into LVL. The LVL is sawn and trimmed to the proper width and length. Outputs include LVL, panel trim, and sawdust. A single unit process approach was used to model LVL production because the steps for producing LVL are relatively simple and there are a low number of sub-unit processes.

Dry veneers, PLV, and resin are the primary raw materials consumed for the production of LVL (Table 6). The weight of the input wood to produce a functional unit of LVL was calculated using the oven-dry density of veneer at 481 kg/m³ (30 lb/ft³) and a density of 486 kg/m³ (30.34 lb/ft³) for PNW PLV (without resin). The density of the LVL is 529 kg/m³ (33.0 lb/ft³) including both wood and resin.

Table 6 Unit process inputs/outputs for Laminated Veneer Production (1 m³), PNW

Products	Value	Unit/m³	Allocation (%)
Laminated Veneer Lumber	1.00	m ³	96.14
Co-Products (waste, scrap, trim, sawdust)	21.25	kg	3.86
Resources			
Water, cooling, surface	35.23	L	
Materials/fuels			
Electricity, at Grid	59.51	kWh	
Diesel	0.17	L	
LPG	0.25	L	
Natural gas	3.83	m ³	
Phenol-formaldehyde resin	8.20	kg	
Phenol resorcinol formaldehyde resin	0.59	kg	
PLV	430.87	kg	
Veneer, dry	122.32	kg	
Wrapping material - Packaging	0.460	kg	
Strap Protectors - Packaging	0.200	kg	
Strapping - Packaging	0.083	kg	
Spacers - Packaging	4.672	kg	
Emissions to air			
Acetaldehyde	0.0005	kg	
Acetone	0.0040	kg	
Formaldehyde	0.0002	kg	
Methanol	0.0094	kg	
Particulates, unspecified	0.0108	kg	
Emissions to water			
Propanol	0.0002	kg	

3.2.2.8 Packaging

Materials used for packaging LVL for shipping are shown in Table 7.

Table 7 Materials used in packaging and shipping per m³, Laminated Veneer Production, PNW

Material	Value	Unit
Wrapping Material – HDPE and LDPE laminated paper	0.4601	kg
PET Strapping	0.0834	kg
Cardboard strap protectors	0.2002	kg
Wooden spacers	4.6721	kg

Packing materials for represent 1.02 percent of the cumulative mass of the model flow. The wooden spacers make up the bulk of this mass, representing 86 percent of the total packaging material. The wrapping material, strap protectors, and strapping made up, 8, 4, and 2 percent of the packaging by mass.

4 Cut-off rules

According to the PCR, 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 and with the exception of packaging noted above, raw materials/energy from upstream processes that were used in small quantities that comprise less than 1% of the product mass/energy were not included in the LCA.

In the primary surveys, manufacturers were asked to report total hazard air pollutants (HAPS) specific to their wood products manufacturing process: formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde. If applicable to the wood product, HAPS are reported in Table 9 and would be included in the impact assessment. Table 9 shows all air emissions to 10⁻⁴ to simplify and report on the dominant releases by mass. There were no cut-offs used in the impact assessment. A complete list of all air emissions is located in Section 13 Appendix of this report.

5 Data quality requirements

This study collected data from representative LVL production facilities in the PNW regions of the US. Total annual production in the PNW region was 0.572 million cubic meters (20.2 million cubic feet) (APA 2001). This represents the equivalent of roughly 45 percent of the total LVL produced in the U.S. in the year 2001. The survey data collected for the PNW region totaled 0.187 million cubic meters (6.6 million cubic feet) of LVL, representing roughly 33% of the production for the region.

An external critical review of the survey procedures, data, analysis, and report was done for conformance with CORRIM and ISO 14040 standards (Werner 2004). The review provided assurances that the study methodology, data collection, and analyses are scientifically sound, and are in conformance with ISO 14040 and CORRIM research protocol (ISO 2006). Complete details of this study for LVL production and the overall CORRIM project can be found in Wilson and Dancer (2004) and Lippke et al. (2004), respectively.

6 Life cycle inventory analysis

6.1 Data collection

Primary data for the LCI was collected through mill surveys administered in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production and emissions data provided by LVL producers from the PNW for the 2000 production year, with some secondary data on electrical grid inputs (Goemans 2010) from the US LCI database. The data were gathered through primary surveys that were sent out to LVL production facilities. Two mills participated in the surveys. The surveys were extensive and included questions about annual production, energy and fuel uses, as well as emissions, and co-product volumes. The states covered in the PNW region included Oregon and Washington for both manufacturing data and forest resources data. Data for packaging was obtained from field sampling and personal communications with manufacturers.

The primary mill survey data are more than 10 years old and were updated using current electricity grid and boiler data to complete this LCA. Boilers are the most energy intensive process for the cradle to production gate and therefore generate the dominant share of the environmental footprint. LVL production technology has not changed substantially in the past 10 years so the data likely continue to reflect processes as they are now with one caveat.

6.2 Calculation rules

Fuel consumption was calculated per seedling and then multiplied by the number of planted seedlings per unit area specified for each of the three management scenarios to determine fuel consumption rates per unit area. Total fuel consumption per unit area was divided by the final harvested volume per unit area to establish the contribution of fuel consumption for site preparation, seedlings, and planting per unit of harvested volume.

To determine the environmental burdens of equipment used for forest extraction part of the forest management life cycle stage (Figure 2) the applicable fuel and oil consumption rates were developed for each equipment component within the harvesting system (Table 2). These data were derived from existing studies for the types of harvesting equipment used in the region and included both published information and personal interviews with timber harvesting contractors (Biltonen 2002; Hochrein and Kellogg 1988; Jorgenson 2002; Keegan et al. 1995; Kellogg and Bettinger 1995; Kellogg et al. 1996; Lawson 2002; Ledoux 1984; Reynolds 2002; Stevens and Clarke 1974). Production and consumption factors of the harvesting system were calculated by adding the emissions for each piece of equipment used per m³ of production.

The survey results for each unit process were converted to a production basis (e.g., logs used per m³ of LVL produced) and production-weighted averages were calculated for each material. This approach resulted in a mill complex that represents a composite of the mills surveyed, but may not represent any mill in particular. Survey data was converted from cubic feet to cubic meters. One thousand cubic feet (MCF) is equivalent to 0.02832 thousand cubic meters (1,000 m³). Veneer and inputs were given in MSF (1,000 ft² 3/8-in. basis) volumes and converted to cubic meters or mass. The USLCI database (NREL 2012) was used to assess off-site impacts associated with the materials and energy consumed. SimaPro, version 7.3.3 (Pré Consultants 2012) was used as the accounting program to track all of the materials.

Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros.

6.3 Allocation rules

Allocation was based on mass. PNW LVL production generates low value co-products (3.86% by mass of input). Co-products are sold as dry wood residues with a price differential approximately 32 times³ lower than LVL based on equivalent mass. The differential on a mass versus economic allocation is 0.89 percent.

6.4 LCI Results

Life cycle inventory results for laminated veneer lumber are presented by three life stages, 1) Forestry operations, 2) veneer and PLV production, and 3) LVL production (Tables 8-11). The majority of the raw material energy consumption occurs during wood production with only a small portion arising from forestry operations. LVL and PLV production (wrapped up) encompasses resin production. Raw material energy requirements are presented in Table 8 for 1 cubic meter (m³) of laminated veneer lumber. Air emissions are reported in Table 9, water emissions are reported in Table 10, and solid waste emissions are reported in Table 11.

Table 8 Raw material energy consumption per 1 m³ of Laminated Veneer Lumber, PNW

Fuel	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m ³			
Coal, in ground	31.9902	0.2090	21.0673	10.7139
Gas, natural, in ground	27.7107	0.1879	16.6059	10.9169
Oil, crude, in ground	17.7361	3.5575	7.3824	6.7962
Uranium oxide, in ore	0.0007	0.0000	0.0004	0.0002
Wood waste	146.0733	0.0000	144.9892	1.0841

³ Based on <http://www.wbpionline.com/features/euphoria-will-subside-but-recovery-will-continue/image/euphoria-will-subside-but-recovery-will-continue-1.html> for LVL prices and Timber-Mart South Market News quarterly 2nd Q 2013 vol 18 no. 2 for wood residues.

Table 9 Air emissions released per 1 m³ of Laminated Veneer Lumber, PNW.

