CORRIM Report:
Life Cycle Assessment for the Production of Pacific Northwest Glued Laminated Timbers

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Addendum

The original report "CORRIM Report – Module G1 Cradle-to-gate life-cycle assessment of glued laminated timbers US Pacific Northwest (PNW) region 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. In addition, process production for resins were corrected in this report. 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. Due to correction of resin processes, this report supersedes the previous report and should be the primary reference for the LCA of PNW glulam. Other changes and additions from the original report may include additional required reporting impact factors and impact methods (Table A1) per the PCR and ISO 14044 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	Yes
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	
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

BF	Board foot
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
MBF	1000 Board Feet
odkg	Oven Dry Weight Wood in Kilograms
PCR	Product Category Rules
tkm	Metric Tonne – Kilometers

Table of Contents

Addendum **2**

Abbreviations **4**

Table of Contents **5**

List of Figures **7**

List of Tables **7**

1 Background **8**

2 Goal and Scope **8**

2.1 Goal and Objectives *8*
2.1.1 Goals 8
2.1.2 Intended Audience 8
2.1.3 Comparative Assertions 9

2.2 Scope of Considered System *9*
2.2.1 Functional and declared unit 9
2.2.2 System boundary 9
2.2.3 Allocation rules 11
2.2.4 Cut off rules 11
2.2.5 Data collection 11
2.2.6 Calculation rules 11

3 Description of Industry **13**

3.1 Annual operating and production statistics of the industry (US total, regional) *13*

3.2 Typical emission control measures by plant type *13*

4 Description of Product **14**

4.1 Wood species and wood density *15*

4.2 Moisture content *16*

5 Life cycle inventory analysis **17**

5.1 A1- Resource extraction *17*
5.1.1 Forestry Operations 17
5.1.2 Resins 19
5.1.3 Lamstock Production 19

5.2 A2 – Transport of raw materials from extraction site *19*

5.3 A3 – Glulam Manufacturing *20*
5.3.1 Material Flows 20
5.3.2 Glulam Manufacturing 20
5.3.3 Energy use and generation 22
5.3.4 Wood-base fuels 22
5.3.5 Packaging 24

5.4 Secondary Data Sources *24*

6 Life cycle impact assessment **29**

6.1 Interpretation *34*

6.2 Identification of the significant issues *34*

6.3 Life cycle phase contribution analysis *35*

6.4 Uncertainty Analysis *40*

6.5 Completeness, consistency and sensitivity *40*

6.6 Limitations *41*

7 Treatment of Biogenic Carbon **41**

8 Discussion **43**

9 Conclusions **44**

10 Critical review **45**

10.1 Internal Review *45*

10.2 External Review *45*

11 Acknowledgements **45**

12 Units and Conversions **46**

13 References **47**

14 Appendix 1 Conformance to North American Structural and Architectural Wood Product Category Rules .. **49**

15 Appendix 2 Original LCA Report **50**

List of Figures

Figure 1 Cradle-to-gate system boundary for glulam production in the PNW region 10
Figure 2 Glulam layup (left) and glulam header (right) (APA) 14
Figure 3 Cradle-to-gate glulam LCIA results for A1-Resource extraction, PNW 38
Figure 4 Gate-to-gate LCIA results for A3-glulam production, PNW 39

List of Tables

Table A1 Original and updated reporting requirements 2
Table 1 System boundary inclusions and exclusions for the cradle-to-gate of PNW glulam production 11
Table 2 Lamstock sizes used in production of glulam, PNW 15
Table 3 Species used in Glued-Laminated Timber production, PNW 16
Table 4 Species density and specific gravity at various moisture contents 16
Table 5 Management and Harvest Timeline and Yield (Oneil and Puettmann, 2017) 18
Table 6 Harvesting Inputs (per cubic meter) (Oneil and Puettmann, 2017) 18
Table 7 Delivery distance of input materials for glulam production in the PNW region 19
Table 8 Mass balance of glulam manufacturing process for in the PNW region 20
Table 9 Unit process inputs/outputs for glulam production (one cubic meter), PNW 22
Table 10 Inputs to wood boiler per bone dry kg of wood fuel combusted (Puettmann and Milota 2017) 23
Table 11 Materials used in packaging and shipping per m^3 PNW glulam 24
Table 12 Secondary Data Sources and Data Quality Assessment 25
Table 13 Selected impact indicators, characterization models, and impact categories 29
Table 14 Environmental performance of 1 m^3 of glulam, PNW 32
Table 15 Cradle to gate glulam LCIA results for A1-Resource extraction: Forestry operations and lamstock and resin production, PNW 33
Table 16 Cradle to gate glulam LCIA results for A3-Glulam production, PNW 34
Table 17 Cradle-to-gate PNW glulam LCIA contribution analysis LCIA results for A1-Resource extraction, A2-Transporation, and A3-Product production 36
Table 18 Cradle-to-gate PNW glulam production energy contribution by fuel type 37
Table 19 Cradle-to-gate PNW glulam LCIA results for A1-Resource extraction: forestry operations and lamstock and resin production 38
Table 20 Gate-to-gate PNW glulam LCIA results for A3-Glulam production, PNW 39
Table 21 Survey data statistics for selected parameters in glulam production, PNW 40
Table 22 Life cycle stages contribution analysis per 1 m^3 glulam, PNW (mass and economic allocation) *(NOTE: Results are based on the reporting requirements and impact methods from the 2015 PCR)* 40
Table 23 Sensitivity analysis of mass allocation versus economic allocation methodologies 41
Table 24 Biogenic carbon inventory parameters 43
Table 25 LCIA comparison between updated 2013 data (based on 2001 industry surveys) and current study data (based on 2013 industry surveys) on glulam production in the PNW 44
Table 26 Unit Conversion Factors 46

1 Background

The environmental consequences of producing a material such glue laminated timbers (glulam) is 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 glulam produced in the US Pacific Northwest (PNW) region.

This report describes the energy and materials for producing glulam 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 as well as energy and water use and waste production.

Glulam mills were surveyed to determine their material use and energy consumption for the 2012 calendar year. The respondent production data were averaged after weighting by mill annual production to obtain an industry average. Inputs included lamstock, fuels, packaging materials, resins, and chemicals necessary for glulam production. The products included glulam and co-products that are used for onsite fuel.

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 goal of this study is to update a 2004 CORRIM Phase I report with current LCI data on material and energy inputs associated with the production of glulam produced in the PNW region. This report will provide a "cradle-to-gate" life cycle inventory while measuring the environmental impacts from the production of one cubic meter of glulam in the region.

2.1.2 Intended Audience

The primary audience for the results of this LCA report is glulam 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 glulam is one cubic meter (417 board feet, BF) of finished glulam packaged for shipment. 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 combining the PNW glulam manufacturing data collected by survey with previously published datasets for upstream manufacturing of lamstock production (lumber production), 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 of the forest in the PNW region and ends with glulam packaged at the plant gate. The system boundary includes forest operations, which may include growing seedlings in a nursery, planting the seedlings, managing the forest which may include pre-commercial and commercial thinnings and fertilizations, and final harvesting with the logs brought to a landing, lamstock production, and resin production (A1), Transportation of all resources and materials (A2), and PNW glulam production (A3) (Figure 1). Excluded from the system boundaries are fixed capital equipment and facilities, transportation of employees, land use, delivery of glulam 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.

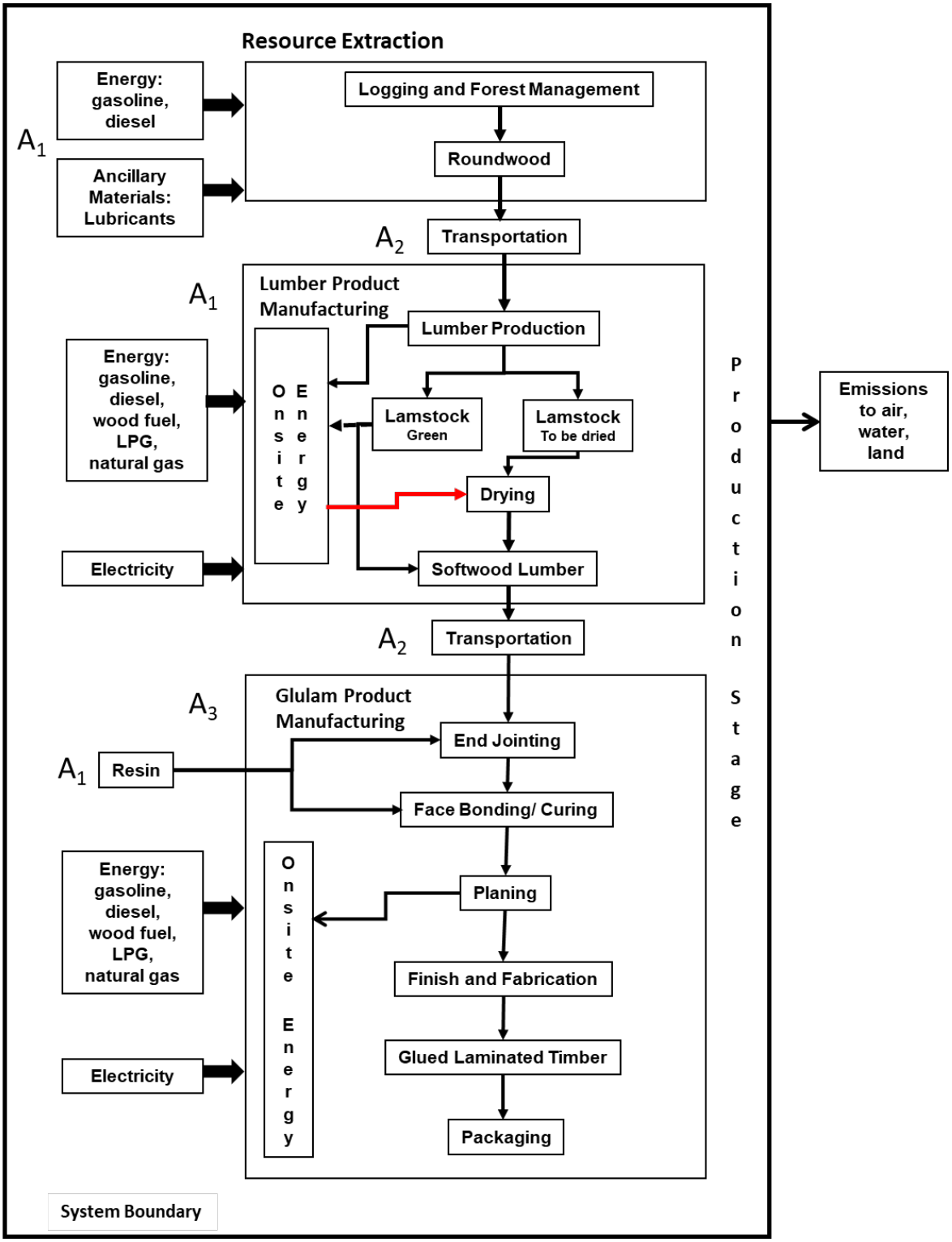

Figure 1 Cradle-to-gate system boundary for glulam production in the PNW region

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

Included	Excluded
• Production of upstream processes for all resources, raw materials, fuels, and energy for glulam production used in forestry operations, harvesting, and glulam 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

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 lamstock. Processing involves trimming lamstock boards before pressing. There are minimal coproducts generated. A mass allocation was applied to the product and coproduct generated.

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 glulam 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 14044 standards. This study relied almost exclusively on production and emissions data provided by glulam 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). Four mills provided data for 2013 glulam and co-product production, raw material and fuel use, electricity consumption, and on-site emissions.

2.2.6 Calculation rules

Lumber inputs (lamstock) were provided in board feet (BF) and a ratio of nominal to actual BF was used to calculate actual wood volumes. This ratio was determined by weight averaging the BF ratio of each size of lamstock used for glulam. The volume was converted to cubic meters (m^3) and the weight of the lamstock input was calculated with the weighted average of the PNW species density in 511kg/m^3. All data from the survey was weight averaged based on a particular mill's production in comparison to the total survey production for the year. All conversion units for forestry and forest products were taken from Briggs (1994). Units were collected from mills with typical industry weights and measures and converted to appropriate SI units.

The values reported by each mill were combined into a production-weighted average for each input (eq. 1). Thus, the value from a large mill had more weight. This approach resulted in a glulam production complex that represents a composite of the mills surveyed and maintains confidentiality. SimaPro, version 8.5.2 (Pré Consultants 2019) was used as the accounting program to track all of the materials.

Missing data is defined as data not reported in surveys. 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.

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

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

Because the surveyed mill data varied between facilities, a statistical analysis was conducted. In the present study, the weighted coefficient of variation was calculated (NIST ITL 1996). The weighted coefficient of variation is the weighted standard deviation divided by the weighted mean:

$$\mathrm{Sd}_w = \sqrt{\sum_{i=1}^{N} \mathrm{w}_i \, (\mathrm{x}_i - \bar{\mathrm{x}}_w)^2 \; x \; \frac{N'}{(N'-1)\sum_{i=1}^{N} \mathrm{w}_i}}$$

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

3 Description of Industry

One of the original engineered wood products developed over 100 years ago was stacked and glued pieces of lumber. Structural glued-laminated timbers (glulam) were created to fill the void left by the lack of large solid dimensional timbers from old growth forests. Glulam comes in a variety of sizes with their production based on nominal[2] board feet[3], and sold by retailers on a linear-foot basis.

Glulam facilities are primarily located in the US PNW and southeast. The locations of larger manufacturers are typically closer to the wood resource input, in this case lamstock, so that most of the raw material inputs can arrive by truck. Most glulam plants have been in existence for 20 years or more and utilize one of two laminating technologies, either cold curing (no added heat) or radio frequency curing. Emission control devices are required at these facilities since toxic gases are emitted to the air from the curing of melamine and formaldehyde resins. Besides typical air emissions from energy use and equipment combustion, wood waste is generally the main byproduct of the glulam manufacturing process.

Most glulam plants have been in existence for 20 years or more and utilize one of two laminating technologies, either cold curing (no added heat) or radio frequency curing. Emission control devices are required at these facilities since toxic gases are emitted to the air from the curing of melamine and formaldehyde resins. Besides typical air emissions from energy use and equipment combustion, wood waste is generally the main byproduct of the glulam manufacturing process.

3.1 Annual operating and production statistics of the industry (US total, regional)

The total production of glulam in the PNW region was 542,740 m^3 (230,000 MBF, nominal) in 2013 (APA 2014). The surveyed mills (n=4) located in the PNW produced 270,029 m^3 (114,432 MBF, nominal), which represents 49.8 percent of the total production in the US for 2013.

3.2 Typical emission control measures by plant type

Emission control devices are required at these facilities since toxic gases are emitted to the air from the curing of melamine and formaldehyde resins. The air emissions reported by most mills include dust, particulate matter (PM), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs). Mills classed as major sources under EPA rules are required to report methanol, formaldehyde, phenol, acetaldehyde, propionaldehyde, and acrolein which on the EPA's HAPs list. If boilers are included, then there are some sulfur dioxide and oxides of nitrogen emitted. There were emissions recorded in the surveys by NE-NC mills. Some emissions were manually calculated based and included in the LCI.

Glulam manufacturers typically generate minimal solid waste on-site; wood processing waste generated during processing are used for on-site energy generation for drying 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. On-site reported air emissions such as HAPs, VOCs and PM are associated with wood heating and fuel combustion, veneer drying and panel pressing. No dangerous substances were reported by industry that fall under ISO 21930 (ISO 2017).

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[2] Nominal size- The size designation for most lumber. In lumber, the nominal size usually is greater than the actual dimension; a kiln dried 2x4 (nominal) is surfaced to 1-1/2 x 3-1/2 inches (actual).

[3] Board foot (BF)-The basic unit of measurement for lumber. One board foot is equal to a 1-inch board 12 inches in width and 1 foot in length.

4 Description of Product

Glulam is an engineered, stress-rated product that consists of two or more layers of lumber that are glued together with the grain of the layers parallel to the length of the beam or column. These layers are typically referred to as laminations as seen in Figure 1. Glulam is made from suitably selected and prepared pieces of wood either in a straight or curved form, with the grain of all pieces essentially parallel to the longitudinal axis of the member (Figure 2). The maximum lamination thickness permitted is 50 mm (2 in.), and the laminations are typically made of standard 25 or 50 mm (nominal 1 or 2 in.) thick lumber. The lumber is joined end to end, edge to edge, and face to face, so the size of glulam is limited only by the capabilities of the manufacturing plant and the transportation system. North American standards require that glulam be manufactured in an approved manufacturing plant. Glulam produced by APA (Engineered Wood Association) members are certified with an APA trademark and are tested for compliance to ANSI/AITC Standard A190.1-2012 (AITC 1983) to verify quality in product manufacturing. All glulam properties are tested to adhere to ASTM D3737 – 12 Standard Practice for Establishing Allowable Properties for Structural Glued-Laminated Timber (Glulam) (ASTM 2012). NAICS product code 321213 is used in identifying products that can be labeled as engineered wood products like glued-laminated timbers. Additional classification codes for Glulam are the United Nations Standard Products and Services Code (UNSPSC) – Engineered wood products/glued laminated timber 111220 05 and Construction Specifications Institute (CSI) code for heavy timber construction 06 1300 and glued-laminated construction 06 18 00.