Air Emission ^{1/}	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m ³			
Carbon dioxide, biogenic	257.3486	0.0091	255.2911	2.0483
Carbon dioxide, fossil	169.5102	11.5622	97.9157	60.0324
Sulfur dioxide	1.1178	0.0075	0.6930	0.4173
Nitrogen oxides	1.0273	0.2096	0.6259	0.1918
Particulates, > 2.5 um, and < 10um	0.8114	0.0064	0.7963	0.0087
Carbon monoxide	0.7885	0.0000	0.7816	0.0068
Particulates, < 2.5 um	0.5629	0.0000	0.5597	0.0032
Methane	0.5456	0.0156	0.3346	0.1954
VOC, volatile organic compounds	0.4324	0.0056	0.4114	0.0154
Carbon monoxide, fossil	0.4056	0.1051	0.1690	0.1315
Acrolein	0.3075	0.0000	0.3075	0.0000
Particulates, unspecified	0.2603	0.0011	0.2315	0.0276
Carbon dioxide	0.1478	0.0315	0.0575	0.0588
Sulfur oxides	0.0930	0.0116	0.0573	0.0241
Methanol	0.0826	0.0000	0.0735	0.0091
Hydrocarbons (other than methane)	0.0815	0.0000	0.0815	0.0000
Methane, fossil	0.0605	0.0012	0.0341	0.0251
Metals, unspecified	0.0560	0.0000	0.0557	0.0003
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0557	0.0070	0.0254	0.0233
Hydrogen chloride	0.0415	0.0001	0.0357	0.0057
alpha-Pinene	0.0399	0.0000	0.0399	0.0000
Isoprene	0.0289	0.0002	0.0193	0.0093
Formaldehyde	0.0212	0.0001	0.0208	0.0003
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	0.0155	0.0000	0.0155	0.0000
Benzene	0.0134	0.0001	0.0093	0.0040
Cumene	0.0111	0.0000	0.0055	0.0056
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0097	0.0001	0.0058	0.0038
Acetaldehyde	0.0087	0.0000	0.0081	0.0005
Acetone	0.0065	0.0000	0.0026	0.0038
TOC, Total Organic Carbon	0.0054	0.0000	0.0053	0.0000
D-limonene	0.0045	0.0000	0.0045	0.0000
Propene	0.0043	0.0002	0.0021	0.0021
Dinitrogen monoxide	0.0024	0.0002	0.0008	0.0014
Manganese	0.0021	0.0000	0.0021	0.0000
Hydrogen fluoride	0.0021	0.0000	0.0014	0.0007
Phenol	0.0020	0.0000	0.0019	0.0000

Air Emission ^{1/}	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m ³			
Chlorine	0.0017	0.0000	0.0010	0.0007
Radionuclides (Including Radon)	0.0009	0.0000	0.0006	0.0003
Particulates, < 10 um	0.0008	0.0000	0.0000	0.0008
Aldehydes, unspecified	0.0007	0.0001	0.0003	0.0003
Methyl ethyl ketone	0.0006	0.0000	0.0006	0.0000
Ammonia	0.0006	0.0001	0.0002	0.0003
Methane, dichloro-, HCC-30	0.0004	0.0000	0.0004	0.0000
Particulates, > 10 um	0.0003	0.0000	0.0000	0.0003
2-Butanone, 3,3-dimethyl-	0.0003	0.0000	0.0003	0.0000
Sulfate	0.0002	0.0000	0.0000	0.0002
Hydrocarbons, unspecified	0.0002	0.0000	0.0001	0.0001
Hydrogen	0.0002	0.0000	0.0000	0.0002
Magnesium	0.0002	0.0000	0.0001	0.0001
Naphthalene	0.0001	0.0000	0.0001	0.0000
Hydrocarbons, aliphatic, alkanes, unspecified	0.0001	0.0000	0.0000	0.0001

^{1/} Due to the extensive list of emissions, those emissions less than 10⁻⁴ are not shown. A complete list of all air emissions can be found in Section 13.

Most waterborne emissions are all off-site (Table 10). No mill in the survey discharged any process water. The water sprayed on logs is collected and recycled or soaks into the ground. Water used at the boiler and kilns is evaporated. A complete list of all emissions to water is located in the Appendix (Section 13) of this report.

Table 10 Emissions to water released per 1 m³ Laminated Veneer Lumber, PNW.

Water Emission ^{1/}	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m ³			
Solved solids	8.3895	0.6012	4.5370	3.2513
Chloride	6.8774	0.4874	3.6620	2.7279
Sodium, ion	1.9744	0.1374	1.0328	0.8042
Calcium, ion	0.6114	0.0434	0.3258	0.2422
Suspended solids, unspecified	0.2573	0.0354	0.1223	0.0996
COD, Chemical Oxygen Demand	0.2374	0.0047	0.1152	0.1176
BOD5, Biological Oxygen Demand	0.2108	0.0025	0.1020	0.1063
Lithium, ion	0.1341	0.0009	0.0807	0.0524
Magnesium	0.1212	0.0085	0.0637	0.0491
Barium	0.1124	0.0158	0.0536	0.0430
Sulfate	0.0656	0.0011	0.0173	0.0471
TOC, Total Organic Carbon	0.0507	0.0000	0.0243	0.0264

Water Emission ^{1/}	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m ³			
DOC, Dissolved Organic Carbon	0.0507	0.0000	0.0243	0.0264
Bromide	0.0457	0.0029	0.0217	0.0211
Cumene	0.0266	0.0000	0.0132	0.0135
Benzene	0.0191	0.0000	0.0092	0.0099
Iron	0.0191	0.0023	0.0095	0.0073
Strontium	0.0103	0.0007	0.0055	0.0041
Propene	0.0099	0.0000	0.0049	0.0050
Silicon	0.0065	0.0000	0.0000	0.0065
Aluminum	0.0064	0.0012	0.0030	0.0022
Oils, unspecified	0.0042	0.0003	0.0021	0.0018
Potassium, ion	0.0029	0.0000	0.0000	0.0029
Ammonia	0.0028	0.0003	0.0014	0.0011
Carbonate	0.0026	0.0000	0.0000	0.0026
Aluminium	0.0025	0.0000	0.0009	0.0016
Iodide	0.0022	0.0000	0.0000	0.0022
Phosphate	0.0018	0.0007	0.0000	0.0011
Ammonium, ion	0.0016	0.0000	0.0000	0.0016
Nitrate	0.0015	0.0000	0.0000	0.0015
Fluoride	0.0014	0.0009	0.0001	0.0004
Iron, ion	0.0010	0.0000	0.0000	0.0010
Chloroacetic acid	0.0010	0.0000	0.0000	0.0010
Formate	0.0008	0.0000	0.0000	0.0008
Manganese	0.0007	0.0000	0.0003	0.0004
Solids, inorganic	0.0006	0.0000	0.0000	0.0006
Boron	0.0006	0.0000	0.0003	0.0003
Sulfur	0.0006	0.0000	0.0003	0.0003
Benzene, chloro-	0.0005	0.0000	0.0000	0.0005
Acetic acid	0.0004	0.0000	0.0000	0.0004
Silver	0.0004	0.0000	0.0002	0.0002
Ethanol	0.0003	0.0000	0.0000	0.0003
Toluene	0.0003	0.0000	0.0002	0.0002
Propanal	0.0002	0.0000	0.0000	0.0002
Chlorate	0.0002	0.0000	0.0000	0.0002
Borate	0.0002	0.0000	0.0000	0.0002
Formaldehyde	0.0002	0.0000	0.0000	0.0002
Zinc	0.0002	0.0000	0.0001	0.0001
Benzoic acid	0.0002	0.0000	0.0001	0.0001
Detergent, oil	0.0002	0.0000	0.0001	0.0001
Xylene	0.0002	0.0000	0.0001	0.0001
Chromium	0.0002	0.0000	0.0001	0.0001

Water Emission^{1/}	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m³			
Phenol	0.0001	0.0000	0.0000	0.0001
Acetaldehyde	0.0001	0.0000	0.0000	0.0001

^{1/} Due to the extensive list of emissions, those emissions less than 10⁻⁴ are not shown.

Solid emissions include ash generated at the boiler and the extraction of natural gas. Some waste is collected from the log-yard and debarking and cannot be sent to the boiler is sent the landfill (Table 11).

Table 11 Waste to treatment per 1 m³ of Laminated Veneer Lumber production, PNW.

Waste to treatment	Total	Forestry Operations	Veneer/PLV Production	LVL Production
	kg/m³			
Solid Waste	39.88	0.19	35.70	3.98

7 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 in Table 12. Environmental impacts are determined using the TRACI method (Bare et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (PCR 2011).

Table 12 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 CFC's HCFC's, 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 (H ⁺) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of H ⁺ mole-eq. is used as a reference unit.	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photo-chemically 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 to others. For the same reasons, indicators should not be combined or added. Table 13 provides the environmental impact by category for LVL produced in the PNW region. In addition, energy and material resource consumption values and the waste generated are also provided.

Table 13 provides the environmental impact by category for one cubic meter of LVL produced in the PNW region. In addition, energy and material resource consumption values and the waste generated are also provided. Environmental performance results for global warming potential (GWP), acidification, eutrophication, ozone depletion and smog, energy consumption from non-renewables, renewables, wind, hydro, solar, and nuclear fuels, renewable and nonrenewable resources, and solid waste are shown in Table 13. For GWP, 58 percent of the CO₂ equivalent emissions come from producing the dry veneer and 36 percent from LVL production with remainder (7%) arising from forestry operations. Values in Table 13 are the cumulative impact of all upstream processes required for LVL production including those from forestry, veneer, plywood, resin, and packaging production and transportation energy required to move these materials to the LVL facility. For example, differences between LVL Production data in table 6 with results in table 13 are a result of the resources and fuels used in the upstream processes, i.e. fresh water use.

Table 13 Environmental performance of 1 m³ Laminated Veneer Lumber, PNW

Impact category	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Global warming potential (GWP)	kg CO ₂ equiv	185.53	12.07	107.44	66.02
Acidification Potential	H+ moles equiv	104.71	9.38	64.89	30.44
Eutrophication Potential	kg N equiv	0.0762	0.0115	0.0397	0.0250
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000	0.0000
Smog Potential	kg O ₃ equiv	30.37	5.22	20.17	4.98
Total Primary Energy Consumption	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Non-renewable fossil	MJ	3153.66	177.58	1791.94	1184.15
Non-renewable nuclear	MJ	249.32	1.87	163.51	83.95
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	179.47	0.30	121.75	56.81
Renewable, biomass	MJ	3059.24	0.00	3035.37	23.74
Material resources consumption (non-fuel resources)	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Non-renewable materials	kg	1.33	0.01	0.46	0.86
Renewable materials	kg	602.37	0.00	601.59	5.78
Fresh water	L	774.96	11.56	488.27	275.13
Waste generated	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Solid waste	kg	396.88	0.19	35.70	3.98

8 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, it is accepted that 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 the product LCA to prevent double counting. Standards such as ASTM D7612, 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 for 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 has adopted an identical approach to ensure comparability and consistency. The North American PCR approach is followed here for GWP reporting therefore the default TRACI impact assessment method was used. This default method does not count the CO₂ emissions released during the combustion of woody biomass during production. Other emissions associated from wood combustion, e.g., methane or nitrogen oxides, do contribute to and are included in the GWP impact category. For a complete list of emissions factors for the GWP method used, see Bare et al. (2011). Using this method, 186 kg CO₂e were released in the production of 1 m³ of LVL. That same 1 m³ of LVL stores 954 kg CO₂e (Table 14).

Table 14 Carbon balance per 1 m³ softwood LVL, PNW.

	kg CO₂ equivalent
released forestry operations	12.07
released manufacturing	173.46
CO ₂ eq. stored in product	954.34

9 Conclusions

The cradle to gate LCA for laminated veneer lumber includes the LCI of forest resources that relies on secondary and tertiary data and the LCI of manufacturing that relies on primary survey data for wood product inputs and secondary data on process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest and manufacturing operations in the PNW region. The survey data are representative of the processes and production volumes consistent with trade association data.

Veneer and parallel laminated veneer were produced during plywood production and required 716 kg of roundwood for LVL production in the PNW. To produce one cubic meter of LVL finished product including resin (529 kg) required 118 kg of dry veneer and 414 kg of PLV. The LVL production process produced 21.25 kg of co-product (chips, trimming, veneer waste). Any wood fuel would have been consumed during veneer production. See PNW plywood for information of self-generated wood fuel.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The LVL manufacturing process has some onsite emissions from pressing of the billets with the resin. The production of veneer and PLV used for producing LVL generates the most emissions and consequently has the highest level for every impact category. This is primarily due to the drying process for veneers which can consume up to 85 – 90 percent of the total energy from cradle to gate.

Energy use for manufacturing PNW LVL is dominated by the combustion of wood fuel (biomass), which is comprised of wood and bark waste generated during veneer and PLV production. Wood fuel represented 69 percent of the heat energy during veneer and PLV production and 54 percent of the total cradle to gate energy to produce LVL. Total nonrenewable fossil fuel use was 54 percent of the total energy from cradle to gate. Resins used to bond the veneers also almost exclusively dependent upon fossil fuels for both energy and feedstock. The production of the veneer dominated the total energy (76%). Forestry operations consumed exclusively (99%) fossil fuels, but only represent only 2 percent of the total energy. Laminated veneer lumber production consumed 90 percent of the total energy from nonrenewable fossil fuels and contributed about 22 percent to the total cradle to gate energy consumption.

The TRACI impact method does not count the contribution of wood-derived CO₂ emissions from burning wood fuel in the boiler towards the global warming impact estimate. This is consistent with the current US EPA rules on wood emissions from stationary sources which counts the CO₂ taken up by the forest ecosystem when the tree grew as balancing any CO₂ emissions when it is burned. Under the TRACI method, combustion of fossil fuels generates CO₂ and other air emissions that contribute to the global warming impact as do methane and nitrous oxides that are emitted during biomass burning. Using this method, 186 kg CO₂e were released in the production of 1 m³ of LVL. That same 1 m³ of LVL stores 954 kg CO₂e.

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11 Critical Review

11.1 Internal Review

An internal review of the LCA product was provided using two knowledgeable and experienced LCA and wood products reviewers. They are:

- Wayne B. Trusty, President, Wayne B. Trusty and Associates Limited,
- Bruce Lipke, Professor Emeritus, University of Washington

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 the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011). Following CORRIM's internal review evaluation, documents were submitted to UL Environment (ULE) for independent external review. The independent external review performed by ULE was conducted by:

- Thomas Gloria, Ph.D., Industrial Ecology Consultants.

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13 Appendix

13.1 Air Emissions

Table A.1 Air emissions released per 1 m³ of laminated veneer lumber, PNW.

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
1,4-Butanediol	kg	7.45E-06			7.45E-06
1-Butanol	kg	1.62E-06			1.62E-06
1-Pentanol	kg	1.84E-14			1.84E-14
1-Pentene	kg	1.39E-14			1.39E-14
1-Propanol	kg	8.90E-12			8.90E-12
2,4-D	kg	1.37E-09			1.37E-09
2-Aminopropanol	kg	9.44E-07			9.44E-07
2-Butanone, 3,3-dimethyl-	kg	2.76E-04		2.76E-04	
2-Butene, 2-methyl-	kg	3.08E-18			3.08E-18
2-Chloroacetophenone	kg	4.05E-10	1.99E-12	9.29E-11	3.10E-10
2-Methyl-1-propanol	kg	1.44E-06			1.44E-06
2-Nitrobenzoic acid	kg	3.86E-06			3.86E-06
2-Propanol	kg	3.23E-06			3.23E-06
5-methyl Chrysene	kg	3.02E-10	2.01E-12	2.00E-10	9.98E-11
Acenaphthene	kg	7.00E-09	4.66E-11	4.64E-09	2.31E-09
Acenaphthylene	kg	3.43E-09	2.29E-11	2.27E-09	1.13E-09
Acetaldehyde	kg	8.70E-03	4.81E-05	8.10E-03	5.44E-04
Acetic acid	kg	7.90E-05			7.90E-05
Acetochlor	kg	1.90E-08			1.90E-08
Acetone	kg	6.47E-03		2.64E-03	3.82E-03
Acetonitrile	kg	1.34E-09			1.34E-09
Acetophenone	kg	8.68E-10	4.26E-12	1.99E-10	6.64E-10
Acrolein	kg	3.08E-01	5.83E-06	3.07E-01	3.33E-05
Acrylic acid	kg	3.51E-10			3.51E-10
Actinides, radioactive, unspecified	Bq	8.83E-05			8.83E-05
Aerosols, radioactive, unspecified	Bq	1.97E-03			1.97E-03
Alachlor	kg	1.87E-09			1.87E-09
Aldehydes, unspecified	kg	7.30E-04	1.45E-04	3.08E-04	2.77E-04
alpha-Pinene	kg	3.99E-02		3.99E-02	
Aluminium	kg	2.36E-05			2.36E-05
Ammonia	kg	5.53E-04	9.67E-05	1.88E-04	2.67E-04
Ammonium carbonate	kg	2.29E-09			2.29E-09