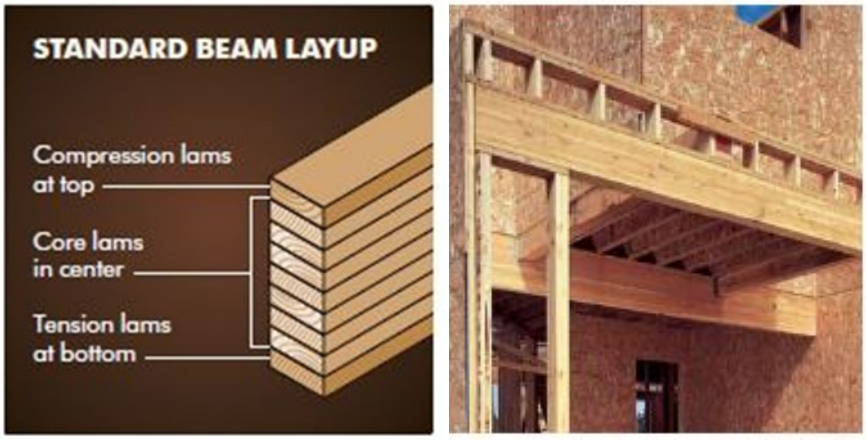

Figure 2 Glulam layup (left) and glulam header (right) (APA)

Glulam beams are used as concealed or exposed structural beams and columns in residential and commercial construction, warehouse roof beams and purlins, church arches, and girders and deck panels for timber bridges. Glulam comes in a variety of sizes with production based on a volume basis, typically board feet (1 BF = 0.0024 m^3) and sold by retailers on a linear basis. Approximately 60 percent of glulam produced in the US is used in domestic new residential and remodeling construction (Adair 2002). The next largest segments are the nonresidential market representing 31 percent, and the remainder of production being sold to industrial (4%) and export (5%) markets.

Glulam is produced from softwood lumber called lamstock. Lamstock is defined as a special grade of lumber used in the construction of laminated timbers. Sizes of lamstock lumber produced in the PNW are shown in Table 2. Included in Table 2 is the relative mix of lamstock utilized for glulam production during the time period of the study.

Green lamstock cut from logs must be kiln-dried to a moisture content (MC) of 16 percent or less to minimize any additional dimensional changes. Lamstock can be purchased green and dried on site or purchased dry from various suppliers. Lamstock that exceeds the 16 percent MC limit cannot be utilized and has to be re-dried, since this will prevent the laminations to properly adhere to each other in the following processes. Lamstock grading entails either one of two methods, either visual or machine grading. Visual grading is based upon the appearance of the material and any apparent flaws. Machine e-rated lamstock is graded by stiffness and visual characteristics (AITC 1983, WWPA 1994). Machine graded lamstock is typically required for the tension lam (bottom lamination) of a glulam since that will be taking a large proportion of the load stress.

Table 3 Lamstock sizes used in production of glulam, PNW

Nominal Dimension	Actual Dimension		Actual Dimension		Mix
Depth x Width	Depth (mm)	Width (mm)	Depth (in)	Width (in)	%
2x4	44.45	95.25	1.75	3.75	24.3%
2x6	44.45	149.225	1.75	5.875	51.2%
2x8	44.45	196.85	1.75	7.75	15.6%
2x10	44.45	247.65	1.75	9.75	5.3%
2x12	44.45	298.45	1.75	11.75	3.2%

4.1 Wood species and wood density

Glulams can be made from any wood species provided its mechanical and physical properties are suitable and it can be properly glued together. In the PNW region glulam is made from mostly Douglas-fir (*Pseudotsuga menziesii*), with the balance coming from Alaska Yellow Cedar (*Cupressus nootkatensis*), and Port Orford Cedar (*Chamaecyparis lawsoniana*) (Table 3). Species utilized in the production of glulam in this study were comprised of the species in Table 3, with Douglas-fir representing the 96.3 percent of lamstock input (by volume), with the remainder consisting of southern yellow pine, Alaska yellow cedar, and Port Orford cedar. Southern yellow pine is a generic trade name that consists of a various mix of the four species below. PNW glulam facilities produce a small quantity of beams utilizing southern yellow pine for wood treatment facilities to be used in exterior applications.

Table 4 Species used in Glued-Laminated Timber production, PNW

Species	Latin Name	
Douglas-fir	*Pseudotsuga menziesii*	96.31%
Alaska yellow cedar	*Cupressus nootkatensis*	0.54%
Port Orford cedar	*Chamaecyparis lawsoniana*	1.05%
Southern yellow pine		2.10%
Longleaf pine	*Pinus palustris*	
Shortleaf pine	*Pinus echinata*	
Loblolly pine	*Pinus taeda*	
Slash pine	*Pinus elliottii*	
	Total	100%

Species' densities were calculated based on the specific gravity at given moisture content volumes. These volumes were averaged as reported in by the surveys. Specific gravity starting points (30% MC) were taken from the wood handbook (USDA 2010) and utilized to calculate wood densities at 0 percent MC for these LCI inputs (Table 4). A weighted average was generated to give an overall density based on the quantity of each species utilized in the production of PNW glulam.

Table 5 Species density and specific gravity at various moisture contents

Pacific Northwest Species								
	Douglas Fir		Port Orford		Alaskan Yellow		Weighted Average*	
	% Total = 96.3%		% Total % = 0.54%		% Total = 1.05%		100%	
MC %	Specific Gravity	Density kg/m^3	Specific Gravity	Density kg/m^3	Specific Gravity	Density kg/m^3	Specific Gravity	Density kg/m^3
0%	0.511	510.9	0.473	472.6	0.435	435	0.511	510.79
12%	0.48	542.08	0.44	504	0.43	465.7	0.484	543.2
30%	0.45	585	0.42	546	0.39	507	0.45	585
* Includes some southern yellow pine glulam production (2.1%) which is not a local species in this region								

4.2 Moisture content

Volumetric shrinkage exists after the moisture content (MC) in the wood starts going below 30 percent for most species. Specific gravity based on volumes at different moisture contents is necessary to calculate the correct density of wood products (Simpson 1993). Specific Gravity relies on the volume of wood after shrinkage occurs from drying. Specific gravity is the ratio of the density of the wood to the density of water at a reference temperature and typically is based on oven dry weight, but since this report is utilizing wood weights at specific moisture contents, adjustments need to be made for shrinkage in wood volume (USDA 2010). Density at given moisture contents includes the water contained within it, so as moisture content rises, so does wood density, however, as moisture content drops toward 0 percent (oven-dry), specific gravity goes up. Logs coming in from the forest were green volumes, whereas all of the lamstock used in glulam production were kiln-dried (16% MC or less).

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 glulam production is considered to comprise wood resource extraction, the transport of resources and materials to the mill, lamstock production, resin production, and the on-site glulam manufacturing process. These steps are described separately below.

5.1 A1- Resource extraction

5.1.1 Forestry Operations

Consideration of the logs used in the production of glulam 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 5 and 5) come from Oneil and Puettmann (2017). For more details on the PNW Forest Operations see Oneil and Puettmann (2017).

Table 5 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 6 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 (m^3/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 Oneil and Puettmann (2017) 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 6). 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 7 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 Resins

Resins used in the production of glulam were transported to the site from various manufacturers by truck. Some resins were premixed, and others needed water to be added before use. Two resins were utilized in the face-bonding and finger-jointing of lamstock during glulam layup and curing, phenol-resorcinol-formaldehyde (PRF) and melamine-urea-formaldehyde (MUF).

5.1.2.1 Phenol Resorcinol Formaldehyde Resin

Phenol-resorcinol-formaldehyde resin is used in the face bonding process that glues the lamstock layers together. Phenol-resorcinol-formaldehyde resins differ from the other resins because hardeners are required to help in curing glue laminated timbers. Phenol-resorcinol-formaldehyde resin can be cold or hot cured and can also be radiofrequency cured.

5.1.2.2 Melamine Urea Formaldehyde Resin

Melamine-urea-formaldehyde resin is used in the finger jointing process of glulam production. Melamine-urea-formaldehyde resin production is essentially identical to the production of urea formaldehyde resin (these resins are used for particleboard and medium density fiberboards) with the exception that melamine, about 8 percent by weight on a neat resin basis, is substituted for a portion of the urea input.

5.1.3 Lamstock Production

The lamstock production process is similar to lumber production reported by Milota (2015). It starts at the sawmill and includes debarking logs, sawing logs into rough-green lamstock, chipping portions of logs that did not make lamstock, sorting rough-green lamstock into size classes, and stacking rough-green lamstock for drying. The lamstock is transported unplaned (rough) either green or dry to glulam production facilities. Inputs include logs with bark and electricity. Outputs include green lamstock, green sawdust, green chips, bark, and green fuel wood (Milota 2015).

5.2 A2 – Transport of raw materials from extraction site

Logs are transported to lumber mills by truck (Table 7). The specific gravity of logs being transported to the mill was 0.45 at green weight. Lamstock for glulam production is transported by rail or truck. Lamstock could be transported green and/or dry, and rough to the glulam facility. Wood transported between the lamstock mill and glulam stages was determined to have a specific gravity of 0.482 at approximately 13 percent MC. Southern yellow pine was the only species transported by rail and made up 2.4 percent of the incoming lamstock by weight (Table 7). Other materials such as resins and packaging materials are brought in by truck in containers or resins are brought in by liquid container trucks. Table 7 shows the average distances one way from manufacturer to the glulam facility

Table 8 Delivery distance of input materials for glulam production in the PNW region

Material delivered to Facility	Delivery Distance	
	km	miles
Dry Lamstock, truck	173	108
Dry Lamstock, rail	3,493	2,170
Resin	224	139
Strapping	390	242
Wrapping Material	486	302

5.3 A3 – Glulam Manufacturing

5.3.1 Material Flows

Table 8 shows the mass balance of the glulam material inputs and outputs for the PNW region. The wood and resins going into the production of 1 m^3 of glulam during the manufacturing process results in either glulam, shavings from planning the glulam, trimmings from the ends to get to various lengths, and wood waste or scrap. Unaccounted inputs are assumed to be lumber from the previous year. The output of finished glulam was 510.70 kg/m^3 oven dry mass.

Table 9 Mass balance of glulam manufacturing process for in the PNW region

	Mass	Mass	CoVw[1]
Feedstocks Inputs	**kg**	**(%)**	**(%)**
Lamstock	559.02	95.82%	4.16%
Unaccounted inputs (lumber)[2]	15.52	2.66%	
Additives Inputs			
Phenol-resorcinol-formaldehyde resin	5.97	1.02%	47.56%
Melamine-urea-formaldehyde resin	1.19	0.20%	68.55%
Catalyst/fillers/extenders	1.68	0.29%	41.20%
Total Additives	8.84	1.52%	23.10%
Total Inputs	583.38	100%	
Product Outputs			
Glulam	510.70	87.54%	0.47%
Co-Products Outputs			
Shavings	29.71	5.09%	135.12%
Trimmings	42.21	7.24%	62.76%
Waste	0.76	0.13%	0.00%
Total Co-Products	72.68	12.46%	39.25%
Total Outputs	583.38	100%	

[1] Coefficient of Variation for the weight average of input and outputs
[2] Unaccounted for inputs is assumed to be lumber on site prior to year of survey

5.3.2 Glulam Manufacturing

Once the lumber input is at the necessary moisture content, the actual glulam manufacturing process can begin. Resins are the other primary material input at this stage.

5.3.2.1 End Jointing

Glulam beams are typically longer than the available lamstock. Lamstock can be joined end to end to extend the length of each lamination. The most common joint utilized to combine lumber end to end is a finger joint. The joints are cut on both ends of the lamstock and resin is applied. A structural resin such as MUF is used for finger joints and cured with RF drying. Curing occurs under pressure and heat for a strong and stable bond between the pieces. Manufacturers typically employ a continuous RF curing system for end finger jointing, so that they can quickly process the laminations before face bonding.

5.3.2.2 Face Bonding

During the face bonding process, the finger jointed lamstock is planed and resin is applied to the face with a glue extruder. Phenol-resorcinol-formaldehyde is the most common used resin for face bonding, but MUF resin can also be used. The laminations are then assembled into the required layup and pressure is applied. Either cold cure or radio frequency curing are utilized during this process. Glulams are allowed to cure until they are ready for finishing and fabrication.

5.3.2.3 Finishing and Fabrication

After pressing and curing, glulams are removed from the presses and the wide faces are planed to remove adhesive that had squeezed out during pressing. The remaining two faces of the member may be lightly planed or sanded. For premium and architectural classified glulams, knots and planer skips are covered up. Depending upon use, final cuts are made, holes are drilled, connectors are added, and a finish may be applied. Each glulam is individually wrapped for protection before shipping. Final product density for PNW beams, excluding resin were 546 kg/m3 at 13 percent MC, dry basis.

5.3.2.4 Radio Frequency and Cold Cure Processes

Glulam production plants use both radio frequency (RF) drying and cold curing (CC) processes to cure the resin for face bonding. Radio frequency drying is used exclusively for finger jointing curing of MUF resins. The surveys indicated that both radio frequency and cold cure processes were used in PNW glulam production. The amount of electricity used by each curing process was not known or reported by the mills, so there was no way to discern how much either method was used compared to the other. In radio frequency drying, material is exposed to an electronic field that alternates about 40,000,000 times per second. Pressure and heat are applied during face bonding that is in excess of 200+ ºF. When the field alternates, the water molecules in the material also alternate. The resulting friction causes the water to heat uniformly throughout the product. Radio frequency drying saves energy over the former method of heat bonding because only the product itself is heated. Other benefits are that the equipment does not have to warm up or cool down, so steam heat is no longer required, and less resin is needed during production versus cold cure methods.

Single unit process inputs and outputs collected from the glulam mill surveys are listed in Table 9. These show the weighted-average values for each of the various inputs and outputs used in glulam product manufacturing system boundary A3 (Figure 1). These numbers represent the amount of each item utilized or emitted per 1 m^3 of glulam output wrapped and ready for shipment.

Table 10 Unit process inputs/outputs for glulam production (one cubic meter), PNW

Products	Value	Unit/m^3	Mass Allocation
Glue-laminated timber	1	m^3	88%
Co-Products (sawdust, shavings, trimmings)	71.9	kg	12%
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	71.26	kWh	
Natural Gas	0.0534	m^3	
Diesel	0.940	L	
LPG	2.48	L	
Gasoline	0.0858	L	
Wood Waste combusted in boiler	25.46	kg	
Transport, Total	162.10	tkm	Transport Distribution
Transport, truck - Lumber	106.68	tkm	97.64%
Transport, rail - Lumber (southern yellow pine only)	51.70	tkm	2.36%
Transport, truck - Resin	1.92	tkm	
Transport, truck -Wrapping	1.43	tkm	
Transport, truck - Strapping	0.09	tkm	
Melamine urea formaldehyde resin	1.47	kg	
Phenol resorcinol formaldehyde resin	7.73	kg	
Sawn Lumber, rough, kiln dried, PNW	1.117	m^3	
Sawn Lumber, rough, kiln dried, (southern yellow pine)	0.237	m^3	
Wrapping Material – Packaging	0.00314	kg	
Strapping – Packaging	0.00061	kg	
Spacers - Packaging	0.00341	kg	
Emissions to air	**Value**	**Units/m^3**	
Particulates. Unspecified	0.0592	kg	
VOC, volatile organic compounds	0.0522	kg	
Phenol	0.6129	kg	
Formaldehyde	0.0241	kg	
HAPS	0.3426	kg	

5.3.3 Energy use and generation

Energy for producing glulam comes from electricity, diesel, liquid propane gas (LPG), and wood fuel. Diesel-powered loaders are used in the mill yard to move logs. Electrically driven cranes may also be used. Electrically driven motors in the mill materials conveying, finger jointing, and trims saws. Lifts for transporting products and materials in the mill are powered by liquefied propane gas. Diesel fuel use is for onsite transportation to move material. Forklift trucks used small amounts of LPG throughout the mill.

5.3.4 Wood-base fuels

A wood boiler was used at glulam facilities. The boiler and the emission control processes were considered separately. Wood fuel represented 37 percent and natural gas representing 20 percent of the onsite heat at glulam facilities. 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 10).

Table 11 Inputs to wood boiler per bone dry kg of wood fuel combusted (Puettmann and Milota 2017)

	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			
Wood Fuel, shavings, at planer	3.90E+00	kg	39%
Wood fuel, trimmings, at saw	5.60E-01	kg	56%
Wood fuel, purchased	5.00E-02	kg	5%
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[4]	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			
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	

[4] 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
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	

5.3.5 Packaging

Materials used for the packaging of glulam for protection during transportation and storage are in Table 11 for the PNW. Packaging materials comprise less than 1 percent of the cumulative mass of the model flows. Strap protectors, wrapping materials and strapping represent 48, 44, and 9 percent of packaging by mass.

Table 12 Materials used in packaging and shipping per m^3 PNW glulam

Material	Value	Value
Wrapping Material	kg	0.00314
Metal strapping	kg	0.00061
Cardboard protectors	kg	0.00341
TOTAL	kg	0.00716

5.4 Secondary Data Sources

Table 12 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 13 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: Sawn lumber, softwood, rough, kiln dried, at kiln, m3 / PNW_US Sawn lumber, softwood, rough, kiln dried, at kiln, m3 / SE_US	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 (MUF)	Database: US EI 2.2 (Datasmart2018) Process: Melamine-urea-formaldehyde resin, at plant NREL/US U	North America – Region Specific	2018	**Technology**: very good Process models region-specific technology. **Time**: very good Some data is less than 10 years old **Geography**: very good Data is representative of regional production.
Resin (PRF)	Database: US EI 2.2 (Datasmart2018) Process: Phenol-resorcinol-formaldehyde resin, at plant NREL/US U	North America – Region Specific	2018	**Technology**: very good Process models region-specific technology. **Time**: very good Some data is less than 10 years old **Geography**: very good Data is representative of regional production.
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.