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Ammonium chloride	kg	3.45E-05	2.60E-07	2.28E-05	1.14E-05
Aniline	kg	5.89E-06			5.89E-06
Anthracene	kg	2.88E-09	1.92E-11	1.91E-09	9.53E-10
Anthranilic acid	kg	1.78E-06			1.78E-06
Antimony	kg	1.06E-05	1.65E-09	1.04E-05	1.60E-07
Antimony-124	Bq	1.72E-08			1.72E-08
Antimony-125	Bq	1.80E-07			1.80E-07
Argon-41	Bq	1.03E+00			1.03E+00
Arsenic	kg	3.48E-05	5.21E-08	3.25E-05	2.27E-06
Arsine	kg	4.09E-15			4.09E-15
Atrazine	kg	3.70E-08			3.70E-08
Barium	kg	3.32E-07			3.32E-07
Barium-140	Bq	1.17E-05			1.17E-05
Bentazone	kg	1.51E-10			1.51E-10
Benzal chloride	kg	1.98E-17			1.98E-17
Benzaldehyde	kg	1.59E-11			1.59E-11
Benzene	kg	1.34E-02	5.87E-05	9.26E-03	4.04E-03
Benzene, 1,2-dichloro-	kg	4.34E-06			4.34E-06
Benzene, 1-methyl-2-nitro-	kg	3.34E-06			3.34E-06
Benzene, chloro-	kg	1.27E-09	6.25E-12	2.92E-10	9.75E-10
Benzene, ethyl-	kg	2.32E-07	2.67E-11	6.23E-08	1.70E-07
Benzene, hexachloro-	kg	3.93E-11			3.93E-11
Benzene, pentachloro-	kg	4.62E-12			4.62E-12
Benzo(a)anthracene	kg	1.10E-09	7.32E-12	7.27E-10	3.63E-10
Benzo(a)pyrene	kg	7.00E-09	3.47E-12	3.45E-10	6.65E-09
Benzo(b,j,k)fluoranthene	kg	1.51E-09	1.01E-11	1.00E-09	4.99E-10
Benzo(ghi)perylene	kg	3.70E-10	2.47E-12	2.45E-10	1.23E-10
Benzyl chloride	kg	4.05E-08	1.99E-10	9.29E-09	3.10E-08
Beryllium	kg	1.76E-06	2.56E-09	1.64E-06	1.22E-07
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	kg	1.55E-02		1.55E-02	
Biphenyl	kg	2.33E-08	1.55E-10	1.55E-08	7.71E-09
Boron	kg	3.10E-06			3.10E-06
Boron trifluoride	kg	5.60E-17			5.60E-17
Bromine	kg	3.22E-07			3.22E-07
Bromoform	kg	2.26E-09	1.11E-11	5.18E-10	1.73E-09
Bromoxynil	kg	3.31E-10			3.31E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	9.71E-03	6.61E-05	5.84E-03	3.80E-03
Butadiene	kg	3.50E-06	2.45E-06	1.02E-06	1.89E-08

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Butane	kg	7.22E-06			7.22E-06
Butene	kg	2.21E-05			2.21E-05
Butyrolactone	kg	2.10E-12			2.10E-12
Cadmium	kg	6.73E-06	1.27E-08	6.17E-06	5.40E-07
Calcium	kg	2.29E-06			2.29E-06
Carbofuran	kg	2.83E-10			2.83E-10
Carbon dioxide	kg	1.48E-01	3.15E-02	5.75E-02	5.88E-02
Carbon dioxide, biogenic	kg	2.57E+02	9.13E-03	2.55E+02	2.05E+00
Carbon dioxide, fossil	kg	1.70E+02	1.16E+01	9.79E+01	6.00E+01
Carbon dioxide, land transformation	kg	4.16E-05			4.16E-05
Carbon disulfide	kg	2.14E-06	3.69E-11	1.73E-09	2.14E-06
Carbon monoxide	kg	7.88E-01	4.30E-06	7.82E-01	6.81E-03
Carbon monoxide, biogenic	kg	2.68E-06			2.68E-06
Carbon monoxide, fossil	kg	4.06E-01	1.05E-01	1.69E-01	1.31E-01
Carbon-14	Bq	8.26E+00			8.26E+00
Cerium-141	Bq	2.84E-06			2.84E-06
Cesium-134	Bq	1.36E-07			1.36E-07
Cesium-137	Bq	2.41E-06			2.41E-06
Chloramine	kg	2.41E-06			2.41E-06
Chloride	kg	8.82E-10	7.00E-12	5.90E-10	2.85E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	1.79E-07		7.84E-08	1.00E-07
Chlorine	kg	1.73E-03		1.03E-03	7.01E-04
Chloroacetic acid	kg	1.22E-05			1.22E-05
Chloroform	kg	4.14E-05	1.68E-11	7.83E-10	4.14E-05
Chlorosilane, trimethyl-	kg	4.74E-11			4.74E-11
Chlorosulfonic acid	kg	1.84E-06			1.84E-06
Chlorpyrifos	kg	2.17E-09			2.17E-09
Chromium	kg	3.28E-05	3.74E-08	3.02E-05	2.60E-06
Chromium VI	kg	1.11E-06	7.22E-09	7.18E-07	3.83E-07
Chromium-51	Bq	1.82E-07			1.82E-07
Chrysene	kg	1.37E-09	9.14E-12	9.09E-10	4.54E-10
Cobalt	kg	1.05E-05	7.13E-08	9.62E-06	7.63E-07
Cobalt-58	Bq	2.53E-07			2.53E-07
Cobalt-60	Bq	2.24E-06			2.24E-06
Copper	kg	9.30E-07	6.41E-10	2.05E-08	9.09E-07
Cumene	kg	1.11E-02	1.51E-12	5.48E-03	5.60E-03
Cyanazine	kg	3.26E-10			3.26E-10
Cyanide	kg	2.49E-06	7.10E-10	3.32E-08	2.46E-06

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Cyanoacetic acid	kg	1.50E-06			1.50E-06
Dicamba	kg	1.92E-09			1.92E-09
Diethylamine	kg	4.74E-06			4.74E-06
Dimethenamid	kg	4.54E-09			4.54E-09
Dimethyl ether	kg	7.70E-05		3.97E-05	3.73E-05
Dimethyl malonate	kg	1.89E-06			1.89E-06
Dinitrogen monoxide	kg	2.39E-03	1.96E-04	8.32E-04	1.36E-03
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	2.17E-06	2.64E-17	2.17E-06	1.46E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.20E-11	2.30E-13	7.68E-12	4.11E-12
Dipropylamine	kg	2.12E-06			2.12E-06
Dipropylthiocarbamic acid S-ethyl ester	kg	3.11E-09			3.11E-09
D-limonene	kg	4.47E-03		4.47E-03	
Ethane	kg	2.27E-05			2.27E-05
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	1.57E-08			1.57E-08
Ethane, 1,1,1-trichloro-, HCFC-140	kg	2.81E-09	3.39E-10	9.58E-10	1.51E-09
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	1.66E-11			1.66E-11
Ethane, 1,1-difluoro-, HFC-152a	kg	2.47E-10			2.47E-10
Ethane, 1,2-dibromo-	kg	6.94E-11	3.41E-13	1.59E-11	5.32E-11
Ethane, 1,2-dichloro-	kg	8.27E-06	1.14E-11	5.31E-10	8.27E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	3.45E-09			3.45E-09
Ethane, chloro-	kg	2.43E-09	1.19E-11	5.58E-10	1.86E-09
Ethane, hexafluoro-, HFC-116	kg	1.28E-08			1.28E-08
Ethanol	kg	9.62E-06			9.62E-06
Ethene	kg	1.75E-05			1.75E-05
Ethene, chloro-	kg	1.06E-08			1.06E-08
Ethene, tetrachloro-	kg	6.00E-07	4.72E-09	3.95E-07	2.00E-07
Ethene, trichloro-	kg	6.15E-14			6.15E-14
Ethyl acetate	kg	6.69E-07			6.69E-07
Ethyl cellulose	kg	1.27E-09			1.27E-09
Ethylamine	kg	4.38E-06			4.38E-06
Ethylene diamine	kg	4.60E-13			4.60E-13
Ethylene oxide	kg	8.57E-08			8.57E-08
Ethyne	kg	8.14E-06			8.14E-06
Fluoranthene	kg	9.74E-09	6.49E-11	6.45E-09	3.22E-09
Fluorene	kg	1.25E-08	8.32E-11	8.27E-09	4.13E-09
Fluoride	kg	3.72E-06	3.76E-07	1.11E-06	2.24E-06
Fluorine	kg	2.49E-07			2.49E-07

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Fluosilicic acid	kg	1.36E-08			1.36E-08
Formaldehyde	kg	2.12E-02	7.47E-05	2.08E-02	3.24E-04
Formamide	kg	3.36E-14			3.36E-14
Formic acid	kg	9.73E-09			9.73E-09
Furan	kg	2.61E-09	4.18E-13	4.49E-11	2.56E-09
Glyphosate	kg	4.08E-09			4.08E-09
Helium	kg	1.39E-07			1.39E-07
Heptane	kg	6.65E-07			6.65E-07
Hexane	kg	2.32E-06	1.90E-11	8.90E-10	2.32E-06
Hydrazine, methyl-	kg	9.84E-09	4.83E-11	2.26E-09	7.53E-09
Hydrocarbons (other than methane)	kg	8.15E-02		8.15E-02	
Hydrocarbons, aliphatic, alkanes, cyclic	kg	2.42E-07			2.42E-07
Hydrocarbons, aliphatic, alkanes, unspecified	kg	1.00E-04			1.00E-04
Hydrocarbons, aliphatic, unsaturated	kg	2.67E-06			2.67E-06
Hydrocarbons, aromatic	kg	2.74E-06			2.74E-06
Hydrocarbons, chlorinated	kg	3.94E-06			3.94E-06
Hydrocarbons, unspecified	kg	1.99E-04	1.50E-06	1.31E-04	6.61E-05
Hydrogen	kg	1.69E-04		2.85E-06	1.67E-04
Hydrogen chloride	kg	4.15E-02	1.17E-04	3.57E-02	5.66E-03
Hydrogen fluoride	kg	2.06E-03	1.37E-05	1.36E-03	6.84E-04
Hydrogen peroxide	kg	9.44E-10			9.44E-10
Hydrogen sulfide	kg	4.45E-06	2.26E-13	1.91E-11	4.45E-06
Hydrogen-3, Tritium	Bq	4.68E+01			4.68E+01
Indeno(1,2,3-cd)pyrene	kg	8.37E-10	5.58E-12	5.54E-10	2.77E-10
Iodine	kg	1.74E-07			1.74E-07
Iodine-129	Bq	8.21E-03			8.21E-03
Iodine-131	Bq	4.08E-01			4.08E-01
Iodine-133	Bq	2.46E-05			2.46E-05
Iodine-135	Bq	2.29E-05			2.29E-05
Iron	kg	6.47E-06			6.47E-06
Isocyanic acid	kg	3.96E-09			3.96E-09
Isophorone	kg	3.36E-08	1.65E-10	7.70E-09	2.57E-08
Isoprene	kg	2.89E-02	2.29E-04	1.93E-02	9.34E-03
Isopropylamine	kg	2.74E-06			2.74E-06
Kerosene	kg	1.65E-05	1.24E-07	1.09E-05	5.48E-06
Krypton-85	Bq	3.24E+00			3.24E+00
Krypton-85m	Bq	2.20E-01			2.20E-01
Krypton-87	Bq	7.67E-02			7.67E-02
Krypton-88	Bq	8.02E-02			8.02E-02