Train	Database: US EI 2.2 (Datasmart2018) Process: Transport, freight, rail, diesel/US US-EI 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) Process: Lubricating oil, 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.
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 and combustion.
Steel Strap	Database: US EI 2.2 (Datasmart2018) Process: Chromium steel 18/8, 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.

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 13 summarizes the source and scope of each impact category reported in this report as required to be in conformance with the PCR.

Table 14 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, w/biogenic[5]	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

[5] 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	Non-renewable secondary fuel	NRSF	MJ, NCV
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 14 for PNW glulam. The LCIA results in these tables show the absolute values for A1-Resource Extraction, A2-Transportation, and A3-Glulam Production. Resource extraction includes lamstock production and resin production as well as upstream processes for producing these products (i.e. forestry operations). For GWP, 57 percent of the CO_2 equivalent emissions come from resource extraction (77 kg CO_2 eq), with 27

percent assigned to glulam production (includes packaging production) (37 kg CO_2 eq). Transportation was 22 kg CO_2 eq or 16 percent of the cradle-to-gate GWP impact.

Table 16 also provides indicators related to energy use, material resource consumption, and the waste generated. The total cradle to gate energy use was 7,920 MJ/m^3. Fossil energy, 1,957 MJ/m^3, is used for machinery, transportation, electricity, and onsite transportation. The biomass energy, 3,030 MJ/m^3, is used all for drying lamstock in A1. All non-renewable fuel used represents 60 percent of the total energy and is used for machinery, transportation, electricity, and some in drying. Total cradle-to-gate renewable energy total is 3,176 MJ and non-renewable represented 4,743 MJ.

Most of the freshwater use is in the A1 life cycle stage (65%). In the resource extraction stage, lamstock production consumed 96 percent (335 L) of the total freshwater use in A1 (349 L) (Table 16).

Most of the waste is generated in A1 representing 49 percent of the hazardous waste and 55 percent of nonhazardous. Glulam production (A3) 34 percent of the hazard waste generated and 29 percent of the nonhazardous (Table 16).

The results in Tables 17 and 18, further breakdown the LCIA results from Table 16 for A1-Resource extraction and A3-Glulam Production.

Table 15 Environmental performance of 1 m^3 of glulam, PNW

Indicator Name	Abbreviation	Units	A1	A2	A3	Total
Core Mandatory Impact Indicator						
Global warming potential, w/biogenic	GWP	kg CO2e	(2,068.89)	21.49	2,183.06	135.65
Global warming potential, fossil	GWP	kg CO2e	76.86	21.49	37.30	135.65
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	1.98E-06	3.40E-07	2.63E-06	4.95E-06
Acidification potential of soil and water sources	AP	kg SO2e	11.5381	0.1310	0.1355	11.8047
Eutrophication potential	EP	kg Ne	0.8809	0.0122	0.2663	1.1593
Formation potential of tropospheric ozone	SFP	kg O3e	402.45	3.84	4.99	411.28
Abiotic depletion potential (ADP fossil) for fossil resources	ADPf	MJ, NCV	1,240.76	271.20	444.97	1,956.92
Fossil fuel depletion	FFD	MJ Surplus	51.76	40.79	38.51	231.05
Use of Primary Resources						
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	2,564.37	0.5504	611.32	3,176.23
Renewable primary energy carrier used as material	RPRM	MJ, NCV	12,063.33			12,063.33
Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV	3,939.77	274.92	528.62	4,743.30
Non-renewable primary energy carrier used as material	NRPRM	MJ, NCV	289.17	-	-	289.17
Secondary Material, Secondary Fuel and Recovered Energy						
Secondary material	SM	kg	-	-	-	-
Renewable secondary fuel	RSF	MJ, NCV	-	-	31.64	31.64
Non-renewable secondary fuel	NRSF	MJ, NCV	-	-	-	-
Recovered energy	RE	MJ, NCV	-	-	-	-
Mandatory Inventory Parameters						
Consumption of freshwater resources	FW	m3	0.3506	0.0034	0.1887	0.5427
Indicators Describing Waste						
Hazardous waste disposed	HWD	kg	0.0014	0.0005	0.0010	0.0030
Non-hazardous waste disposed	NHWD	kg	6.8488	1.9495	3.6402	12.4385
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 16 Cradle to gate glulam LCIA results for A1-Resource extraction: Forestry operations and lamstock and resin production, PNW

		Forestry Operations	Lamstock Production	Resin Production	TOTAL cradle-to-gate
Global warming potential, fossil	kg CO2e	13.90	31.75	31.22	76.86
Depletion potential of the stratospheric ozone layer	kg CFC11e	9.58E-08	1.88E-06	1.11E-09	1.98E-06
Acidification potential of soil and water sources	kg SO2e	0.21	0.26	11.08	11.54
Eutrophication potential	kg Ne	0.02	0.17	0.70	0.88
Formation potential of tropospheric ozone	kg O3e	6.22	6.32	389.92	402.45
Abiotic depletion potential (ADP fossil) for fossil resources	MJ, NCV	25.90	46.90	78.96	151.76
Fossil fuel depletion	MJ Surplus	172.74	414.15	653.87	1240.76
Non-renewable, fossil	MJ	182.04	422.76	665.01	1269.81
Non-renewable, nuclear	MJ	2.80	63.48	2632.73	2699.01
Non-renewable, biomass	MJ	0.0002	0.0006	0.0000	0.00
Renewable, biomass	MJ	0.0950	2519.54	0.0000	2519.63
Renewable, wind, solar, geothermal	MJ	0.1585	16.30	0.0001	16.46
Renewable, water	MJ	0.3816	27.89	0.0001	28.28
Freshwater	m^3	0.0134	0.3350	0.0003	0.3487
Hazardous waste	kg	4.37E-04	9.62E-04	4.73E-05	0.0014
Non-hazardous waste	kg	1.3282	2.0762	3.4443	6.8488

Table 17 Cradle to gate glulam LCIA results for A3-Glulam production, PNW

Impact Indicator	Unit	Natural gas	Wood combustion	Electricity	Other	TOTAL
Global warming potential, fossil	kg CO2e	1.18E-01	3.08E+00	3.12E+01	2.88E+00	3.73E+01
Depletion potential of the stratospheric ozone layer	kg CFC11e	2.48E-11	2.45E-07	2.38E-06	5.50E-09	2.63E-06
Acidification potential of soil and water sources	kg SO2e	8.90E-05	3.00E-02	6.80E-02	3.74E-02	1.36E-01
Eutrophication potential	kg Ne	1.00E-05	2.19E-02	2.41E-01	2.88E-03	2.66E-01
Formation potential of tropospheric ozone	kg O3e	2.48E-11	2.45E-07	2.38E-06	4.99E+00	4.99E+00
Abiotic depletion potential (ADP fossil) for fossil resources	MJ, NCV	1.65E+00	3.73E+01	3.67E+02	3.92E+01	4.45E+02
Fossil fuel depletion	MJ Surplus	2.75E-01	3.40E+00	2.90E+01	3.00+00	3.56E+01
Non-renewable, fossil	MJ	1.65E+00	3.82E+01	3.75E+02	4.14E+01	4.56E+02
Non-renewable, nuclear	MJ	1.65E-03	8.82E+00	7.43E+01	5.76E-01	8.36E+01
Non-renewable, biomass	MJ	1.49E-10	3.74E-05	5.44E-04	1.31E-05	5.94E-04
Renewable, biomass	MJ	4.13E-05	5.04E+02	6.30E+00	1.43E-01	5.11E+02
Renewable, wind, solar, geothermal	MJ	5.70E-05	1.90E+00	3.45E+01	2.03E-02	3.64E+01
Renewable, water	MJ	1.45E-04	3.13E+00	6.11E+01	5.62E-02	6.43E+01
Freshwater	m^3	4.99E-06	4.86E-02	1.38E-01	1.15E+03	1.15E+03
Hazardous waste	kg	8.30E-08	1.10E-04	8.77E-04	9.20E-06	9.96E-04
Non-hazardous waste	kg	7.20E-04	2.51E-01	2.40E+00	9.88E-01	3.64E+00

6.1 Interpretation

As defined by ISO (2006), 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.

6.2 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.

6.3 Life cycle phase contribution analysis

For global warming impact, 57 percent of the CO_2 equivalent emissions come from resource extraction (A1), with 27 and 16 percent assigned to glulam production (A3) and transportation (A2), respectively (Table 17). Resource extraction (A1) represented the highest impacts in all but one impact category (Ozone depletion). Cradle-to-gate freshwater use was dominated by A1 consuming 65 percent with A3 life cycle stages using 35 percent (Table 17). This was driven by the lamstock production consuming 99 percent of the A1 freshwater use (Table 19).

Total energy, which includes fuel for process heat and equipment and electricity, comes from fossil fuels (25%) wood fuel (38%), non-renewable nuclear (35%), and other renewable (<2%) (Table 18). The non-wood energy component represents an opportunity for improving sustainability by substituting for it with sustainably grown wood fuel.

Non-renewable fuels represented the greatest proportion of energy consumption (60%) with resource extraction (A1) phase using 83 percent. Renewable biomass consumption for energy was 81 percent in the A1 phase and 19 percent use in glulam production (A3). Biomass energy is the primarily used in drying, the lamstock in A1 and some for heating in glulam production (A3) processes.

Table 19 and Figure 3 show the LCIA for the A1 phase of the cradle-to-gate system boundary. Resin production dominates the impacts and energy production in the extraction phase. Resin production represented over 90 percent in three of the impact categories and 41 percent of the global warming within this life cycle stage. Resin production consumed the most energy (Table 14) in A1, while Lamstock production consumed 100 percent of the biomass energy.

During glulam production (A3), electricity generation and use dominates the impacts (Table 20) (Figure 4). Natural gas combustion was not a significant driver. The packaging, biomass energy, diesel, and gasoline consumed at the production facilities account for the “Other” impacts.

Table 18 Cradle-to-gate PNW glulam 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	57%	16%	27%	100%
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	40%	7%	53%	100%
Acidification potential of soil and water sources	AP	kg SO2e	98%	1%	1%	100%
Eutrophication potential	EP	kg Ne	76%	1%	23%	100%
Formation potential of tropospheric ozone	SFP	kg O3e	98%	1%	1%	100%
Abiotic depletion potential (ADPfossil) for fossil resources;	ADPf	MJ, NCV	63%	14%	23%	100%
Fossil fuel depletion	FFD	MJ Surplus	66%	18%	17%	100%
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	81%	0%	19%	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	83%	6%	11%	100%
Non-renewable primary energy carrier used as material	NRPRM	MJ, NCV	100%	0%	0%	100%
Secondary material	SM	kg	0%	0%	0%	0%
Renewable secondary fuel	RSF	MJ, NCV	0%	0%	100%	100%
Non-renewable secondary fuel	NRSF	MJ, NCV	0%	0%	0%	0%
Recovered energy	RE	MJ, NCV	0%	0%	0%	0%
Consumption of freshwater resources;	FW	m3	65%	0.62%	35%	100%
Hazardous waste disposed	HWD	kg	49%	18%	34%	100%
Non-hazardous waste disposed	NHWD	kg	55%	16%	29%	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 19 Cradle-to-gate PNW glulam production energy contribution by fuel type

Impact category	Unit	A1	A2	A3	TOTAL	
Non-renewable, fossil	MJ	1,269.81	286.48	455.96	2,012.25	25.23%
Non-renewable, nuclear	MJ	2,699.01	3.72	83.65	2,786.38	34.94%
Non-renewable, biomass	MJ	0.00	0.00	0.00	0.00	0.00%
Renewable, biomass	MJ	2,519.63	0.09	510.55	,3030.28	38.00%
Renewable, wind, solar, geothe	MJ	16.46	0.13	36.43	53.02	0.66%
Renewable, water	MJ	28.28	0.33	64.33	92.93	1.17%
TOTAL	MJ	6,533.18	290.75	1,150.93	7,974.86	100.00%

Table 20 Cradle-to-gate PNW glulam LCIA results for A1-Resource extraction: forestry operations and lamstock and resin production.

Impact Category	Unit	Forestry Operations	Lamstock Production	Resin Production	TOTAL
Global warming potential, fossil	kg CO2e	18%	41%	41%	100%
Depletion potential of the stratospheric ozone layer	kg CFC11e	5%	95%	0%	100%
Acidification potential of soil and water sources	kg SO2e	2%	2%	96%	100%
Eutrophication potential	kg Ne	2%	19%	80%	100%
Formation potential of tropospheric ozone	kg O3e	2%	2%	97%	100%
Abiotic depletion potential (ADP fossil) for fossil resources	MJ, NCV	17%	31%	52%	100%
Fossil fuel depletion	MJ Surplus	14%	33%	53%	100%
Non-renewable, fossil	MJ	14%	33%	52%	100%
Non-renewable, nuclear	MJ	0%	2%	98%	100%
Non-renewable, biomass	MJ	25%	75%	0%	100%
Renewable, biomass	MJ	0%	100%	0%	100%
Renewable, wind, solar, geothermal	MJ	1%	99%	0%	100%
Renewable, water	MJ	1%	99%	0%	100%
Freshwater	m^3	4%	96%	0%	100%
Hazardous waste	kg	31%	69%	3%	100%
Non-hazardous waste	kg	19%	30%	50%	100%

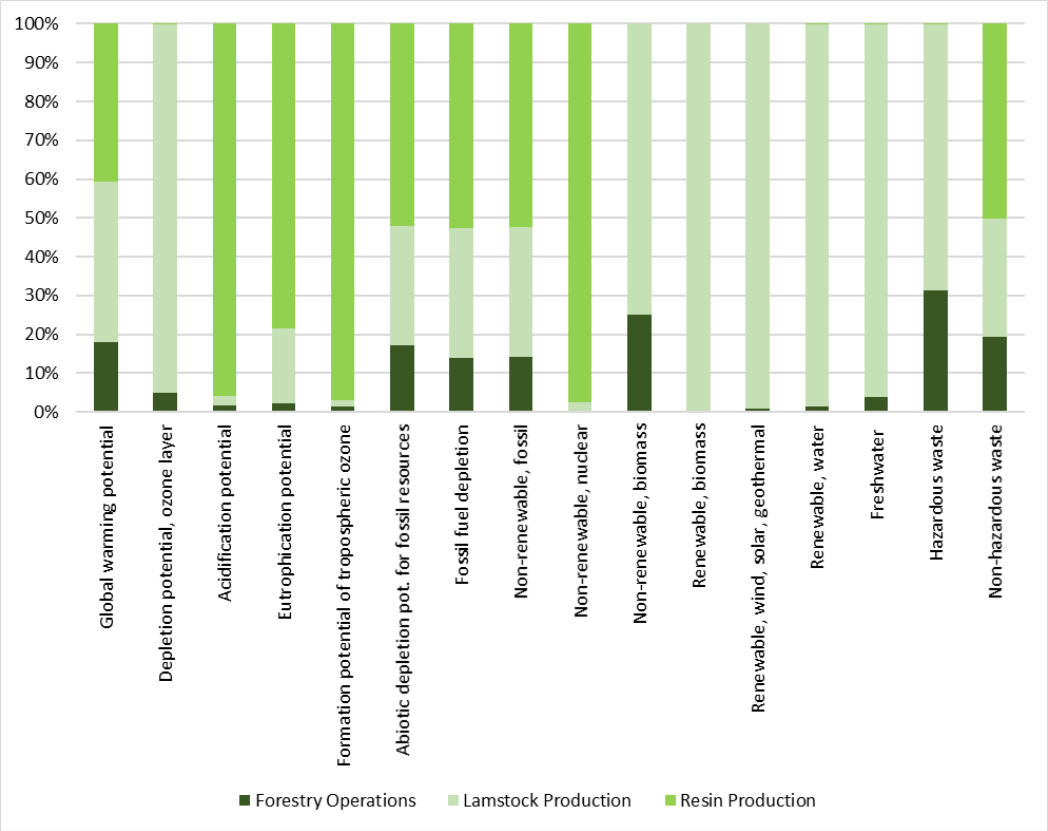

Figure 3 Cradle-to-gate glulam LCIA results for A1-Resource extraction, PNW

Table 21 Gate-to-gate PNW glulam LCIA results for A3-Glulam production, PNW

Impact Category	Unit	Natural gas	Wood combustion	Electricity	Other	TOTAL
Global warming potential, fossil	kg CO2e	0.32%	8.25%	83.71%	7.72%	100.00%
Depletion potential of the stratospheric ozone layer	kg CFC11e	0.00%	9.31%	90.48%	0.21%	100.00%
Acidification potential of soil and water sources	kg SO2e	0.07%	22.17%	50.18%	27.59%	100.00%
Eutrophication potential	kg Ne	0.00%	8.22%	90.69%	1.08%	100.00%
Formation potential of tropospheric ozone	kg O3e	0.00%	0.00%	0.00%	100.00%	100.00%
Abiotic depletion potential (ADP fossil) for fossil resources	MJ, NCV	0.37%	8.38%	82.44%	8.81%	100.00%
Fossil fuel depletion	MJ Surplus	0.77%	9.53%	81.28%	8.42%	100.00%
Non-renewable, fossil	MJ	0.36%	8.38%	82.18%	9.07%	100.00%
Non-renewable, nuclear	MJ	0.00%	10.54%	88.76%	0.69%	100.00%
Non-renewable, biomass	MJ	0.00%	6.29%	91.50%	2.21%	100.00%
Renewable, biomass	MJ	0.00%	98.74%	1.23%	0.03%	100.00%
Renewable, wind, solar, geothermal	MJ	0.00%	5.20%	94.74%	0.06%	100.00%
Renewable, water	MJ	0.00%	4.86%	95.05%	0.09%	100.00%
Freshwater	m^3	0.00%	0.00%	0.01%	99.98%	100.00%
Hazardous waste	kg	0.01%	11.05%	88.02%	0.92%	100.00%
Non-hazardous waste	kg	0.02%	6.89%	65.96%	27.13%	100.00%

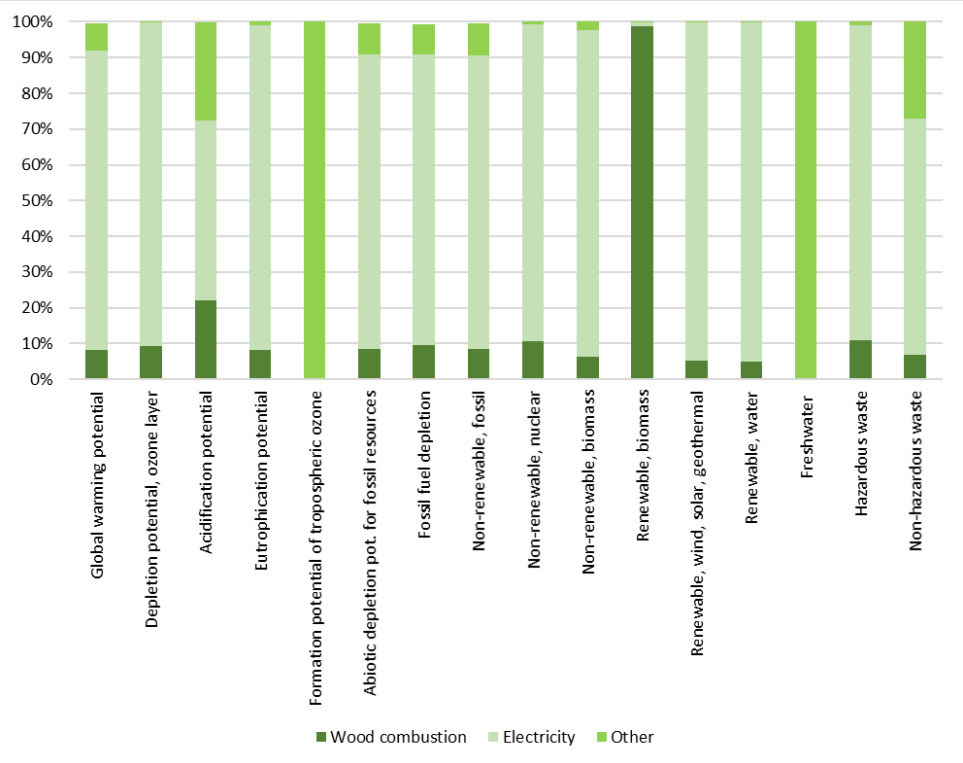

Figure 4 Gate-to-gate LCIA results for A3-glulam production, PNW

6.4 Uncertainty Analysis

Some degree of uncertainty is present in the results due to the variation amongst different data providers. Table 21 provides statistics for some of the key modeling parameters found to be most significant in glulam production.

Table 22 Survey data statistics for selected parameters in glulam production, PNW

		Weighted Average	Standard deviation weighted	CoV	Mean	Standard deviation	Min.	Max
Lamstock	kg	559.02	23.25	4.16%	556.22	23.82	532.48	588.42
Resin	kg	8.56	1.98	23.10%	9.09	2.39	7.23	12.57
Electricity	kWh	71.26	35.52	49.8%	82.25	45.35	53.60	149.13

6.5 Completeness, consistency and sensitivity

Life cycle assessment reports must be reviewed for completeness, consistency and data sensitivity. This report was checked to ensure that it is complete and consistent with the CORRIM guidelines (Puettmann, et al. 2019) and when originally published, the 2015 PCR (FPInnovations 2015). As per the 2015 PCR, LCA reports were required to report results using inputs based on an economic and mass allocation (Table 22).

Table 23 Life cycle stages contribution analysis per 1 m^3 glulam, PNW (mass and economic allocation) ***(NOTE: Results are based on the reporting requirements and impact methods from the 2015 PCR)***

		Mass Allocation			Economic Allocation		
Impact Category	Unit	Forestry Operations	Lamstock Production	Glulam Production	Forestry Operations	Lamstock Production	Glulam Production
Global warming, fossil	kg CO_2 eq.	13.13%	40.85%	46.02%	11.56%	44.24%	44.20%
Acidification	SO_2 eq.	17.15%	41.60%	41.25%	15.45%	43.98%	40.57%
Eutrophication	kg N eq.	32.45%	36.13%	31.42%	29.50%	39.31%	31.19%
Ozone Depletion	kg CFC-11 eq.	5.14%	8.96%	85.93%	4.63%	10.67%	84.67%
Smog	kg O_3 eq	26.26%	37.87%	35.87%	23.92%	40.43%	35.66%
Total Energy	MJ	4.08%	68.17%	27.75%	3.84%	68.23%	27.94%
Non-renewable fossil	MJ	12.61%	41.58%	45.81%	11.13%	44.73%	44.14%
Non-renewable nuclear	MJ	1.49%	42.29%	56.21%	1.32%	44.05%	54.62%
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	0.45%	32.37%	67.18%	0.33%	35.32%	64.33%
Renewable, biomass	MJ	0.00%	83.70%	16.30%	0.00%	83.52%	16.48%
Fresh water	L	3.10%	82.75%	14.15%	2.90%	82.66%	14.45%
Solid waste	kg	2.64%	43.43%	53.93%	2.37%	44.77%	52.86%

Sensitivity analysis can be applied to the LCA to determine changes in results due to variations in assumptions, methods, and data. A sensitivity check was performed on the LCA (Tait et al. 2017) contrasting the mass and economic allocation methods. To stay within conformance with the updated PCR (FPInnovations 2015), an economic allocation was required on the data. In this instance, a mass allocation of emissions is being compared with an economic allocation of emissions based on the value of the end products in the glulam LCI. This allocation was also used for the lumber (lamstock) LCI outputs since lumber has the highest value of all the end products during that particular stage. The difference in the allocation methodologies for a selected group of impact categories are shown in Table 23.

Table 24 Sensitivity analysis of mass allocation versus economic allocation methodologies

Impact Indicator	Mass	Economic	% Change
Global Warming, fossil	115.68	131.45	13.63%
Acidification Potential	1.22	1.35	10.98%
Eutrophication Potential	0.0466	0.0512	9.87%
Ozone Depletion Potential	1.35E-08	1.50E-08	10.66%
Smog Potential	24.94	27.38	9.80%

6.6 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.

7 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[6].

Using the method described above, -2,146 kg CO_2e (A1) were removed in the production of 1 m^3 of PNW glulam (unallocated). One cubic meter of PNW glulam stores 255 kg of carbon or +936 kg CO_2e (C3/C4). The coproducts produced during lamstock and glulam production account for an additional +952.33 kg CO_2e (A3) for a total "emission" in wood products leaving the system boundary of +1,888 kg CO_2e. The combustion of wood fuel emitted during lamstock and glulam production of 276 kg CO_2e. Packaging resulting in removal of -0.01 kg CO_2e) and an emission of +0.01 kg CO_2e (A5). In summary, total removals was -2,146 kg CO_2e and total "emissions" was +2,146 kg CO_2e from cradle-to-gate (A1-A3) (Table 24). In Table 24, 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.

[6] 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.

Table 25 Biogenic carbon inventory parameters

Additional Inventory Parameters		A1	A2	A3	A5	C3/C4	Total
		kg CO2e					
Biogenic Carbon Removal from Product	BCRP	(2,145.76)	-	-			(2,145.76)
Biogenic Carbon Emission from Product	BCEP	-	-	933.06		936.28	1,888.33
Biogenic Carbon Removal from Packaging	BCRK	-	-	(0.0120)			(0.0120)
Biogenic Carbon Emission from Packaging	BCEK	-	-		0.0057		0.0057
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production	BCEW	235.30	-	41.12			276.42

8 Discussion

In 2013 CORRIM updated Puettmann and 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 Puettmann and Wilson (2005). The updates were necessary to comply with the 2015 PCR for North American Structural Wood Products so an EPD on North American Glued-Laminated Timbers could be produced (https://awc.org/pdf/greenbuilding/epd/AWC-EPD-Glulam-190328.pdf). This study conducted all new mill surveys and reported results based on the 2019 PCR (UL 2019) (Bowers et al. 2017).

As noted earlier, total energy for producing 1 cubic meters of glulam from the PNW region was 7,920 MJ, 50 percent higher than (5,266) MJ/m^3 from Puettmann et al. (2013). The 2013 report was an update to electricity and wood boiler data, where this current study updated the full gate-to-gate LCI data for glulam production. In addition, resin production LCI processes have been updated and are significant drivers in the energy consumption and environmental impacts of glulam production. It is worthy to note that although total energy has changed significantly, the type of fuel also changed. Renewable fuels, biomass, increased over the two-survey period by 40 percent while fossil fuel use decreased by 31 percent. Fuels from nuclear energy increased significantly where this could be driven by electricity production in resin LCI processes.

Table 25 shows the changes between the 2013 updated LCA and the current LCA. Global warming impacts lowered 20 percent, while eutrophication and smog increased by over 1000 percent (Table 25). These differences can be attributed to differences in reporting requirements, LCIA methodologies, and LCI accounting methods and updated LCI processes for upstream materials. 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 26 LCIA comparison between updated 2013 data (based on 2001 industry surveys) and current study data (based on 2013 industry surveys) on glulam production in the PNW

Impact category	Unit	Current Study based on 2017 production data	Past Study based on 2013 updated production data
Global warming potential	kg CO_2 eq	135.65	169.85
Eutrophication Potential	kg N eq	1.1593	0.0839
Smog Potential	kg O_3 eq	411.28	20.33
Non-renewable fossil	MJ	1956.92	2,818.46
Non-renewable nuclear	MJ	2786.38	186.06
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	145.96	124.07
Renewable, biomass	MJ	3030.28	2,137.65
Fresh water	L	542.70	806.16
Solid waste (hazardous and non-hazardous)	kg	12.44	29.77

9 Conclusions

The cradle to gate LCA for PNW glulam includes the LCI of forest resources and lamstock and resin production that all rely on secondary and tertiary data for process inputs such as natural gas, diesel, and electricity. The survey results were representative operations in the PNW region that would produce glulam. The survey data are representative of the glulam types and production volumes consistent with trade association production data.

This study provides a comprehensive cradle-to-gate LCA of the production of glulam produced in the Pacific Northwest (PNW) US in accordance 2019 UL Environment Product Category Rules. The cradle-to-gate LCA for glulam includes: Upstream production inputs for forestry and lamstock and resin production (A1), transportation of all materials and resources into the glulam production boundary (A2) and gate-to-gate production for glulam (A3). The survey results for glulam were representative of PNW US average with lamstock inputs representing the PNW region of the US. Representative facilities represented 50 percent of the US glulam production.

Emissions from transportation (A2) represented a small contribution over-all impact factors and energy consumption. Resource extraction and lamstock and resin production (A1) had the greatest contributions to all impact categories. Most of the non-renewable materials were consumed in the A1 stage as well.

Renewable biomass represented 38 percent of the total energy consumption for all stages of production (A1-A3), with 83 percent of the biomass energy used during lamstock production (A1). The use of non-renewable fossil fuels dominated the total energy consumption profile for glulam production at 3,940 of the 7,920 MJ/m^3 (60%). Extraction of resources and resin production were dominated by fossil and nuclear use (61%).

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). Using the method described above, -2,145 kg CO2e were removed in the production of 1 m3 of PNW glulam (unallocated). One cubic meter of PNW glulam stores 255 kg of carbon or +936 kg CO2e. The coproducts produced during lamstock and glulam production account for an additional +933 kg CO2e for a total “emission” in wood products leaving the system boundary of +1,869 kg CO2e. The combustion of wood fuel emitted during lamstock and glulam production of 276 kg CO2e. Packaging

resulting in removal of -0.01 kg CO2e) and an emission of +0.01 kg CO2e. In summary, total removals was -2,146 kg CO2e and total "emissions" was +2,146 kg CO2e from cradle-to-gate (A1-A3).

10 Critical review

10.1 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.

10.2 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.

11 Acknowledgements

Funding for the original LCA 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). Steven Zylkowski and the APA were critical in recruiting mill personnel to participate in the survey.

Our special thanks are extended to those companies and their employees that participated in the surveys to obtain production data. Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the contributing entities.

The LCIA work for this update report was funded by the American Wood Council and the Canadian Wood Council through CORRIM.

12 Units and Conversions

Table 27 Unit Conversion Factors

BTU =	1.054 E-03 MJ
BTU =	1,054.3 J
cubic foot =	7.482 gal
cubic inch =	0.0043 gal
cubic unit =	200 ft^3
cubic yard =	0.7645549 m^3
ft =	0.305 m
ft^3 =	2.832 E-02 m^3
gallon (US) =	3.785 liters
gal/MCF =	133.67 L/1000 m^3
J =	10^6 MJ
kWh/ft^3 =	127 MJ/m^3
kWh=	3,414.4 BTUs
kWh=	3.6 MJ
lb =	0.454 kg
lb/ft^3 =	16.02 kg/m^3
liter =	0.02642 gal (US)
m^3 =	35.32 ft^3
MBF =	2.3597 m^3
miles =	1.852 kilometers
tons (short) =	2,000 lb
tons (short) =	907.185 kg
tons (long) =	2240 lb

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14 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.

- 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

15 Appendix 2 Original LCA Report

CORRIM: Report – Module G1 Cradle-to-Gate Life-Cycle assessment of Glued Laminated Timbers US Pacific Northwest Region

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January 16, 2017

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Information contained in this report is based on new survey data (2013) and supersedes information in the original Phase I report (Puettmann and Wilson 2004; Puettmann et al. 2013). The current 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 Glued Laminated Timber production in the US Pacific Northwest 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.

Executive Summary

The goal of this study is to update the 2000 life cycle inventory (LCI) data on material and energy inputs associated with the production of glued-laminated timbers or glulam produced in the Pacific Northwest region of the United States. Data was obtained by surveying manufacturers within this region. Surveys were consistent with CORRIM protocols for performing LCIs of wood products, and the reporting follows ISO 14040/14044 standards for conducting life cycle assessments (ISO 2006a, 2006b). The methodology adopted for developing the LCA meet the requirements of the Product Category Rule (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015), so that it can be used for developing Environmental Product Declarations (EPDs).

Glulam plants were surveyed to record all inputs and outputs associated with production processes. Input data consists of lamstock and resins consumption, packaging supplies, electricity usage, and fuel inputs to the glulam manufacturing plants. The output data consists of products and co-products along with the emissions to air, water and land. The production outputs for these plants during the year of 2013 represented 49.7 percent of total U.S. glulam production. The surveyed plants produced 270,029 m^3 of glulam (114 MMBF, nominal) in the Pacific Northwest. In the Pacific Northwest region, plant operations included both radio frequency curing and cold curing processes, with all mills utilizing radio frequency to adhere glue joints (finger-jointing) and a combination of cold cure and radio frequency for face bonding of laminations.

The processes for manufacturing glulam were modeled in SimaPro 8.0.5 as a single box process. The glulam model imported the processes from Pacific Northwest lumber production (Milota 2015) and a single unit process for producing phenol-resorcinol-formaldehyde (PRF) or melamine-urea-formaldehyde (MUF) resins (Wilson 2009). The data presented in this paper is comprised of average values derived by weighting the production from each of the mills surveyed.

The cradles to gate LCI results for glulam are presented by three life stages, forestry operations, lamstock production and glulam production. All inputs and outputs are based on the declared unit of 1 m^3 of glulam at the gate and ready for shipment. The most energy is consumed during glulam production, with comparable energy usage for lumber (lamstock) production in the Pacific Northwest. Forest operations consume very little energy per m^3 of glulam produced.

To produce 1 m^3 of finished product glulam in the Pacific Northwest, it took 1.93 m^3 of roundwood. The roundwood produced 1.14 m^3 of lamstock for the production of 1 m^3 of glulam (oven dry mass without resin) and 72 kg of coproducts (sawdust, trimming, shavings). The analyses found that there was a 31.89 percent reduction in global warning potential when compared with 2000 data. There was also a reduction in eutrophication (-44.46%) but an increase in smog (+22.65%) since the 2000 LCI. There was a 41.57 percent reduction in energy from fossil fuels, but an increase in energy from biomass (+52.82%). Fresh water usage also decreased by 43.24 percent when compared with the previous data set.

Using LCI techniques, it was estimated for the impact indicator of Global Warming Potential, that 116 kg of CO_2 equiv. was released during the production of 1 m^3 of glulam in the U.S. Pacific Northwest. For all analyses, it is assumed that the carbon content of softwood lumber is approximately 50 percent of the mass of oven dry wood. Accordingly, using the overall mass of wood in glulam beams it can be

concluded that the carbon sequestered in 1.0 m^3 of Pacific Northwest glulam is equivalent to 938 kg of CO_2, resulting in a net gain in air emissions sequestered in the product versus air emissions from product manufacturing.

The data obtained from this survey is representative of the glulam industry in the Pacific Northwest given that 49.7 percent of the total U.S. glulam production in 2013 was represented in this report. This data accounted for a majority of this regions glulam production. Based on data from participating manufacturers, a comparison of values established the validity of the data. Additional data analysis (i.e., mass and energy balances), and the original glulam LCI (Puettmann and Wilson 2004) further supported the integrity of the findings.