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Krypton-89	Bq	2.36E-02			2.36E-02
Lactic acid	kg	1.66E-06			1.66E-06
Lanthanum-140	Bq	1.00E-06			1.00E-06
Lead	kg	6.97E-05	5.78E-08	6.66E-05	3.08E-06
Lead-210	Bq	7.43E-02			7.43E-02
Magnesium	kg	1.53E-04	1.01E-06	1.00E-04	5.20E-05
Manganese	kg	2.10E-03	7.75E-08	2.09E-03	1.58E-05
Manganese-54	Bq	9.31E-08			9.31E-08
MCPA	kg	2.55E-11			2.55E-11
Mercaptans, unspecified	kg	1.25E-05	6.11E-08	2.88E-06	9.61E-06
Mercury	kg	6.40E-06	1.03E-08	5.57E-06	8.24E-07
Metals, unspecified	kg	5.60E-02	2.60E-14	5.57E-02	3.42E-04
Methacrylic acid, methyl ester	kg	1.16E-09	5.68E-12	2.65E-10	8.85E-10
Methane	kg	5.46E-01	1.56E-02	3.35E-01	1.95E-01
Methane, biogenic	kg	2.16E-05			2.16E-05
Methane, bromo-, Halon 1001	kg	9.26E-09	4.55E-11	2.12E-09	7.09E-09
Methane, bromochlorodifluoro-, Halon 1211	kg	5.54E-09			5.54E-09
Methane, bromotrifluoro-, Halon 1301	kg	1.77E-09			1.77E-09
Methane, chlorodifluoro-, HCFC-22	kg	2.17E-08			2.17E-08
Methane, dichloro-, HCC-30	kg	3.88E-04	7.95E-08	3.80E-04	7.43E-06
Methane, dichlorodifluoro-, CFC-12	kg	7.95E-08	4.13E-10	8.56E-10	7.82E-08
Methane, dichlorofluoro-, HCFC-21	kg	1.12E-13			1.12E-13
Methane, fossil	kg	6.05E-02	1.20E-03	3.41E-02	2.51E-02
Methane, monochloro-, R-40	kg	3.07E-08	1.51E-10	7.04E-09	2.35E-08
Methane, tetrachloro-, CFC-10	kg	4.37E-06	4.13E-11	8.19E-08	4.29E-06
Methane, tetrafluoro-, CFC-14	kg	1.05E-07			1.05E-07
Methane, trichlorofluoro-, CFC-11	kg	1.82E-13			1.82E-13
Methane, trifluoro-, HFC-23	kg	3.56E-11			3.56E-11
Methanesulfonic acid	kg	1.52E-06			1.52E-06
Methanol	kg	8.26E-02		7.35E-02	9.12E-03
Methyl acetate	kg	8.95E-07			8.95E-07
Methyl acrylate	kg	3.98E-10			3.98E-10
Methyl amine	kg	4.66E-07			4.66E-07
Methyl borate	kg	1.55E-07			1.55E-07
Methyl ethyl ketone	kg	6.43E-04	1.11E-10	6.43E-04	6.47E-07
Methyl formate	kg	1.55E-12			1.55E-12
Methyl lactate	kg	1.83E-06			1.83E-06
Methyl methacrylate	kg	1.55E-12		6.23E-13	9.32E-13
Metolachlor	kg	1.50E-08			1.50E-08

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Metribuzin	kg	6.95E-11			6.95E-11
Molybdenum	kg	1.97E-08			1.97E-08
Monoethanolamine	kg	5.17E-05			5.17E-05
m-Xylene	kg	8.80E-09			8.80E-09
Naphthalene	kg	1.28E-04	1.48E-08	1.27E-04	1.10E-06
Nickel	kg	5.57E-05	9.01E-07	4.93E-05	5.46E-06
Niobium-95	Bq	1.11E-08			1.11E-08
Nitrate	kg	4.48E-08			4.48E-08
Nitrobenzene	kg	1.58E-05			1.58E-05
Nitrogen oxides	kg	1.03E+00	2.10E-01	6.26E-01	1.92E-01
Nitrogen, total	kg	7.12E-06	7.11E-06		1.83E-09
NMVOOC, non-methane volatile organic compounds, unspecified origin	kg	5.57E-02	7.00E-03	2.54E-02	2.33E-02
N-Nitrodimethylamine	kg	1.38E-14			1.38E-14
Noble gases, radioactive, unspecified	Bq	7.89E+04			7.89E+04
Organic acids	kg	1.27E-07	9.55E-10	8.37E-08	4.20E-08
Organic substances, unspecified	kg	9.82E-05	5.68E-07	5.77E-05	4.00E-05
Ozone	kg	2.86E-06			2.86E-06
PAH, polycyclic aromatic hydrocarbons	kg	1.51E-05	1.05E-05	4.38E-06	1.51E-07
Paraquat	kg	3.03E-10			3.03E-10
Parathion, methyl	kg	2.29E-10			2.29E-10
Particulates	kg	3.93E-05		1.94E-05	1.99E-05
Particulates, < 10 um	kg	8.40E-04			8.40E-04
Particulates, < 2.5 um	kg	5.63E-01	x	5.60E-01	3.22E-03
Particulates, > 10 um	kg	3.05E-04			3.05E-04
Particulates, > 2.5 um, and < 10um	kg	8.11E-01	6.42E-03	7.96E-01	8.67E-03
Particulates, SPM	kg	8.07E-05			8.07E-05
Particulates, unspecified	kg	2.60E-01	1.15E-03	2.32E-01	2.76E-02
Pendimethalin	kg	1.56E-09			1.56E-09
Pentane	kg	8.26E-06			8.26E-06
Permethrin	kg	1.40E-10			1.40E-10
Phenanthrene	kg	3.70E-08	2.47E-10	2.45E-08	1.23E-08
Phenol	kg	1.96E-03	4.55E-12	1.92E-03	4.07E-05
Phenol, 2,4-dichloro-	kg	2.42E-06			2.42E-06
Phenol, pentachloro-	kg	2.21E-09			2.21E-09
Phenols, unspecified	kg	6.75E-05	4.14E-08	6.67E-05	7.10E-07
Phorate	kg	7.18E-11			7.18E-11
Phosphate	kg	1.63E-07	1.63E-07		x
Phosphine	kg	3.03E-13			3.03E-13

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Phosphorus	kg	1.07E-06			1.07E-06
Phthalate, dioctyl-	kg	4.22E-09	2.07E-11	9.69E-10	3.23E-09
Platinum	kg	1.19E-13			1.19E-13
Plutonium-238	Bq	1.12E-09			1.12E-09
Plutonium-alpha	Bq	2.57E-09			2.57E-09
Polonium-210	Bq	1.24E-01			1.24E-01
Polychlorinated biphenyls	kg	6.36E-11			6.36E-11
Potassium	kg	4.08E-05			4.08E-05
Potassium-40	Bq	1.56E-02			1.56E-02
Propanal	kg	2.59E-06	1.08E-10	5.05E-09	2.58E-06
Propane	kg	1.17E-05			1.17E-05
Propene	kg	4.33E-03	1.62E-04	2.09E-03	2.08E-03
Propionic acid	kg	7.66E-06			7.66E-06
Propylamine	kg	1.07E-14			1.07E-14
Propylene oxide	kg	1.41E-06	x	5.54E-08	1.36E-06
Protactinium-234	Bq	1.13E-03			1.13E-03
Pyrene	kg	4.53E-09	3.02E-11	3.00E-09	1.50E-09
Radioactive species, other beta emitters	Bq	2.51E-02			2.51E-02
Radioactive species, unspecified	Bq	7.73E+05	5.17E+03	5.14E+05	2.54E+05
Radionuclides (Including Radon)	kg	9.23E-04	6.96E-06	6.10E-04	3.06E-04
Radium-226	Bq	7.48E-02			7.48E-02
Radium-228	Bq	3.24E-02			3.24E-02
Radon-220	Bq	4.42E-01			4.42E-01
Radon-222	Bq	1.50E+05			1.50E+05
Ruthenium-103	Bq	2.43E-09			2.43E-09
Scandium	kg	1.43E-08			1.43E-08
Selenium	kg	2.17E-05	1.28E-07	1.55E-05	6.06E-06
Silicon	kg	8.03E-06			8.03E-06
Silicon tetrafluoride	kg	3.81E-11			3.81E-11
Silver	kg	6.14E-10			6.14E-10
Silver-110	Bq	2.41E-08			2.41E-08
Simazine	kg	9.84E-10			9.84E-10
Sodium	kg	1.83E-06			1.83E-06
Sodium chlorate	kg	4.18E-10			4.18E-10
Sodium dichromate	kg	1.46E-09			1.46E-09
Sodium formate	kg	4.14E-11			4.14E-11
Sodium hydroxide	kg	3.52E-09			3.52E-09
Strontium	kg	1.38E-07			1.38E-07
Styrene	kg	7.17E-09	7.10E-12	3.32E-10	6.83E-09