Acknowledgement

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 (12-JV-11111137-050). Steven Zylkowski and the APA were critical in recruiting mill personnel to participate in the survey.

We thank those companies and their employees that participated in the surveys. Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the contributing entities.

Table of Contents

Executive Summary iii

Acknowledgement v

Table of Contents vi

List of Figures ix

List of Tables x

1. Background 1

2. Introduction 1

3. Goal and Scope 1

4. Description of Product 2

4.1 Description of Industry 2
4.2 Description of Product 2
4.3 Specific Gravity, Density and Moisture Content 4
4.4 Functional and Declared unit 5
4.5 Intended Audience 5
4.6 Comparative Assertions 5
4.7 System Boundaries 5

5. Description of Data and Processes 7

5.1 Forestry Operations 7
5.1.1 PNW Operations 7
5.1.2 Regeneration (seedling production and planting process) 7
5.1.3 Forestry Equipment 8
5.1.4 Thinning and Final Harvest 8
5.2 Lamstock Manufacturing 9
5.2.1 Storage Yard 9
5.2.2 Lamstock Production 9
5.2.3 Lamstock Drying and Grading 9
5.3 Resins 9
5.3.1 Phenol Resorcinol Formaldehyde Resin 10
5.3.2 Melamine Urea Formaldehyde Resin 10
5.4 Radio Frequency and Cold Cure Processes 10
5.5 Glulam Manufacturing 10
5.5.1 End Jointing 11
5.5.2 Face Bonding 11
5.5.3 Finishing and Fabrication 11
5.6 Resource and Material Inputs 11
5.7 Packaging 13

5.8 Transportation 13
5.9 Energy Inputs 13
5.9.1 Primary Energy 13
Electricity 14
5.9.3 Wood Boiler 15
5.9.4 Other Purchase Fuels 15
5.10 Mass Balance 16
5.11 Cut off Rules 16
5.12 Primary and Secondary Data Sources 17
5.13 Data Quality Requirements 18
5.14 Assumptions and Limitations 18

6. Life Cycle Inventory Analysis 19

6.1 Data Collection 19
6.2 Allocation Rules 20
6.3 Calculation Rules 20
6.4 Resource and Material Inputs 21
6.4.1 Wood Resource 21
6.4.2 Carbon Dioxide Uptake by Trees 21
6.4.3 Tree Seed 22
6.4.4 Industrial Waste 22

7. Life Cycle Inventory Results 22

8. Life Cycle Impact Assessment 27

8.1 Treatment of Biogenic Carbon 29
8.2 Changes from Previous Report 30

9. Interpretation 32

9.1 Identification of Significant Issues 32
9.2 Life Cycle Phase Contribution 32
9.3 Substance Contribution Analysis 33
9.4 Completeness, Sensitivity and Consistency Checks 34

10. Conclusion, Limitations and Recommendations 35

11. Critical Review 37

11.1 Internal Review 37
11.2 External Review 37

12. References 37

13. Appendix I: Economic Allocation 41

13.1 Cradle to Gate LCI results – Economic Allocation 41
13.2 Life Cycle Impact Assessment – Economic Allocation 44
13.3 Carbon – Economic Allocation 45

14. Appendix II: Emissions 46

14.1 Cradle to Gate LCI Air Emissions (mass allocation) 46
14.2 Cradle to Gate LCI Water Emissions (mass allocation) 50
14.3 Cradle to Gate LCI Air Emissions (economic allocation) 54
14.4 Cradle to Gate LCI Water Emissions (economic allocation) 58

15. Appendix III: List of Terms 62

16. Appendix IV: Unit Conversions 63

17. Appendix V: Glulam Survey 65

List of Figures

Figure 2 Glulam header Source: APA 3
Figure 1 Glulam layup Source: APA 3
Figure 3 Cradle to gate life cycle stages for Glued-Laminated Timbers, PNW 6

List of Tables

Table 1 Lamstock sizes used in production of Glued-Laminated Timbers, PNW 4
Table 2 Species density and specific gravity at various moisture contents 4
Table 3 Unit Processes Inputs/Outputs for Glued-Laminated Timber Production (1 m^3), PNW (mass allocation) 12
Table 4 Materials used in packaging and shipping per 1 m^3 of Glued-Laminated Timber, PNW 13
Table 5 Delivery distance PNW one-way 13
Table 6 Primary energy inputs to produce 1 m^3 of Glued-Laminated Timber, PNW (mass allocation) 14
Table 7 Electricity grid generation mix WECC (NREL 2012) 14
Table 8 Wood boiler process parameters per bone dry kg of wood fuel combusted, PNW Glued-Laminated Timber production (Puettmann and Milota 2016) 15
Table 9 Mass balance of Glued-Laminated Timber manufacturing per 1 m^3, PNW 16
Table 10 Secondary LCI data sources used. 18
Table 11 Species used in Glued-Laminated Timber production, PNW 21
Table 12 Primary energy usage per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation) 22
Table 13 Air emissions released per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation) 24
Table 14 Emissions to water released per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation) 26
Table 15 Solid waste per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation) 27
Table 16 Selected impact indicators, characterization models, and impact categories 28
Table 17 Environmental performance of 1 m^3 Glued-Laminated Timber, PNW (mass allocation) 29
Table 18 Carbon balance per 1 m^3 Glued-Laminated Timber, PNW (mass allocation) 30
Table 19 Comparison of 2000 and 2013 data LCIA data, 1 m^3 Glued-Laminated Timber, PNW (mass allocation) 31
Table 20 Fuel and transport comparisons 2000 and 2013 input data, 1 m^3 Glued-Laminated Timber, PNW (mass allocation) 31
Table 21 Resin use and curing type comparisons, 2000 and 2013 input data, per 1 m^3 Glued-Laminated Timber, PNW (mass allocation) 31
Table 22 Economic allocation methodology versus mass allocation 32
Table 23 Life cycle stages contribution analysis per 1 m^3 Glued-Laminated Timber, PNW (mass and economic allocation) 33
Table 24 Substance contribution analysis to Global Warming Potential (kg CO_2 eq.) by life cycle stage, total percent basis and values are displayed per 1 m^3 34
Table 25 Substance contribution analysis to Acidification (kg SO_2 eq.) by life cycle stage, total percent basis and values are displayed per 1 m^3 34
Table 26 Substance contribution analysis to Eutrophication (kg N eq.) by life cycle stage, total percent basis and values are displayed per 1 m^3 34
Table 27 Sensitivity analysis of mass allocation versus economic allocation methodologies 35
Table 28 Primary energy inputs to produce 1 m^3 of Glued-Laminated Timber, PNW (economic allocation) 41
Table 29 Emissions to air released per 1 m^3 of Glued-Laminated Timber, PNW (economic allocation) 42
Table 30 Emissions to water released per 1 m^3 of Glued-Laminated Timber, PNW (economic allocation) 43

Table 31 Economic allocation methodology for the environmental performance of 1 m^3 Glued-Laminated Timber, PNW 45
Table 32 Carbon balance per 1 m^3 of Glued-Laminated Timber, PNW (economic allocation) 45
Table 33 Air emissions released per 1 m^3 of Glued-Laminated Timbers, PNW (mass allocation) 46
Table 34 Water emissions release per 1 m^3 of Glued- Laminated Timbers, PNW (mass allocation) 50
Table 35 Air emissions released per 1 m^3 of Glued-Laminated Timbers, PNW (economic allocation) 54
Table 36 Water emissions released per 1 m^3 of Glued-Laminated Timbers, PNW (economic allocation) 58
Table 37 List of terms 62
Table 38 Unit Conversion Factors 63
Table 39 Energy Content Conversion – (Higher Heating Values used for conversions) 63
Table 40 Factors Used to Convert Nominal Board Feet to Actual Volume, Pacific Northwest Region Conversions 64

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1. Background

This study is a part of ongoing work by CORRIM, the Consortium for Research on Renewable Industrial Materials, which is a collaboration of researchers developing and updating life cycle inventories (LCI) for major wood products regions in the United States (U.S). This particular study is looking at the LCI of softwood glued-laminated timbers (glulam) as manufactured in the Pacific Northwest (PNW). The PNW regional data is representative of a cross-section of forest growth and manufacturing processes in Washington, Oregon, Idaho, and Montana. While there has been a previous CORRIM model inventorying glulam, Puettmann and Wilson (2004), Puettmann et al. (2013), this is an update on that original data set (taken from 2000 mill production). LCI data are used to produce a life cycle impact assessment (LCIA) by using the North American impact method, TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare 2011). The LCIA data from this study is required for others to develop an environmental product declaration (EPD). The treatment of biogenic carbon was taken from the Norwegian Solid Wood Product PCR (Aasestad 2008), and the product category rules (PCR) from the North American Structural and Architectural Wood Products (FPInnovations 2015) report on preparing EPDs. Updates in this report include: softwood lumber, PNW region Milota (2015), and the wood combustion boiler (Puettmann and Milota 2016). This report follows details outlined in the North American PCR and follows CORRIM research protocols (Puettmann et al. 2014).

2. Introduction

One of the original engineered wood products developed over 100 years ago was stacked and glued pieces of lumber. Structural glued-laminated timbers (glulam) were created to fill the void left by the lack of large solid dimensional timbers from old growth forests. Glulam comes in a variety of sizes with their production based on nominal[1] board feet[2], and sold by retailers on a linear-foot basis.

A single unit process was used in modeling the LCI of all the steps in the glulam production process. The manufacturing process typically consists of lumber drying (if purchasing green lumber), grading, trimming, finger-jointing/end-jointing, face-planing, face-bonding, edge-planing, and then finishing and fabrication. Each beam is individually wrapped before shipping to protect it from moisture and damage.

3. Goal and Scope

The goal of this study is to update the 2004 CORRIM Phase I report with current LCI data on material and energy inputs associated with the production of glued-laminated timbers produced in the U.S. Pacific Northwest region. This report will provide a “cradle-to-gate” life cycle inventory while measuring the environmental impacts from the production of one cubic meter of glulam in the region.

[1] Nominal size-The size designation for most lumber. In lumber, the nominal size usually is greater than the actual dimension; a kiln dried 2x4 (nominal) is surfaced to 1-1/2 x 3-1/2 inches (actual).
[2] Board foot (BF)-The basic unit of measurement for lumber. One board foot is equal to a 1-inch board 12 inches in width and 1 foot in length.

The scope of this work includes the life cycle analysis of glulam from the PNW region of the United States from cradle (seedling) to gate (packaged product ready for transport). The data was taken from glulam mills in 2013 to eventually be used for updating the Environmental Product Declaration (EPD) of glued-laminated timber produced in the U.S. The data was obtained by surveying manufacturers in this region and was consistent with CORRIM protocols for performing LCIs of wood products. These protocols follow ISO 14040/14044 standards for conducting life cycle assessments (ISO 2006a, 2006b), and meet the requirements of the PCR for North American Structural and Architectural Wood Products (FPInnovations 2015).

4. Description of Product

4.1 Description of Industry

Glulam facilities are primarily located in the U.S. Pacific Northwest and southeast. The locations of larger manufacturers are typically closer to the wood resource input, in this case lamstock[3], so that most of the raw material inputs can arrive by truck. The glulam industry produced a total of 542,740 m^3 (230,000 thousand board feet, nominal) of glulam in the U.S. in 2013. This report only considers PNW produced glulam, but represents 49.75 percent of that total U.S. output. This amounted to 270,029 m^3 (114,432 thousand board feet, nominal), as was reported by manufacturers participating in the survey.

Most glulam plants have been in existence for 20 years or more and utilize one of two laminating technologies, either cold curing (no added heat) or radio frequency curing. Emission control devices are required at these facilities since toxic gases are emitted to the air from the curing of melamine and formaldehyde resins. Besides typical air emissions from energy use and equipment combustion, wood waste is generally the main byproduct of the glulam manufacturing process.

4.2 Description of Product

Glulam is an engineered, stress-rated product that consists of two or more layers of lumber that are glued together with the grain of the layers parallel to the length of the beam or column. These layers are typically referred to as laminations as seen in Figure 1. Glulam is made from suitably selected and prepared pieces of wood either in a straight or curved form, with the grain of all pieces essentially parallel to the longitudinal axis of the member (Figure 2). The maximum lamination thickness permitted is 50 mm (2 in.), and the laminations are typically made of standard 25 or 50 mm (nominal 1 or 2 in.) thick lumber. The lumber is joined end to end, edge to edge, and face to face, so the size of glulam is limited only by the capabilities of the manufacturing plant and the transportation system. North American standards require that glulam be manufactured in an approved manufacturing plant. Glulam produced by APA (Engineered Wood Association) members are certified with an APA EWS trademark and are tested for compliance to ANSI/AITC Standard A190.1-2012 (AITC 1983) to verify quality in product manufacturing. All glulam properties are tested to adhere to ASTM D3737 – 12 Standard Practice for Establishing Allowable Properties for Structural Glued-Laminated Timber (Glulam) (ASTM 2012).

[3] Lamstock is defined as a special grade of wood used in constructing laminated beams. In this study, lamstock was cut to 1.73" x 3.75", 1.73" x 5.875", 1.73" x 7.75", 1.73" x 9.75" and 1.73” x 11.75”.

NAICS product code 321213 is used in identifying products that can be labeled as engineered wood products like glued-laminated timbers.

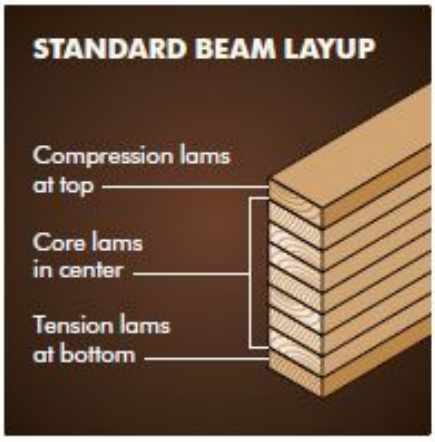

Figure 2 Glulam layup *Source: APA*

Figure 1 Glulam header *Source: APA*

Glulam beams are used as concealed or exposed structural beams and columns in residential and commercial construction, warehouse roof beams and purlins, church arches, and girders and deck panels for timber bridges. Glulam comes in a variety of sizes with production based on a volume basis, typically board feet (1 board foot = 0.0024 m^3), and sold by retailers on a linear basis. Approximately 60 percent of glulam produced in the U.S. is used in domestic new residential and remodeling construction (Adair 2002). The next largest segments are the nonresidential market representing 31 percent, and the remainder of production being sold to industrial (4%) and export (5%) markets. Glulams can be made from any wood species provided its mechanical and physical properties are suitable and it can be properly glued together. In the PNW region glulam is made from mostly Douglas Fir (*Pseudotsuga Menziesii*), with the balance coming from Alaska Yellow Cedar (*Cupressus nootkatensis*), and Port Orford Cedar (*Chamaecyparis lawsoniana*).

Glulam is produced from softwood lumber called lamstock. Lamstock is defined as a special grade of lumber used in the construction of laminated timbers. Sizes of lamstock lumber produced in the PNW are shown in Table 1. Included in the table is the relative mix of lamstock utilized for glulam production during the time period of the study.

Table 1 Lamstock sizes used in production of Glued-Laminated Timbers, PNW

Nominal	Actual		Actual		Mix
Dimension	Dimension		Dimension		%
Depth x Width	Depth (mm)	Width (mm)	Depth (in)	Width (in)	
2x4	44.45	95.25	1.75	3.75	24.3%
2x6	44.45	149.225	1.75	5.875	51.2%
2x8	44.45	196.85	1.75	7.75	15.6%
2x10	44.45	247.65	1.75	9.75	5.3%
2x12	44.45	298.45	1.75	11.75	3.2%

4.3 Specific Gravity, Density and Moisture Content

Volumetric shrinkage exists after the moisture content (MC) in the wood starts going below 30 percent for most species. Specific gravity based on volumes at different moisture contents is necessary to calculate the correct density of wood products (Simpson 1993). Specific Gravity relies on the volume of wood, after shrinkage occurs from drying. Specific gravity is the ratio of the density of the wood to the density of water at a reference temperature and typically is based on oven dry weight, but since this report is utilizing wood weights at specific moisture contents, adjustments need to be made for shrinkage in wood volume (FPL 1999). Density at given moisture contents includes the water contained within it, so as moisture content rises, so does wood density, however, as moisture content drops toward 0 percent (oven-dry), specific gravity goes up.

Table 2 Species density and specific gravity at various moisture contents

Pacific Northwest Species								
	Douglas Fir		Port Orford		Alaskan Yellow		Weighted Average*	
	% Total = 96.3%		% Total % = 0.54%		% Total = 1.05%		100%	
MC %	Specific Gravity	Density kg/m^3	Specific Gravity	Density kg/m^3	Specific Gravity	Density kg/m^3	Specific Gravity	Density kg/m^3
0%	0.511	510.9	0.473	472.6	0.435	435	0.511	510.79
12%	0.48	542.08	0.44	504	0.43	465.7	0.484	543.2
30%	0.45	585	0.42	546	0.39	507	0.45	585

* Includes some southern yellow pine glulam production (2.1%) which is not a local species in this region

Species' densities were calculated based on the specific gravity at given moisture content volumes. These volumes were averaged as reported in by the surveys. Specific gravity starting points (30% MC) were taken from the wood handbook (FPL 1999), and utilized to calculate wood densities at 0 percent MC for these LCI inputs (Table 2). A weighted average was generated to give an overall density based on the quantity of each species utilized in the production of PNW glulam.