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Sulfate	kg	2.34E-04			2.34E-04
Sulfur	kg	4.61E-06			4.61E-06
Sulfur dioxide	kg	1.12E+00	7.54E-03	6.93E-01	4.17E-01
Sulfur hexafluoride	kg	4.23E-08			4.23E-08
Sulfur oxides	kg	9.30E-02	1.16E-02	5.73E-02	2.41E-02
Sulfur trioxide	kg	9.01E-05			9.01E-05
Sulfur, total reduced	kg	2.70E-06			2.70E-06
Sulfuric acid	kg	7.37E-10			7.37E-10
Sulfuric acid, dimethyl ester	kg	2.78E-09	1.36E-11	6.37E-10	2.13E-09
Tar	kg	9.92E-10	7.87E-12	6.63E-10	3.21E-10
t-Butyl methyl ether	kg	2.24E-09	9.95E-12	4.65E-10	1.77E-09
t-Butylamine	kg	2.64E-06			2.64E-06
Terbufos	kg	2.45E-09			2.45E-09
Terpenes	kg	1.11E-09			1.11E-09
Thallium	kg	7.58E-10			7.58E-10
Thorium	kg	8.53E-10			8.53E-10
Thorium-228	Bq	4.40E-03			4.40E-03
Thorium-230	Bq	2.56E-02			2.56E-02
Thorium-232	Bq	4.95E-03			4.95E-03
Thorium-234	Bq	1.13E-03			1.13E-03
Tin	kg	1.87E-08			1.87E-08
Titanium	kg	4.20E-07			4.20E-07
TOC, Total Organic Carbon	kg	5.35E-03		5.32E-03	3.27E-05
Toluene	kg	8.67E-05	2.57E-05	1.09E-05	5.01E-05
Toluene, 2,4-dinitro-	kg	1.62E-11	7.96E-14	3.72E-12	1.24E-11
Toluene, 2-chloro-	kg	7.24E-06			7.24E-06
Trimethylamine	kg	1.72E-15			1.72E-15
Tungsten	kg	1.55E-09			1.55E-09
Uranium	kg	1.12E-09			1.12E-09
Uranium alpha	Bq	6.16E-02			6.16E-02
Uranium-234	Bq	3.46E-02			3.46E-02
Uranium-235	Bq	6.40E-04			6.40E-04
Uranium-238	Bq	4.66E-02			4.66E-02
Vanadium	kg	1.18E-06			1.18E-06
Vinyl acetate	kg	4.40E-10	2.16E-12	1.01E-10	3.37E-10
VOC, volatile organic compounds	kg	4.32E-01	5.62E-03	4.11E-01	1.54E-02
Water	kg	2.32E-05			2.32E-05
Xenon-131m	Bq	3.62E-01			3.62E-01
Xenon-133	Bq	1.19E+01			1.19E+01

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Xenon-133m	Bq	4.16E-02			4.16E-02
Xenon-135	Bq	4.84E+00			4.84E+00
Xenon-135m	Bq	2.90E+00			2.90E+00
Xenon-137	Bq	6.48E-02			6.48E-02
Xenon-138	Bq	5.41E-01			5.41E-01
Xylene	kg	2.79E-05	1.79E-05	7.57E-06	2.47E-06
Zinc	kg	1.46E-06	1.32E-07	1.36E-08	1.32E-06
Zinc-65	Bq	4.65E-07			4.65E-07
Zirconium	kg	1.71E-10			1.71E-10
Zirconium-95	Bq	4.54E-07			4.54E-07

13.1 Water Emissions

Table 15 Emissions to water released per 1 m³ of laminated veneer lumber, PNW.

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
1,4-Butanediol	kg	2.98E-06			2.98E-06
1-Butanol	kg	6.75E-06			6.75E-06
1-Pentanol	kg	4.41E-14			4.41E-14
1-Pentene	kg	3.34E-14			3.34E-14
1-Propanol	kg	8.44E-14			8.44E-14
2,4-D	kg	5.86E-11			5.86E-11
2-Aminopropanol	kg	3.83E-06			3.83E-06
2-Hexanone	kg	1.22E-06	8.81E-08	6.62E-07	4.74E-07
2-Methyl-1-propanol	kg	3.46E-06			3.46E-06
2-Methyl-2-butene	kg	7.40E-18			7.40E-18
2-Propanol	kg	1.52E-05			1.52E-05
4-Methyl-2-pentanone	kg	7.88E-07	5.67E-08	4.26E-07	3.05E-07
Acenaphthene	kg	1.96E-11			1.96E-11
Acenaphthylene	kg	1.22E-12			1.22E-12
Acetaldehyde	kg	1.09E-04			1.09E-04
Acetic acid	kg	4.10E-04			4.10E-04
Acetochlor	kg	8.13E-10			8.13E-10
Acetone	kg	1.01E-05	1.35E-07	1.01E-06	8.94E-06
Acetonitrile	kg	1.26E-06			1.26E-06
Acetyl chloride	kg	3.47E-14			3.47E-14
Acidity, unspecified	kg	7.55E-07			7.55E-07
Acids, unspecified	kg	3.62E-06	1.47E-10	1.24E-08	3.61E-06
Acrylate, ion	kg	8.30E-10			8.30E-10
Actinides, radioactive, unspecified	Bq	1.33E-02			1.33E-02
Alachlor	kg	8.00E-11			8.00E-11
Aluminium	kg	2.45E-03		8.72E-04	1.58E-03
Aluminum	kg	6.43E-03	1.15E-03	3.04E-03	2.23E-03
Ammonia	kg	2.75E-03	2.52E-04	1.44E-03	1.07E-03
Ammonia, as N	kg	9.30E-09	7.38E-11	6.22E-09	3.01E-09
Ammonium, ion	kg	1.59E-03	5.56E-08	4.87E-06	1.58E-03
Aniline	kg	2.39E-05			2.39E-05
Antimony	kg	6.21E-06	7.18E-07	2.31E-06	3.18E-06
Antimony-122	Bq	6.95E-06			6.95E-06
Antimony-124	Bq	2.28E-03			2.28E-03
Antimony-125	Bq	2.10E-03			2.10E-03

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
AOX, Adsorbable Organic Halogen as Cl	kg	3.19E-07			3.19E-07
Arsenic, ion	kg	4.77E-05	3.99E-06	2.40E-05	1.97E-05
Atrazine	kg	1.58E-09			1.58E-09
Barite	kg	2.68E-05			2.68E-05
Barium	kg	1.12E-01	1.58E-02	5.36E-02	4.30E-02
Barium-140	Bq	3.04E-05			3.04E-05
Bentazone	kg	6.46E-12			6.46E-12
Benzene	kg	1.91E-02	2.26E-05	9.16E-03	9.90E-03
Benzene, 1,2-dichloro-	kg	3.60E-05			3.60E-05
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.87E-08	1.35E-09	1.01E-08	7.25E-09
Benzene, chloro-	kg	5.36E-04			5.36E-04
Benzene, ethyl-	kg	1.78E-05	1.27E-06	9.57E-06	6.92E-06
Benzene, pentamethyl-	kg	1.40E-08	1.01E-09	7.60E-09	5.44E-09
Benzenes, alkylated, unspecified	kg	4.30E-06	6.30E-07	2.03E-06	1.65E-06
Benzoic acid	kg	1.90E-04	1.37E-05	1.03E-04	7.36E-05
Beryllium	kg	2.73E-06	2.05E-07	1.16E-06	1.37E-06
Biphenyl	kg	2.79E-07	4.08E-08	1.31E-07	1.07E-07
BOD5, Biological Oxygen Demand	kg	2.11E-01	2.47E-03	1.02E-01	1.06E-01
Borate	kg	2.17E-04			2.17E-04
Boron	kg	6.18E-04	4.24E-05	3.18E-04	2.58E-04
Bromate	kg	2.96E-05			2.96E-05
Bromide	kg	4.57E-02	2.89E-03	2.17E-02	2.11E-02
Bromine	kg	3.34E-06			3.34E-06
Bromoxynil	kg	8.55E-12			8.55E-12
Butene	kg	1.09E-05			1.09E-05
Butyl acetate	kg	3.65E-07			3.65E-07
Butyrolactone	kg	5.04E-12			5.04E-12
Cadmium, ion	kg	7.46E-06	6.47E-07	3.56E-06	3.25E-06
Calcium, ion	kg	6.11E-01	4.34E-02	3.26E-01	2.42E-01
Carbofuran	kg	1.21E-11			1.21E-11
Carbon disulfide	kg	2.06E-12			2.06E-12
Carbonate	kg	2.62E-03			2.62E-03
Carboxylic acids, unspecified	kg	1.38E-05			1.38E-05
Cerium-141	Bq	1.22E-05			1.22E-05
Cerium-144	Bq	3.71E-06			3.71E-06
Cesium	kg	3.15E-09			3.15E-09
Cesium-134	Bq	1.84E-03			1.84E-03
Cesium-136	Bq	2.16E-06			2.16E-06
Cesium-137	Bq	1.54E+0			1.54E+00

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
		0			
CFCs, unspecified	kg	2.54E-09			2.54E-09
Chloramine	kg	3.63E-05			3.63E-05
Chlorate	kg	2.26E-04			2.26E-04
Chloride	kg	6.88E+00	4.87E-01	3.66E+00	2.73E+00
Chlorinated solvents, unspecified	kg	1.54E-07			1.54E-07
Chlorine	kg	1.26E-08			1.26E-08
Chloroacetic acid	kg	9.78E-04			9.78E-04
Chloroacetyl chloride	kg	5.10E-06			5.10E-06
Chloroform	kg	4.47E-06			4.47E-06
Chlorosulfonic acid	kg	4.58E-06			4.58E-06
Chlorpyrifos	kg	9.32E-11			9.32E-11
Chromate	kg	3.38E-13			3.38E-13
Chromium	kg	1.50E-04	3.07E-05	6.27E-05	5.67E-05
Chromium VI	kg	4.23E-06	1.27E-07	2.64E-07	3.84E-06
Chromium, ion	kg	7.31E-05	2.39E-06	4.21E-05	2.86E-05
Chromium-51	Bq	3.20E-03			3.20E-03
Cobalt	kg	1.24E-05	2.99E-07	2.25E-06	9.86E-06
Cobalt-57	Bq	6.86E-05			6.86E-05
Cobalt-58	Bq	2.09E-02			2.09E-02
Cobalt-60	Bq	1.68E-02			1.68E-02
COD, Chemical Oxygen Demand	kg	2.37E-01	4.67E-03	1.15E-01	1.18E-01
Copper, ion	kg	5.19E-05	4.03E-06	2.27E-05	2.52E-05
Cumene	kg	2.66E-02		1.32E-02	1.35E-02
Cyanazine	kg	1.40E-11			1.40E-11
Cyanide	kg	5.24E-06	9.75E-10	7.36E-09	5.23E-06
Decane	kg	5.46E-06	3.93E-07	2.96E-06	2.11E-06
Detergent, oil	kg	1.77E-04	1.14E-05	9.67E-05	6.84E-05
Dibenzofuran	kg	3.56E-08	2.57E-09	1.93E-08	1.38E-08
Dibenzothiophene	kg	2.97E-08	2.21E-09	1.60E-08	1.15E-08
Dicamba	kg	8.23E-11			8.23E-11
Dichromate	kg	3.22E-09			3.22E-09
Diethylamine	kg	1.14E-05			1.14E-05
Dimethenamid	kg	1.94E-10			1.94E-10
Dimethylamine	kg	5.01E-05			5.01E-05
Dipropylamine	kg	5.09E-06			5.09E-06
Dipropylthiocarbamic acid S-ethyl ester	kg	8.03E-11			8.03E-11
Disulfoton	kg	4.80E-12			4.80E-12

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Diuron	kg	1.35E-12			1.35E-12
DOC, Dissolved Organic Carbon	kg	5.07E-02	4.51E-13	2.43E-02	2.64E-02
Docosane	kg	2.01E-07	1.44E-08	1.08E-07	7.76E-08
Dodecane	kg	1.04E-05	7.46E-07	5.61E-06	4.01E-06
Eicosane	kg	2.85E-06	2.06E-07	1.54E-06	1.10E-06
Ethane, 1,2-dichloro-	kg	1.98E-05			1.98E-05
Ethanol	kg	3.46E-04			3.46E-04
Ethene	kg	3.14E-06			3.14E-06
Ethene, chloro-	kg	6.55E-10			6.55E-10
Ethyl acetate	kg	1.56E-08			1.56E-08
Ethylamine	kg	1.05E-05			1.05E-05
Ethylene diamine	kg	1.11E-12			1.11E-12
Ethylene oxide	kg	1.70E-05			1.70E-05
Fluorene, 1-methyl-	kg	2.13E-08	1.54E-09	1.15E-08	8.26E-09
Fluorenes, alkylated, unspecified	kg	2.49E-07	3.65E-08	1.18E-07	9.54E-08
Fluoride	kg	1.40E-03	9.10E-04	7.92E-05	4.11E-04
Fluorine	kg	1.31E-07	1.80E-08	6.30E-08	5.03E-08
Fluosilicic acid	kg	2.44E-08			2.44E-08
Formaldehyde	kg	2.04E-04			2.04E-04
Formamide	kg	8.07E-14			8.07E-14
Formate	kg	8.13E-04			8.13E-04
Formic acid	kg	2.34E-14			2.34E-14
Furan	kg	9.32E-11			9.32E-11
Glutaraldehyde	kg	3.31E-09			3.31E-09
Glyphosate	kg	1.75E-10			1.75E-10
Heat, waste	MJ	4.59E-01			4.59E-01
Hexadecane	kg	1.13E-05	8.15E-07	6.12E-06	4.38E-06
Hexanoic acid	kg	3.94E-05	2.84E-06	2.13E-05	1.52E-05
Hydrocarbons, aliphatic, alkanes, unspecified	kg	4.09E-07			4.09E-07
Hydrocarbons, aliphatic, unsaturated	kg	4.28E-06			4.28E-06
Hydrocarbons, aromatic	kg	1.71E-06			1.71E-06
Hydrocarbons, unspecified	kg	3.46E-06	5.65E-13	4.76E-11	3.46E-06
Hydrogen peroxide	kg	1.56E-07			1.56E-07
Hydrogen sulfide	kg	2.42E-07			2.42E-07
Hydrogen-3, Tritium	Bq	3.52E+03			3.52E+03
Hydroxide	kg	2.05E-06			2.05E-06
Hypochlorite	kg	1.88E-07			1.88E-07
Iodide	kg	2.16E-03			2.16E-03

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Iodine-131	Bq	4.27E-04			4.27E-04
Iodine-133	Bq	1.91E-05			1.91E-05
Iron	kg	1.91E-02	2.30E-03	9.46E-03	7.29E-03
Iron, ion	kg	1.01E-03			1.01E-03
Iron-59	Bq	5.25E-06			5.25E-06
Isopropylamine	kg	6.58E-06			6.58E-06
Lactic acid	kg	3.99E-06			3.99E-06
Lanthanum-140	Bq	3.24E-05			3.24E-05
Lead	kg	7.89E-05	7.87E-06	3.99E-05	3.11E-05
Lead-210	Bq	3.37E-02			3.37E-02
Lead-210/kg	kg	1.95E-14	1.40E-15	1.05E-14	7.54E-15
Lithium, ion	kg	1.34E-01	9.27E-04	8.07E-02	5.24E-02
Magnesium	kg	1.21E-01	8.48E-03	6.37E-02	4.91E-02
Manganese	kg	7.09E-04	1.51E-05	2.61E-04	4.33E-04
Manganese-54	Bq	1.28E-03			1.28E-03
MCPA	kg	1.09E-12			1.09E-12
Mercury	kg	2.10E-07	1.73E-08	4.72E-08	1.46E-07
Metallic ions, unspecified	kg	2.92E-09	6.90E-12	5.81E-10	2.33E-09
Methane, dichloro-, HCC-30	kg	5.61E-06			5.61E-06
Methane, monochloro-, R-40	kg	7.54E-09	5.43E-10	4.08E-09	2.92E-09
Methanol	kg	5.12E-05			5.12E-05
Methyl acetate	kg	2.15E-06			2.15E-06
Methyl acrylate	kg	7.77E-09			7.77E-09
Methyl amine	kg	1.12E-06			1.12E-06
Methyl ethyl ketone	kg	1.51E-08	1.09E-09	8.16E-09	5.84E-09
Methyl formate	kg	6.20E-13			6.20E-13
Metolachlor	kg	6.42E-10			6.42E-10
Metribuzin	kg	2.98E-12			2.98E-12
Molybdenum	kg	6.34E-06	3.10E-07	2.33E-06	3.70E-06
Molybdenum-99	Bq	1.12E-05			1.12E-05
m-Xylene	kg	5.68E-06	4.09E-07	3.07E-06	2.20E-06
Naphthalene	kg	3.41E-06	2.46E-07	1.84E-06	1.32E-06
Naphthalene, 2-methyl-	kg	2.97E-06	2.14E-07	1.61E-06	1.15E-06
Naphthalenes, alkylated, unspecified	kg	7.05E-08	1.03E-08	3.32E-08	2.70E-08
n-Hexacosane	kg	1.25E-07	9.01E-09	6.77E-08	4.84E-08
Nickel	kg	3.92E-05	3.78E-06	2.04E-05	1.51E-05
Nickel, ion	kg	3.01E-05			3.01E-05
Niobium-95	Bq	1.81E-04			1.81E-04
Nitrate	kg	1.46E-03	4.95E-14	4.17E-12	1.46E-03