4.4 Functional and Declared unit

A declared unit defined within the PCR (FPInnovations 2015) for glued-laminated timbers is one cubic meter (1 m^3) of final product packaged for shipment. A declared unit is utilized when the function and reference scenario for the whole life cycle of a wood building material cannot be stated (FPInnovations 2015). The unit conversion for the U.S. industry standard measure of 1 board foot equals 0.0024 m^3. Inputs and outputs were allocated to the declared unit of product based on the mass of product and co-products in accordance with ISO 14040/14044 standards (ISO 2006a, 2006b). These standards provide the principles and framework for the life cycle analyses while stating the requirements and guidelines necessary for reporting.

4.5 Intended Audience

Life cycle assessment provides designers, engineers and regulators important information by verifying the environmental impacts of products and services while providing data to help them make decisions on material choices and use. Additionally this report provides information for glulam manufacturers for marketing purposes. This ISO compliant document helps in supporting any type of eco-labeling or environmental product declarations attached to their product. Market demands are increasing for this type of information to be available on products by providing transparency and credibility in a reliable reporting process.

4.6 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 14040/44:2006 (ISO 2006a, 2006b) guidelines and principles and compliance with the Wood Products PCR (FPInnovations 2015). This report maintains anonymity from participating mills, but attempts to provide transparency of data collected where possible.

4.7 System Boundaries

When collecting data for a LCI, the system boundaries have to be defined and inputs and outputs into each system process are shown to follow the material flows within the system. For the different production stages, inputs and outputs are measured separately since each stage is usually performed by a separate company. 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 (roundwood) (Figure 3). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The production stage for glulam includes an extraction module (A_1), transportation modules (A_2), and lamstock and glulam manufacturing and fabrication module (A_3) (Figure 3). The extraction module includes forest regeneration and stand management, if any, felling the trees with a feller buncher, processing the trees by removing limbs, and cutting to shipping lengths, and transportation of logs to landing using a skidder. Excluded from the extraction module are maintenance and repair of equipment, and building and maintenance of logging roads, logging camps, and weigh stations. The transportation of logs from the woods to the mill is accounted for in the transportation module (A_2) (Figure 3). Lumber manufacturing (A_3) includes the sawmill production of lamstock, drying, grading, and packaging (Milota 2015). The glulam complex was modeled with a single

unallocated unit process. This unit process does not contains transport of lumber to the glulam facility (A_2), but starts with end-jointing, face-bonding/curing, planning (finish and fabrication), and packaging (A_3) (Figure 3) Outputs to the system boundary include 1 m^3 of glulam ready to be shipped, air and water emissions, solid waste and co-products. The co-products are no longer tracked once they leave the system boundary.

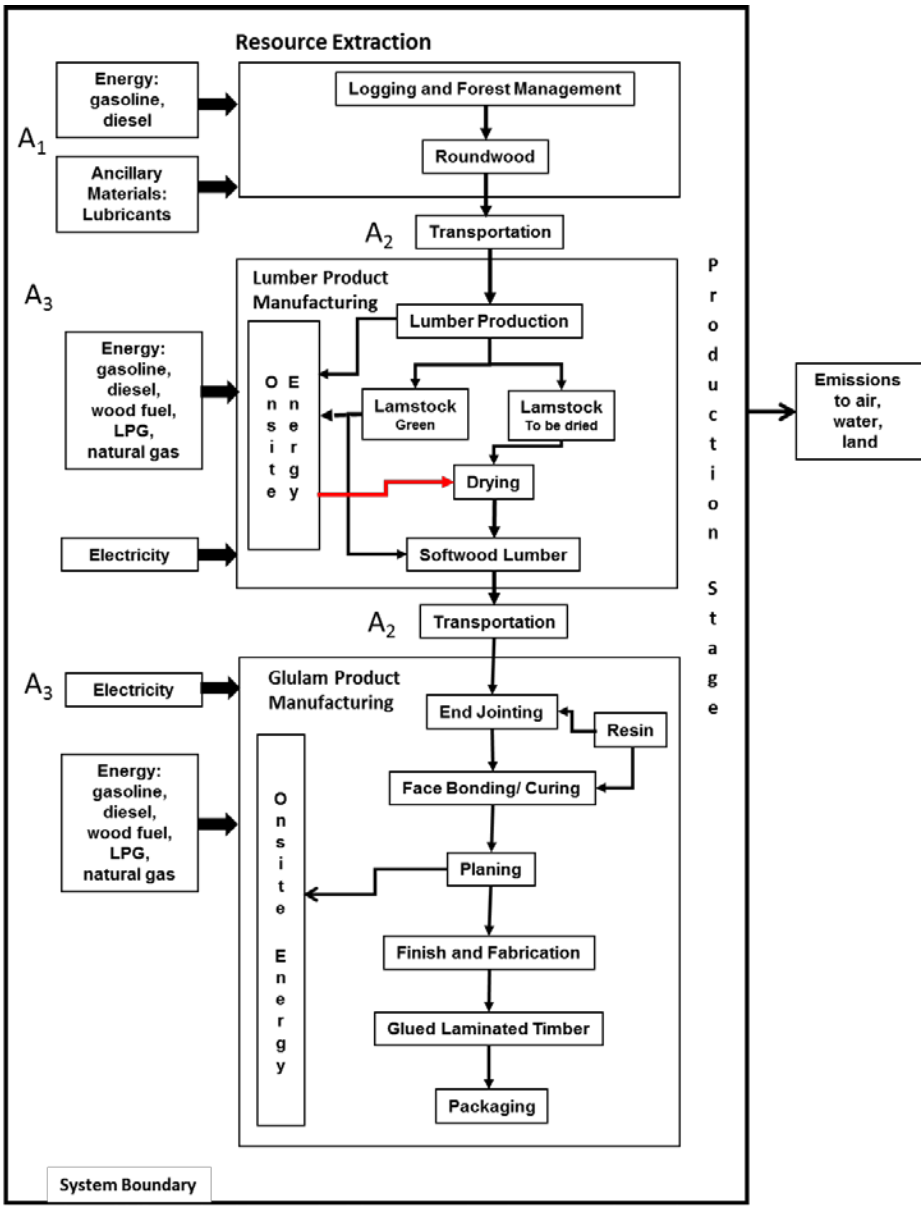

Figure 3 Cradle to gate life cycle stages for Glued-Laminated Timbers, PNW

5. Description of Data and Processes

5.1 Forestry Operations

5.1.1 PNW Operations

Forestry operations include growing seedlings, site preparation, planting, fertilization (where applicable) and final harvest. The specific processes involved are reforestation: which includes seedling production, site preparation, planting, and fertilization, and harvesting: which includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. A 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 life cycle inventory (LCI) include seeds, 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 site preparation, fertilization, and harvest operations. The primary output for this analysis is a log destined for the saw mill. The co-product, non-merchantable slash, is generally left at a landing and disposed of through mechanical activities or prescribed fire.

In the PNW, most of the harvested volume comes from forest operations on private lands where investment in timber is the precursor to harvest. 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 estimation of productivity gains over time is not 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 the potential productivity gains from future technologies. Outputs representing quantities of product, measures of consumed resources, and the emission factors associated with those resources were developed as a weighted average across the hectares managed for timber production. These quantities of product are used as inputs to the wood product manufacturing LCI and the consumed resources and emission factors 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. 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.

5.1.2 Regeneration (seedling production and planting process)

Environmental burdens associated with the production of seedlings included fertilizer used in greenhouses or fields, and the electrical energy required to operate forest nursery pumps to keep seedlings cool for

planting. 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 factors 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 Comnick 2002). Fertilization also 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.

5.1.3 Forestry Equipment

Timber harvesting activities include five 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, and 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. Cable yarding systems used in steep terrains have the processing step occur prior to the secondary transport step. Primary transportation is 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. Variations in harvest equipment size operation (thinning versus final harvest) affect machine productivity and therefore emissions per m^3 of logs produced. To account for this, equipment usage was allocated between thinning operations and final harvest (clearcut) for those management regimes that use thinning. 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.

5.1.4 Thinning and Final Harvest

A single estimate of the average volume harvested per unit area was developed by weighting three combinations of site productivity and management intensity in the PNW 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 that was obtained from the U.S. Forest Service Resource Planning Assessment database (USDA 2000, Mills 2001). A combination of these data and expert opinion were used to categorize the number of private forest hectares into 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. In the PNW, 42 percent of the lands were classified in the lowest productivity/ management intensity class, 46 percent in the

middle class, and 12 percent 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 433 m^3 (low), 490 m^3 (medium), 782 m^3 (high) (Puettmann et al. 2013) . The total yield of 501 m^3/ha is used to carry forward the environmental burdens of the reforestation effort on a per m^3 basis. Details on these management intensity levels are found in Johnson et al. (2005).

5.2 Lamstock Manufacturing

5.2.1 Storage Yard

After transportation from the forest, the log yard process includes unloading trucks, scaling the logs (volume measure), storing logs in decks, water spraying the logs to prevent dry-out and blue stain, and transporting logs to the sawmill (Milota 2015). Inputs may include gasoline, diesel, and electricity. Outputs include logs with bark. Fork lifts and/or lift trucks are utilized to transport logs to the debarker to begin the lamstock production process.

5.2.2 Lamstock Production

The lamstock production process is similar to lumber production reported by Milota (2015). It starts at the sawmill and includes debarking logs, sawing logs into rough-green lamstock, chipping portions of logs that did not make lamstock, sorting rough-green lamstock into size classes, and stacking rough-green lamstock for drying. The lamstock is transported unplaned (rough) either green or dry to glulam production facilities. Inputs include logs with bark and electricity. Outputs include green lamstock, green sawdust, green chips, bark, and green fuel wood (Milota 2015).

5.2.3 Lamstock Drying and Grading

Green lamstock cut from logs must be kiln-dried to a moisture content (MC) of 16 percent or less to minimize any additional dimensional changes. Lamstock can be purchased green and dried on site or purchased dry from various suppliers. Lamstock that exceeds the 16 percent MC limit cannot be utilized and has to be re-dried, since this will prevent the laminations to properly adhere to each other in the following processes.

Lamstock grading entails either one of two methods, either visual or machine grading. Visual grading is based upon the appearance of the material and any apparent flaws. Machine e-rated lamstock is graded by stiffness and visual characteristics (AITC 1983, WWPA 1994). Machine graded lamstock is typically required for the tension lam (bottom lamination) of a glulam since that will be taking a large proportion of the load stress.

5.3 Resins

Resins used in the production of glulam were transported to the site from various manufacturers by truck. Some resins were premixed and others needed water to be added before use. Two resins were utilized in the face-bonding and finger-jointing of lamstock during glulam layup and curing, Phenol-resorcinol-formaldehyde (PRF) and melamine-urea-formaldehyde (MUF).

5.3.1 Phenol Resorcinol Formaldehyde Resin

Phenol-resorcinol-formaldehyde resin is used in the face bonding process that glues the lamstock layers together. The PRF data was collected by survey from 8 plants in U.S. that represented 63 percent of total production for the year 2005 (Wilson 2009). Total annual production of PRF was 15,513,000 kg (34,166,667 lb) of neat[4] resin at 60 percent non-volatile solids content. Phenol-resorcinol-formaldehyde resins differ from the other resins because hardeners are required to help in curing glue laminated timbers. Phenol-resorcinol-formaldehyde resin can be cold or hot cured, and can also be radio-frequency cured.

5.3.2 Melamine Urea Formaldehyde Resin

Melamine-urea-formaldehyde resin is used in the finger jointing process of glulam production. MUF production data was collected by survey from 6 plants in U.S. that represented 77 percent of total production for the year 2005 (Wilson 2009). Total annual production was 86,588,000 kg (190,893,000 lb) of neat resin at 60 percent non-volatile solids content. Melamine-urea-formaldehyde resin production is essentially identical to the production of urea formaldehyde resin (these resins are used for particle board and medium density fiberboards) with the exception that melamine, about 8 percent by weight on a neat resin basis, is substituted for a portion of the urea input. The inputs to produce 1.0 kg of neat MUF resin at 60 percent non-volatile solids content consists of three primary chemicals on a dry basis of melamine at 0.081 kg, urea at 0.397 kg and methanol at 0.304 kg, much lesser amounts of formic acid, ammonium sulfate, and sodium hydroxide, and 0.791 kg of water. A significant portion of the processing water is recycled back into the resin.

5.4 Radio Frequency and Cold Cure Processes

Glulam production plants use both radio frequency (RF) drying and cold curing (CC) processes to cure the resin for face bonding. Radio frequency drying is used exclusively for finger jointing curing of MUF resins. The surveys indicated that both radio frequency and cold cure processes were used in PNW glulam production. The amount of electricity used by each curing process was not known or reported by the mills, so there was no way to discern how much either method was used compared to the other. In radio frequency drying, material is exposed to an electronic field that alternates about 40,000,000 times per second. Pressure and heat are applied during face bonding that is in excess of 200+ ^{o}F. When the field alternates, the water molecules in the material also alternate. The resulting friction causes the water to heat uniformly throughout the product. Radio frequency drying saves energy over the former method of heat bonding because only the product itself is heated. Other benefits are that the equipment does not have to warm up or cool down, so steam heat is no longer required, and less resin is needed during production versus cold cure methods.

5.5 Glulam Manufacturing

Once the lumber input is at the necessary moisture content, the actual glulam manufacturing process can begin. Resins are the other primary material input at this stage.

[4] Neat resin means the resin as purchased from the supplier, does not include inert fillers.

5.5.1 End Jointing

Glulams are typically longer than the available lamstock. Lamstock can be joined end to end to extend the length of each lamination. The most common joint utilized to combine lumber end to end is a finger joint. The joints are cut on both ends of the lamstock and resin is applied. A structural resin such as MUF is used for finger joints and cured with RF drying. Curing occurs under pressure and heat for a strong and stable bond between the pieces. Manufacturers typically employ a continuous RF curing system for end finger jointing, so that they can quickly process the laminations before face bonding.

5.5.2 Face Bonding

During the face bonding process, the finger jointed lamstock is planed and resin is applied to the face with a glue extruder. Phenol-resorcinol-formaldehyde is the most common used resin for face bonding, but MUF resin can also be used. The laminations are then assembled into the required layup and pressure is applied. Either cold cure or radio frequency curing are utilized during this process. Glulams are allowed to cure until they are ready for finishing and fabrication.

5.5.3 Finishing and Fabrication

After pressing and curing, glulams are removed from the presses and the wide faces are planed to remove adhesive that had squeezed out during pressing. The remaining two faces of the member may be lightly planed or sanded. For premium and architectural classified glulams, knots and planer skips are covered up. Depending upon use, final cuts are made, holes are drilled, connectors are added, and a finish may be applied. Each glulam is individually wrapped for protection before shipping. Final product density for PNW beams, excluding resin were 546 kg/m^3 at 13 percent MC, dry basis.

5.6 Resource and Material Inputs

Single unit process inputs and outputs collected from the glulam mill surveys are listed in Table 3. These show the weighted-average values for each of the various inputs and outputs used in glulam product manufacturing system boundary A_3 (Figure 3). These numbers represent the amount of each item utilized or emitted per 1 m^3 of glulam output wrapped and ready for shipment.

Table 3 Unit Processes Inputs/Outputs for Glued-Laminated Timber Production (1 m^3), PNW (mass allocation)

Products	**Value**	**Unit/m^3**	**Mass Allocation**
Glue-laminated timber	1	m^3	88%
Co-Products (sawdust, shavings, trimmings)	71.9	kg	12%
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	71.26	kWh	
Natural Gas	0.0534	m^3	
Diesel	0.940	L	
LPG	2.48	L	
Gasoline	0.0858	L	
Wood Waste combusted in boiler	25.46	kg	
Transport, Total	162.10	tkm	Transport Distribution
Transport, truck – Lumber	106.68	tkm	97.64%
Transport, rail - Lumber (southern yellow pine only)	51.70	tkm	2.36%
Transport, truck - Resin	1.92	tkm	
Transport, truck -Wrapping	1.43	tkm	
Transport, truck - Strapping	0.09	tkm	
Melamine urea formaldehyde resin	1.47	kg	
Phenol Resorcinol Formaldehyde resin	7.73	kg	
Sawn Lumber, rough, kiln dried, PNW	1.117	m^3	
Sawn Lumber, rough, kiln dried, (southern yellow pine)	0.237	m^3	
Wrapping Material – Packaging	0.00314	kg	
Strapping – Packaging	0.00061	kg	
Spacers - Packaging	0.00341	kg	
Emissions to air	**Value**	**Units/m^3**	
Particulates. Unspecified	0.0592	kg	
VOC, volatile organic compounds	0.0522	kg	
Phenol	0.6129	kg	
Formaldehyde	0.0241	kg	
HAPS	0.3426	kg	

5.7 Packaging

Materials used for the packaging of glulam for protection during transportation and storage are in Table 4 for the PNW. Packaging materials comprise less than 1 percent of the cumulative mass of the model flows. Strap protectors, wrapping materials and strapping represent 45, 45, and 10 percent of packaging by mass.

Table 4 Materials used in packaging and shipping per 1 m^3 of Glued-Laminated Timber, PNW

Material	Value	Unit
Wrapping Material – HDPE and LDPE laminated paper	0.00314	kg
Metal Strapping – Steel	0.00061	kg
Cardboard strap protectors	0.00341	kg

5.8 Transportation

Logs are transported to lumber mills by truck. The specific gravity of logs being transported to the mill was 0.45 at green weight. Lamstock for glulam production is transported by rail or truck. Lamstock could be transported green and/or dry, and rough to the glulam facility. Wood transported between the lamstock mill and glulam stages was determined to have a specific gravity of 0.482 at approximately 13 percent MC. Southern yellow pine was the only species transported by rail and made up 2.4 percent of the incoming lamstock, by weight (Table 3). Other materials such as resins and packaging materials are brought in by truck in containers or in some instances resins are brought in by liquid container trucks. Table 5 shows the average distances one way from manufacturer to the glulam facility

Table 5 Delivery distance PNW one-way

Material delivered to Facility	Delivery Distance (km)	
	km	miles
Dry Lamstock, truck	173	108
Dry Lamstock, rail	3,493	2,170
Resin	224	139
Strapping	390	242
Wrapping Material	486	302
Hog Fuel	N/A	N/A

5.9 Energy Inputs

5.9.1 Primary Energy

Raw material energy requirements are presented in Table 6 for 1 m^3 of glulam timber. Non-renewable energy use in the PNW region consisted mainly of electricity generated from natural gas. The majority of the raw material energy consumption occurs during glulam production stage with only a small portion arising from forestry operations. The lamstock production process also uses a considerable amount of energy, but due to mass allocation some of this energy is allocated to other outputs during the lamstock production process. Lamstock production generated most of its energy from wood waste and relied less on fossil fuel inputs. The energy inputs to the system are used for producing green or dry, rough lamstock

and the production of MUF and PRF resins. All primary transportation steps are assigned to the transport of logs (roundwood) to the mill or lamstock, resins, packaging transport to the glulam production phase. Higher heating values for fossil and biofuels were used when conducting energy calculations, unless otherwise noted. Energy figures are expressed in megajoules (MJ), and electricity in kilowatt hour (kWh). See energy conversion values in Table 39 in appendix IV.

Table 6 Primary energy inputs to produce 1 m^3 of Glued-Laminated Timber, PNW (mass allocation)

Fuel	Total	Forestry Operations	Lamstock Production	Glulam Production
	MJ/m^3			
Coal, in ground MJ	510.67	6.94	205.96	297.77
Gas, natural, in ground MJ	579.00	13.32	286.75	278.94
Oil, Crude, in ground MJ	557.25	187.37	192.06	177.81
Uranium oxide, in ore MJ	137.30	2.04	58.07	77.18
Total Non-Renewable	**1,784.22**	**209.67**	**742.84**	**831.70**
Wood waste MJ	3,266.70	0.00	2,734.96	531.74
Other renewables, solar, hydro, wind, etc.[1] MJ	96.82	0.43	31.32	65.07
Total	**5,147.75**	**210.10**	**3,509.12**	**1,428.52**

[1] Includes a small amount of renewable biomass for energy from various sources

Electricity

The PNW utilizes electricity from the WECC (2008) grid. The PNW grid utilizes the following fuel mix as shown in Table 6. Coal, Gas and Hydro generated power are the three largest contributors (82% combined) to the WECC grid with about 30.2 percent of the grid attributed to renewable energy sources.

Table 7 Electricity grid generation mix WECC (NREL 2012)

Grid Generation Mix	WECC
Gas	29.4%
Hydro	22.3%
Coal	30.3%
Nuclear	9.9%
Biomass	1.3%
Wind	3.4%
Petroleum	0.2%
Other Renewables	3.2%
Total	100.00%

5.9.3 Wood Boiler

A wood boiler was used during lamstock and glulam production. The boiler processes utilized data from the CORRIM model from U.S. wood producing facilities for the purpose of on-site energy generation (Puettmann and Milota 2016). This process measures the inputs and outputs for wood combusted at the boiler (Table 8). Wood waste generated on-site was the primary source of fuel for the boiler (95%). Hog fuel was purchased as a secondary source (5%) at the glulam manufacturing stage.

Table 8 Wood boiler process parameters per bone dry kg of wood fuel combusted, PNW Glued-Laminated Timber production (Puettmann and Milota 2016)

Inputs – Materials and Fuels	Value	Unit/m^3	Allocation %
Wood fuel, glulam shavings, at planer, kg / PNW US	3.90E+00	kg	39.0%
Wood fuel, glulam trimmings, at saw, kg / PNW US	5.60E-01	kg	56.0%
Wood Fuel, purchased, unspecified, kg / PNW US	5.00E-02	kg	5.0%
Transport, combination truck, diesel powered/US, On-Site	0	tkm	
Diesel, combusted in industrial equipment/US	8.05E-04	L	
Gasoline, combusted in equipment/US	3.96E-05	L	
Liquefied petroleum gas, combusted in industrial boiler/US	1.21E-05	L	
Lubricants	1.91E-05	L	
Engine oil	2.22E-05	L	
Hydraulic oil	0.00E+00	L	
Antifreeze	4.81E-07	L	
Ethylene glycol, at plant/RNA	1.07E-06	kg	
Solvents[5]	7.17E-07	kg	
Water Treatment	1.23E-04	kg	
Boiler streamline treatment	3.67E-06	kg	
Urea, as N, at regional storehouse/RER U	3.15E-03	kg	
Disposal, ash, to unspecified landfill/kg/RNA	7.59E-03	kg	
Disposal, solid waste, unspecified, to unspecified landfill/kg/RNA	7.26E-06	kg	
Disposal, metal, to recycling/kg/RNA	3.96E-08	kg	
Electricity, at Grid, WECC, 2008	8.20E-02	kWh	
Natural gas, combusted in industrial boiler/US	1.38E-03	m^3	
Inputs - Water			
Water, process, surface	3.10E-01	kg	
Water, process, well	2.40E-01	kg	
Water, municipal, process, surface	7.90E-01	kg	
Water, municipal, process, well	2.40E-01	kg	
Outputs – Products and Co-Products			
CORRIM Wood Combusted, at boiler, at mill, kg, RNA	1.00E+00	kg	98.1%
CORRIM Wood ash, at boiler, at mill, kg, RNA	2.00E-02	kg	1.9%

5.9.4 Other Purchase Fuels

Purchased fuels that were utilized by glulam mills in this study and their approximate heating values in are listed in Table 39 in appendix IV.

[5] 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 January 2016

5.10 Mass Balance

Table 9 shows the mass balance of the glulam material inputs and outputs for the PNW region. The wood and resins going into the production of 1 m^3 of glulam during the manufacturing process results in either glulam, shavings from planning the glulam, trimmings from the ends to get to various lengths, and wood waste or scrap. Unaccounted inputs are assumed to be lumber from the previous year. The output of finished glulam was 510.70 kg/m^3 oven dry mass.

Table 9 Mass balance of Glued-Laminated Timber manufacturing per 1 m^3, PNW

	OD kg	Mass	CoVw[1]
Feedstocks	**INPUTS**	(%)	(%)
Lamstock	559.02	95.82%	4.16%
Unaccounted inputs (lumber)[2]	15.52	2.66%	
Additives			
Phenol-resorcinol-formaldehyde resin	5.97	1.02%	47.56%
Melamine-urea-formaldehyde resin	1.19	0.20%	68.55%
Catalyst/fillers/extenders	1.68	0.29%	41.20%
Total Additives	8.84	1.52%	23.10%
Total Inputs	583.38	100%	
Products	**OUTPUTS**		
Glulam	510.70	87.54%	0.47%
Co-Products			
Shavings	29.71	5.09%	135.12%
Trimmings	42.21	7.24%	62.76%
Waste	0.76	0.13%	0.00%
Total Co-Products	72.68	12.46%	39.25%
Total Outputs	583.38	100%	

[1] Coefficient of Variation for the weight average of input and outputs
[2] Unaccounted for inputs is assumed to be lumber on site prior to year of survey

5.11 Cut off Rules

According to the PCR, if the mass flow of a particular input or output is less than 1 percent of the cumulative mass of the model flow it may be excluded, provided its environmental relevance is minor. Raw materials used in small quantities and comprise less than 1percent of the product mass (excluding packaging) were not included in the LCA. These included sealer, epoxy, stain, and poly patch that were utilized when needed.

In the primary surveys, manufacturers were asked to report total hazardous air pollutants (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 product 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, and cut off rules do not apply. If applicable to the wood product, HAPS are reported in Table 13 and are included in the impact assessment. Table 13 shows all air

emission to the 10^{-4} to simplify and report only the dominant releases by mass. There were no cut-offs used in the impact assessment therefore a complete list of all air emissions (smaller than 10^{-4}) is located in appendix II of this report.

5.12 Primary and Secondary Data Sources

Forest management and harvesting LCI data used in this study were derived from earlier studies on forest operations in the PNW (Johnson et al. 2005). The data included a weighted average of various harvesting and forest management methods used in each forest types. The forestry systems for the PNW region were weighted to represent a common forestry system for cellulosic fiberboard production. This data source is listed in Table 10. Lamstock production data used in this study was derived from CORRIM data using PNW softwood lumber data (Milota 2015) also shown in Table 10.

Transportation for materials and resources was primarily by road with some transportation by rail. The LCA incorporated an appropriate diesel tractor-trailer and diesel locomotive LCI from the U.S. LCI database (https://www.lcacommons.gov/nrel/) based on transportation distances and mass of logs for each mill location. Table 10 lists the secondary LCI data sources used in this LCA study.

Primary data glulam manufacturing was collected from mills in the U.S. Pacific Northwest. The mills provided production data for the year 2013. The participating facilities also provided information and data on the use of fuels, resins, additives, energy consumption, electricity use, and ancillary inputs (e.g. lubricants, oils, packaging, etc.).

Table 10 Secondary LCI data sources used.

Process	LCI data Source	Publication date
Diesel truck	USLCI data for "Transport, combination truck, diesel powered/US"	2008
Diesel locomotive	USLCI data for "Transport, train, diesel powered/US"	2008
Electricity	USLCI data for "Electricity, at Grid, WECC, 2008/RNA U"	2008
Forestry and Harvesting	CORRIM data for PNW softwood forestry operation;	2005, updated 2013
Wood residue production	CORRIM data for PNW softwood lumber production modified for Canada electricity	2015
Lamstock production	CORRIM data for PNW softwood lumber	2015
Hydraulic fluid, Lubricants, motor oil, thermal fluid	USLCI data for "Gasoline, at refinery/l/US" without combustion emissions.	2008
Propane	USLCI data for "Liquefied petroleum gas, combusted in industrial boiler/US". Combustion emission removed if mill reported emissions	2008
Gasoline	USLCI data for "Gasoline, combusted in equipment/US". Combustion emission removed if mill reported emissions	2008
Diesel	USLCI data for "Diesel, combusted in industrial equipment/US." Combustion emission removed if mill reported emissions	2008
Natural gas	USLCI data for "Natural gas, processed, at plant/US." Combustion emission removed if mill reported emissions	2008
Plastic strapping/wrapping material	USLCI data for "Low density polyethylene resin, at plant/RNA"	2008
Metal strapping	USLCI data for "Hot rolled sheet, steel, at plant/RNA"	2008
Resins	USLCI data for "Phenol-resorcinol-formaldehyde Melamine-urea-formaldehyde Resins" at plant, US 1.0 kg neat resin"	2009
Wood Boiler	CORRIM data for Wood combusted from self-generated waste.	2015

5.13 Data Quality Requirements

Four manufacturing plants provided data in terms of glulam and co-product production, raw materials, electricity and fuel use, and emissions. The producers surveyed represent 49.75 percent of the U.S. production (APA 2013). Total annual production from producers surveyed in the PNW was 270,029 m^3 (114,432 thousand board feet, nominal). An external critical review of the survey procedures, data, analysis, and report was done for compliance with the North American PCR criterion and following CORRIM and ISO 14040, 14044 standards (FPInnovations 2015, Puettmann et al. 2014, ISO 2006a, ISO 2006b).

5.14 Assumptions and Limitations

Assumptions were made for the extraction of the wood resource based on the CORRIM forest resource model (Johnson et. al. 2005). Forest resource harvest and operations data were based on averages for the region since it was not documented where logs processed by the mill were from. Similar technology and

geographical region data was used for the lamstock production, which was assumed to be the same as dried rough lumber production. Primary data on resin production was not collected for this study. Data available in the USCLI was used when available, or substituted with European data if necessary. Future work should include updated resin data and a thorough tracking of co-products and waste through the system since many mills only reported waste at certain points in the production process.

6. Life Cycle Inventory Analysis

ISO 14040 is an international standard for the development of a Life Cycle Assessment (ISO 2006a). This standard provides guidelines to perform LCA studies that allow for flexibility but adhere to particular protocols. ISO 14040 presents four phases in the framework of a completed LCA: Goal and Scope definition, Life Cycle Inventory, Life Cycle Impact Assessment, and Interpretation.

6.1 Data Collection

Primary data was collected from participating U.S. glulam manufacturing facilities located in the U.S. PNW. This data included production and emission data related to their operations during the calendar year of 2013. Information gathered for this study included material inputs, electricity and fuel use, and emissions. Qualtrics software (Qualtrics 2014) was utilized to conduct two of the surveys online to reduce errors and streamline data input for analysis. Two surveys were collected manually on site as this was the quickest way to attain survey information from those mills, while having time to verify any questions on the data. The survey was emailed to appropriate mill managers with a welcome letter addressing the needs for the data and that it was being used to update the LCI database. Four mills from the PNW volunteered to participate in the survey, which represented 49.75 percent of U.S. glulam production for 2013.

The primary data obtained from the surveys were weight-averaged using the formula shown below (Milota 2015):

$$\bar{x}_w = \frac{\sum wx}{\sum w}$$

Where $\bar{x}_w$ is the weighted average of the values reported by the mills, x_i the reported mill value, and w_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 the present study, the weighted coefficient of variation was calculated (NIST ITL 1996). The weighted coefficient of variation is the weighted standard deviation divided by the weighted mean:

$$\mathrm{Sd}_w = \sqrt{\sum_{i=1}^{N} \mathrm{w}_i \left(\mathrm{x}_i - \bar{\mathrm{x}}_w\right)^2 \; x \; \frac{N'}{(N'-1)\sum_{i=1}^{N} \mathrm{w}_i}}$$

Where w_i is the weight of the ith observation, N' is the number of non-zero weights, and $\bar{x}_w$ is the weighted mean of the observations.

Secondary data was utilized from electrical grid inputs, other input materials (resins), and forest resource activities from the USLCI database (NREL 2012) and CORRIM database. This additional data provided necessary inputs to complete the LCI profile for U.S. Pacific Northwest glulam production.

6.2 Allocation Rules

If one or more co-products are generated during the production process, it is necessary to allocate the inputs and outputs using a standardized approach. This LCA follows the allocation rules in the PCR (FPInnovations 2015) which states that when the total revenues between the main product and co-products is more than 10 percent, allocation shall be based on the revenue (economic) allocation. The 10 percent rule is applied based on a per unit basis, in this case per m^3 of glulam. To ensure comparability with previous CORRIM wood product LCAs (http://www.corrim.org/pubs/reports.asp), this report also presents results based on mass allocation. Economic allocation methodology results as required by the North American Structural and Architectural Wood Products PCR (FPInnovations 2015) are included at the end of this report.

6.3 Calculation Rules

Calculation procedures utilized Simapro version 8.0+ (PreConsultants 2016). In measuring heat released from equipment or machinery use, no heat was captured or reutilized during forest operations and was released to the atmosphere. At the manufacturing facilities, some heat was captured and reutilized at the facility. The TRACI 2.1 V1.01 impact method (Bare 2011) was used to quantify the environmental impacts of the forest operations, lamstock production, and glulam manufacturing.

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 in the PNW 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. Data were derived from existing studies for the types of harvesting equipment used in the region to calculate the environmental burdens associated with equipment used during the resource extraction stage (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).

Lumber inputs (lamstock) were provided in board feet[6] (BF) and a ratio of nominal to actual BF was used to calculate actual wood volumes. This ratio was determined by weight averaging the BF ratio of each size of lamstock used for glulam (Table 40 in appendix IV). The volume was converted to cubic meters (m^3) and the weight of the lamstock input was calculated with the weighted average of the PNW species density in kg/m^3 (Table 2). All data from the survey was weight averaged based on a particular mill's production in comparison to the total survey production for the year. All conversion units for forestry and forest products were taken from Briggs (1994).

Missing data is defined as data not reported in surveys by the glulam facilities. Missing data were carefully noted so they were not averaged as zeros. When data was missing for a variable, the weighted

[6] One board foot (BF) nominal = 0.05 cubic feet actual; 1 ft^3 (actual) = 19.02 BF (nominal)

average for that variable reflected those facilities reporting the data in the surveys. Data was analyzed for outliers based on inputs or outputs per declared unit of glulam produced. Not all respondents answered every question on the survey so comparisons to the previous report (Puettmann et al. 2013) were utilized to find potential outliers.

Units were collected from mills with typical industry weights and measures. These were converted to appropriate SI units and these conversions are listed in appendix IV tables 38 and 39. All outputs were documented in SI units unless an appropriate replacement was not available.

6.4 Resource and Material Inputs

6.4.1 Wood Resource

Species utilized in the production of glulam in this study were comprised of the species in Table 11, with Douglas-fir representing the 96.3 percent of lamstock input (by volume), with the remainder consisting of southern yellow pine, Alaska Yellow Cedar, and Port Orford Cedar. Southern yellow pine is a generic trade name that consists of a various mix of the four species below. PNW glulam facilities produce a small quantity of beams utilizing southern yellow pine for wood treatment facilities to be used in exterior applications. Logs coming in from the forest were green volumes, whereas all of the lamstock used in glulam production were kiln-dried (16% MC or less).