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Nitrate compounds	kg	2.51E-10	1.99E-12	1.68E-10	8.11E-11
Nitric acid	kg	5.63E-07	4.47E-09	3.77E-07	1.82E-07
Nitrite	kg	5.35E-07			5.35E-07
Nitrobenzene	kg	6.34E-05			6.34E-05
Nitrogen	kg	8.40E-06			8.40E-06
Nitrogen, organic bound	kg	1.25E-06			1.25E-06
Nitrogen, total	kg	2.88E-05	1.38E-07	1.21E-05	1.66E-05
o-Cresol	kg	5.39E-06	3.88E-07	2.92E-06	2.09E-06
Octadecane	kg	2.80E-06	2.01E-07	1.51E-06	1.08E-06
Oils, unspecified	kg	4.20E-03	3.11E-04	2.11E-03	1.77E-03
Organic substances, unspecified	kg	1.86E-09			1.86E-09
o-Xylene	kg	6.18E-13			6.18E-13
PAH, polycyclic aromatic hydrocarbons	kg	1.96E-08			1.96E-08
Paraquat	kg	1.30E-11			1.30E-11
Parathion, methyl	kg	9.82E-12			9.82E-12
p-Cresol	kg	5.82E-06	4.19E-07	3.15E-06	2.25E-06
Pendimethalin	kg	6.68E-11			6.68E-11
Permethrin	kg	6.00E-12			6.00E-12
Phenanthrene	kg	3.38E-08	3.72E-09	1.71E-08	1.30E-08
Phenanthrenes, alkylated, unspecified	kg	2.92E-08	4.28E-09	1.38E-08	1.12E-08
Phenol	kg	1.30E-04	5.63E-06	1.17E-05	1.13E-04
Phenol, 2,4-dimethyl-	kg	5.25E-06	3.78E-07	2.84E-06	2.03E-06
Phenols, unspecified	kg	6.01E-05	1.17E-06	3.54E-05	2.35E-05
Phorate	kg	1.86E-12			1.86E-12
Phosphate	kg	1.80E-03	6.84E-04		1.12E-03
Phosphorus	kg	3.41E-05			3.41E-05
Phosphorus compounds, unspecified	kg	3.44E-08			3.44E-08
Phosphorus, total	kg	3.07E-06			3.07E-06
Polonium-210	Bq	4.14E-02			4.14E-02
Potassium, ion	kg	2.85E-03			2.85E-03
Potassium-40	Bq	2.57E-02			2.57E-02
Process solvents, unspecified	kg	9.32E-09			9.32E-09
Propanal	kg	2.33E-04			2.33E-04
Propene	kg	9.87E-03		4.85E-03	5.02E-03
Propionic acid	kg	1.82E-05			1.82E-05
Propylamine	kg	2.56E-14			2.56E-14
Propylene oxide	kg	3.12E-06			3.12E-06
Protactinium-234	Bq	2.09E-02			2.09E-02
Radioactive species, alpha emitters	Bq	1.21E-02			1.21E-02

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Radioactive species, Nuclides, unspecified	Bq	1.08E+03	8.07E+00	7.07E+02	3.63E+02
Radium-224	Bq	1.57E-01			1.57E-01
Radium-226	Bq	1.33E+01			1.33E+01
Radium-226/kg	kg	6.77E-12	4.88E-13	3.66E-12	2.62E-12
Radium-228	Bq	3.15E-01			3.15E-01
Radium-228/kg	kg	3.47E-14	2.50E-15	1.87E-14	1.34E-14
Rubidium	kg	3.15E-08			3.15E-08
Ruthenium-103	Bq	2.36E-06			2.36E-06
Scandium	kg	8.73E-07			8.73E-07
Selenium	kg	4.83E-06	1.59E-07	2.16E-06	2.52E-06
Silicon	kg	6.48E-03			6.48E-03
Silver	kg	3.93E-04	2.83E-05	2.13E-04	1.52E-04
Silver, ion	kg	4.06E-08			4.06E-08
Silver-110	Bq	1.58E-02			1.58E-02
Simazine	kg	4.22E-11			4.22E-11
Sodium formate	kg	9.95E-11			9.95E-11
Sodium, ion	kg	1.97E+00	1.37E-01	1.03E+00	8.04E-01
Sodium-24	Bq	8.46E-05			8.46E-05
Solids, inorganic	kg	6.47E-04	1.14E-11	9.57E-10	6.47E-04
Solved solids	kg	8.39E+00	6.01E-01	4.54E+00	3.25E+00
Strontium	kg	1.03E-02	7.36E-04	5.53E-03	4.07E-03
Strontium-89	Bq	3.01E-04			3.01E-04
Strontium-90	Bq	1.13E+01			1.13E+01
Styrene	kg	3.43E-10		1.64E-10	1.79E-10
Sulfate	kg	6.56E-02	1.09E-03	1.73E-02	4.71E-02
Sulfide	kg	7.46E-05	6.54E-07	3.27E-06	7.07E-05
Sulfite	kg	5.09E-07			5.09E-07
Sulfur	kg	6.14E-04	3.58E-05	2.69E-04	3.09E-04
Sulfuric acid	kg	8.15E-11			8.15E-11
Suspended solids, inorganic	kg	9.41E-05			9.41E-05
Suspended solids, unspecified	kg	2.57E-01	3.54E-02	1.22E-01	9.96E-02
Tar	kg	1.42E-11	1.13E-13	9.49E-12	4.59E-12
t-Butyl methyl ether	kg	9.10E-09			9.10E-09
t-Butylamine	kg	6.33E-06			6.33E-06
Technetium-99m	Bq	2.58E-04			2.58E-04
Tellurium-123m	Bq	2.39E-04			2.39E-04

Substance	Unit	Total	Forestry Operations	Veneer/PLV Production	LVL Production
Tellurium-132	Bq	6.47E-07			6.47E-07
Terbufos	kg	6.34E-11			6.34E-11
Tetradecane	kg	4.54E-06	3.27E-07	2.46E-06	1.76E-06
Thallium	kg	1.11E-06	1.51E-07	4.88E-07	4.69E-07
Thorium-228	Bq	6.30E-01			6.30E-01
Thorium-230	Bq	2.85E+00			2.85E+00
Thorium-232	Bq	4.46E-03			4.46E-03
Thorium-234	Bq	2.09E-02			2.09E-02
Tin	kg	2.78E-05	2.94E-06	1.42E-05	1.07E-05
Tin, ion	kg	6.24E-07			6.24E-07
Titanium, ion	kg	9.78E-05	1.10E-05	3.56E-05	5.12E-05
TOC, Total Organic Carbon	kg	5.07E-02		2.43E-02	2.64E-02
Toluene	kg	3.33E-04	2.14E-05	1.61E-04	1.51E-04
Toluene, 2-chloro-	kg	1.27E-05			1.27E-05
Tributyltin compounds	kg	6.25E-09			6.25E-09
Triethylene glycol	kg	6.28E-08			6.28E-08
Trimethylamine	kg	4.14E-15			4.14E-15
Tungsten	kg	7.72E-07			7.72E-07
Uranium alpha	Bq	1.20E+00			1.20E+00
Uranium-234	Bq	2.51E-02			2.51E-02
Uranium-235	Bq	4.14E-02			4.14E-02
Uranium-238	Bq	8.00E-02			8.00E-02
Urea	kg	7.56E-14			7.56E-14
Vanadium	kg	5.09E-06	3.66E-07	2.75E-06	1.97E-06
Vanadium, ion	kg	2.94E-06			2.94E-06
VOC, volatile organic compounds, unspecified origin	kg	1.15E-06			1.15E-06
Waste water/m3	m3	7.68E-04			7.68E-04
Xylene	kg	1.56E-04	1.15E-05	8.42E-05	6.07E-05
Yttrium	kg	1.26E-06	9.10E-08	6.83E-07	4.89E-07
Zinc	kg	2.02E-04	2.66E-05	9.89E-05	7.69E-05
Zinc, ion	kg	5.64E-05			5.64E-05
Zinc-65	Bq	1.15E-03			1.15E-03
Zirconium-95	Bq	1.33E-05			1.33E-05