Table 11 Species used in Glued-Laminated Timber production, PNW

Species	Latin Name	
Douglas-fir	*Pseudotsuga menziesii*	96.31%
Alaska Yellow Cedar	*Cupressus nootkatensis*	0.54%
Port Orford Cedar	*Chamaecyparis lawsoniana*	1.05%
Southern Yellow Pine		2.10%
Longleaf Pine	*Pinus palustris*	
Shortleaf Pine	*Pinus echinata*	
Loblolly Pine	*Pinus taeda*	
Slash Pine	*Pinus elliottii*	
	Total	100%

6.4.2 Carbon Dioxide Uptake by Trees

Forest management scenarios take into account the CO_2 uptake by trees and its storage as carbon. Over the long term, sustainably managed forests are under the assumption that they are carbon neutral as trees continue to grow to balance the carbon removed by harvest (FPInnovations 2015). These carbon stores within the wood remain in the final product until deconstruction and disposal or recycling. This report takes the glulam output only to the gate and therefor an end of life scenario is not part of this analysis. Associated co-products like residues may release their carbon through decomposition or combustion depending on their prescribed end use. CO_2 emissions due to respiration, decay, slash burning, fires, insect damage, etc., are not included in the model, but combustion of the residues for energy at the glulam facility are included.

6.4.3 Tree Seed

As an input from nature a "tree seed" is the starting resource for the forest resource model. Seedlings used in the forestry process included fertilizer used in the greenhouse and/or fields and the electrical energy utilized to operate nursery pumps to cool seedlings prior to planting. Greenhouse data was used from Wenny (2003). All seedlings in the PNW were planted by hand and included travel to and from the planting site.

6.4.4 Industrial Waste

Industrial waste was taken to the appropriate waste facility unless otherwise noted.

7. Life Cycle Inventory Results

Life-cycle inventory results for glulam are presented by three life cycle stages, 1) forestry operations, 2) lamstock production, and 3) glulam production (Table 12- Table 15). The majority of fuel consumption for energy production occurs during glulam manufacturing, followed by the production of lamstock and only a very small portion allocated to forestry operations. Table 12 shows the consumption of energy inputs per m^3 of glulam. The highest fossil fuel use was coal with 19.34 kg/m^3 being consumed. Onsite energy use was primarily for lamstock production (wood waste) and off site for electricity generation. Wood fuel usage represented 63 percent of the primary energy mass and was used for lamstock production and drying.

Table 12 Primary energy usage per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation)

	PNW (kg/m^3)			
Fuel	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Coal, in ground kg	19.14	0.14	7.74	11.26
Gas, natural, in ground kg	11.10	0.12	5.62	5.35
Oil, Crude, in ground kg	10.89	2.32	4.62	3.94
Uranium oxide, in ore kg	4.01E-04	3.20E-06	1.70E-04	2.30E-4
Total Non-Renewable	**41.12**	**2.58**	**17.98**	**20.55**
Wood waste kg	132.36	0	106.90	25.46
Total	173.48	2.58	124.88	46.01

Table 13 lists the cradle to gate air emissions (on-site) generated as a result of glulam production. Glulam manufacturing generates air emissions like CO_2 from the electricity used by equipment during the jointing, bonding, planning, and finish/fabrication stages. Air emissions including Hazardous Air Pollutants (HAPs)s are a result of resin use during face bonding and curing and particulate matter during resizing (jointing, planning, finishing). Emissions from formaldehyde and methanol use are required to be reported by mills and are quantified by measuring acetaldehyde, acrolein, formaldehyde, methanol, phenol, propionaldehyde (or propanal), and other volatile organic compounds (VOCs) outputs.

These are all noted as components of HAPs. The following table has the inventory results of air emission outputs released for each declared unit of 1 m^3 of glulam produced in the PNW to 10^{-4} kg/m^3 (Table 13). All air emission results appear in appendix II (Table 33).

Table 13 Air emissions released per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation)

Air Emission[1]	Total	Forestry Operations	Lamstock Production	Glulam Production
	kg/m^3			
Acetaldehyde	0.0240	0.0001	0.0239	0.0000
Acrolein	0.0011	0.0000	0.0011	0.0000
Aldehydes, unspecified	0.0007	0.0002	0.0002	0.0003
Ammonia	0.0026	0.0001	0.0020	0.0004
Benzene	0.0001	0.0001	0.0000	0.0000
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0038	0.0001	0.0019	0.0018
Carbon dioxide	0.1114	0.0534	0.0493	0.0086
Carbon dioxide, biogenic	269.4694	0.0115	228.7752	40.6827
Carbon dioxide, fossil	108.1363	14.5040	43.8310	49.8014
Carbon monoxide	0.0064	0.0000	0.0001	0.0063
Carbon monoxide, biogenic	0.5323	0.0000	0.4191	0.1132
Carbon monoxide, fossil	0.3464	0.1318	0.1088	0.1058
Dinitrogen monoxide	0.0017	0.0003	0.0008	0.0006
Formaldehyde	0.0247	0.0001	0.0022	0.0224
HAPs	0.3149	0.0000	0.0008	0.3141
Heat, waste	0.5515	0.0000	0.4687	0.0829
Hydrocarbons, unspecified	0.0001	0.0000	0.0001	0.0001
Hydrogen chloride	0.0102	0.0001	0.0042	0.0058
Hydrogen fluoride	0.0012	0.0000	0.0005	0.0007
Isoprene	0.0145	0.0003	0.0042	0.0099
Methane, biogenic	0.0034	0.0000	0.0029	0.0005
Methane, fossil	0.2747	0.0214	0.1234	0.1299
Methanol	0.0199	0.0000	0.0197	0.0002
Nitrogen oxides	0.8691	0.2628	0.3322	0.2742
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0330	0.0088	0.0096	0.0146
Organic substances, unspecified	0.0028	0.0000	0.0005	0.0023
Particulates, < 10 um	0.1271	0.0000	0.0610	0.0661
Particulates, < 2.5 um	0.0283	0.0000	0.0251	0.0032
Particulates, > 10 um	0.0191	0.0000	0.0191	0.0001
Particulates, > 2.5 um, and < 10um	0.0181	0.0081	0.0048	0.0052
Particulates, unspecified	0.0312	0.0014	0.0123	0.0174
Phenol	0.5617	0.0000	0.0001	0.5615
Propanal	0.0002	0.0000	0.0002	0.0000
Propene	0.0003	0.0002	0.0000	0.0000
Radionuclides (Including Radon)	0.0006	0.0000	0.0002	0.0003
Sulfur dioxide	0.5353	0.0100	0.2493	0.2760
Sulfur monoxide	0.0321	0.0146	0.0040	0.0134
Sulfur oxides	0.0271	0.0000	0.0129	0.0143
VOC, volatile organic compounds	0.3521	0.0071	0.2675	0.0775
Wood (dust)	0.0966	0.0000	0.0837	0.0129

Most of the water emissions from glulam manufacturing were from upstream processes such as fuel and resin production. During glulam production, little water was utilized, but most of the water use was attributed to steam during additional kiln drying or steam for heat during RF curing. Other water consumption was for cleaning and general maintenance of equipment, etc. Water emissions attributed to glulam production to 10^{-4} kg/m^3 are in Table 14. Water emissions results that are smaller than 10^{-4} kg/m^3 appear in appendix II (Table 34).

Table 14 Emissions to water released per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation)

Water Emission[1]	Total	Forestry Operations	Lamstock Production	Glulam Production
	kg/m^3			
Aluminium	0.0052	0.0014	0.0020	0.0018
Ammonia	0.0015	0.0003	0.0006	0.0006
Ammonia, as N	0.0002	0.0000	0.0000	0.0002
Ammonium, ion	0.0001	0.0000	0.0001	0.0000
Barium	0.0709	0.0198	0.0270	0.0241
Benzene	0.0002	0.0000	0.0001	0.0001
BOD5, Biological Oxygen Demand	0.0427	0.0031	0.0121	0.0275
Boron	0.0003	0.0001	0.0001	0.0001
Bromide	0.0204	0.0036	0.0088	0.0080
Calcium	0.2210	0.0546	0.0490	0.1173
Calcium, ion	0.0856	0.0000	0.0830	0.0026
Chloride	3.4466	0.6144	1.4835	1.3487
COD, Chemical Oxygen Demand	0.0310	0.0059	0.0132	0.0119
Fluoride	0.0016	0.0015	0.0001	0.0000
Formaldehyde	0.0025	0.0000	0.0000	0.0025
Iron	0.0115	0.0029	0.0045	0.0041
Lithium	0.0374	0.0013	0.0119	0.0242
Lithium, ion	0.0152	0.0000	0.0147	0.0005
Magnesium	0.0599	0.0107	0.0258	0.0234
Manganese	0.0003	0.0000	0.0001	0.0001
Oils, unspecified	0.0025	0.0004	0.0010	0.0011
Phenol	0.0008	0.0000	0.0000	0.0008
Phosphate	0.0012	0.0012	0.0000	0.0000
Silver	0.0002	0.0000	0.0001	0.0001
Sodium	0.7004	0.1732	0.1553	0.3719
Sodium, ion	0.2713	0.0000	0.2631	0.0082
Solids, inorganic	0.0003	0.0000	0.0000	0.0003
Solved solids	1.2018	0.0000	1.1509	0.0510
Strontium	0.0052	0.0009	0.0022	0.0020
Sulfate	0.0170	0.0014	0.0070	0.0086
Sulfur	0.0003	0.0000	0.0001	0.0001
Suspended solids, inorganic	0.0017	0.0000	0.0000	0.0017
Suspended solids, unspecified	3.2267	0.8022	0.7417	1.6827
Toluene	0.0002	0.0000	0.0001	0.0001
Waste water/m3	87.2170	0.0000	0.0001	87.2169
Zinc	0.0001	0.0000	0.0000	0.0000

There was solid waste generated as a result of this system process. Most of the wood waste was recycled or utilized as fuel for the wood boiler. Glulam mills did not report other solid waste being generated from manufacturing processes. The solid waste flows are below in Table 15. Solid emissions include ash generated at the boiler. Other waste generated is a result of upstream processes, primarily fuels and resins, used in lamstock and glulam production. A total of 8.71 kg of solid waste was generated from cradle to gate during the production of 1 m^3 of glulam including these upstream processes.

Table 15 Solid waste per 1 m^3 of Glued-Laminated Timber, PNW (mass allocation)

Solid Waste	Total Emissions	Forestry Operations	Lamstock Production	Glulam Production
	kg/m^3			
Total Solid Waste	8.836	0.233	3.837	4.765
Percent of Total	100%	2.6%	43.4%	53.9%

8. 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 16. Environmental impacts are determined using the TRACI method (Bare 2011). The five impact categories reported are consistent with the requirement of the wood products PCR (FPInnovations 2015).

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. All are presented as equals. 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 17 provides the environmental impact by category for one cubic meter of glulam produced in the PNW region. In addition, energy and material resource consumption values and the waste generated are also provided.

Table 16 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 measured in SO_2 equivalents for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of kg SO_2 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

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. For GWP in the PNW, 46 percent of the CO_2 equivalent emissions come from producing glulam, with the remaining 41 percent attributed to lamstock production and 13 percent assigned to forestry operations. The totals in table 17 include the cumulative impacts of all of the upstream processes that are required for glulam production including those from forestry, lamstock, resin, and packaging production and the transportation energy required to move these materials to the glulam facility. For example, differences between glulam production data in Table 2 with results in Table 17 are a result of the resources and fuels used in the upstream processes, i.e. fresh water use.

Table 17 Environmental performance of 1 m^3 Glued-Laminated Timber, PNW (mass allocation)

Impact category	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Global warming potential (GWP)	kg CO_2 equiv	115.69	15.19	47.26	53.24
Acidification Potential	kg SO_2 equiv	1.2187	0.2090	0.5070	0.5027
Eutrophication Potential	kg N equiv	0.0466	0.0151	0.0168	0.0146
Ozone depletion Potential	kg CFC-11 equiv	1.35E-08	6.94E-10	1.21E-09	1.16E-08
Smog Potential	kg O_3 equiv	24.94	6.55	9.44	8.94
Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Total Primary Energy Consumption	MJ	5,147.75	210.10	3,509.12	1,428.52
Non-renewable fossil	MJ	1,646.92	207.63	684.77	754.52
Non-renewable nuclear	MJ	137.30	2.04	58.07	77.18
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	95.21	0.43	30.82	63.96
Renewable, biomass	MJ	3,268.32	0.00	2,735.46	532.86
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Non-renewable materials	kg	9.374	0.007	0.014	9.353
Renewable materials	kg	510.07	0	592.42	510.07
Fresh water	L	457.61	14.17	378.68	64.75
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Solid waste	kg	8.84	0.23	3.84	4.77

8.1 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, but 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 (FPInnovations 2015) 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 CO_2 emissions released from the combustion of woody biomass during manufacturing. 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 (2011). Using this method, 116 kg CO_2 equivalent were released in the production of 1 m^3 of PNW glulam (including lamstock and resin production). That same 1 m^3 of glulam stores 938 kg CO_2 equivalent (Table 18).

The carbon balance on wood based materials in the glulam process is shown in Table 18. The CO_2 uptake for wood and bark is determined by multiplying the product process input dry weight of wood and associated bark in kg (tracked separately) by 1.832062 (assuming a 50% carbon content of wood and bark) which gives the equivalent CO_2 uptakes based on the carbon content of wood and bark (the conversion of carbon to CO_2 equivalent is 3.664 based on carbon mole wt. at 12.011 and oxygen mole wt. at 15.9994). The CO_2 uptake is determined on the volume of wood and bark (dry weight basis) input to the product process. There are very few if any co-products in the glulam manufacturing process.

Table 18 Carbon balance per 1 m^3 Glued-Laminated Timber, PNW (mass allocation)

	kg CO_2 equivalent
Released forestry operations	15.19
Released lumber manufacturing	47.26
Released glulam manufacturing	53.24
CO_2 eq. stored in product	937.69

8.2 Changes from Previous Report

To show how these results compare to the last glulam LCIA, Table 19 provides results from this report versus the LCIA of Puettmann et al. (2013) that utilized onsite glulam production data from the year 2000. These results show that there was a 31.89 percent reduction in CO_2 emissions since the previous report. There were also reductions in eutrophication (-44.46%), but an increase in smog potential (+22.65%) since the 2000 LCI. Ozone depletion could not be determined when compared with the previous study and the accounting method for acidification has changed since the previous report. There was a decrease in total energy use (-2.25%), which was primarily attributed to the reduction of energy from fossil fuels (-41.57%). This reduction was replaced by an increase in energy from renewable biomass (+52.89%). Fresh water usage had also decreased during this time with a 43.24 percent reduction being reported.

Table 20 shows the reduction in fuel use that contributes to the large reduction in fossil fuel use at the glulam production stage. The large increase in energy from renewable biomass offset the reduction in natural gas use since the boilers could be run almost completely on residual biomass from the mills. Respondents reported an increase in diesel and LPG use, but a significant reduction in gasoline use (17.5 L to 0.08 L). Respondents did not report why there was such a decrease, but some of this was probably from the increase use of LPG use during this survey period. There was an increase in transportation which led to the increased diesel use, but the emissions related to this increase were not significant with the inclusion of some transport by rail (2.36% of total).

Table 21 shows an increase in resin use from the last report. This section needs to be examined closely in future studies to get a clearer view of which method of face bonding is less impactful; Cold curing because of less energy use or radio frequency because of a reduction in resin required for curing (upstream energy use). There were very few if any technology changes between the years of these two studies, but energy use, supplier locations (distance to production facilities), and changes in the electricity grid composition can also be attributed to differences between the reports.

Table 19 Comparison of 2000 and 2013 data LCIA data, 1 m^3 Glued-Laminated Timber, PNW (mass allocation)

Impact Indicator	2000 Data	2013 Data[1]	% Change
Global Warming (GWP) kg CO_2 equiv	169.85	115.68	-31.89%
Eutrophication Potential kg N equiv	0.084	0.0466	-44.46%
Smog Potential kg O_3	20.33	24.94	22.65%
Natural Resource Use			
Total Energy (MJ)	5,266.24	5,147.75	-2.25%
Fossil Fuel (MJ)	2,818.46	1,646.92	-41.57%
Renewable biomass (MJ)	2,137.65	3,268.31	52.89%
Fresh Water (L)	806.16	457.61	-43.24%

[1] Changes from previous report are updated lumber, boiler and glulam data. Same resin and harvest data was used for this report

Table 20 Fuel and transport comparisons 2000 and 2013 input data, 1 m^3 Glued-Laminated Timber, PNW (mass allocation)

Fuels and Transport		2000 Data	2013 Data	% Change
Electricity	kWh	84.44	71.26	-15.6%
Natural Gas	m^3	3.98	0.0534	-98.7%
Diesel	L	0.36	0.94	161.1%
LPG	L	1.62	2.48	53.1%
Gasoline	L	17.46	0.0858	-99.5%
Transport	tkm	84.58	162.10	91.65%

Table 21 Resin use and curing type comparisons, 2000 and 2013 input data, per 1 m^3 Glued-Laminated Timber, PNW (mass allocation)

Resin and Method of Cure		2000 Data	2013 Data
Phenol Resorcinol Formaldehyde resin	kg	5.17	7.73
Melamine Urea Formaldehyde resin	kg	0.96	1.47
Cold Cure	% used	19%	83%
Radio Frequency	% used	81%	17%

9. Interpretation

As defined by ISO (2006a), 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 presented in 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.

9.1 Identification of 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 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, unit process contributions in a multi-unit manufacturing process, or specific substances which contribute an impact.

9.2 Life Cycle Phase Contribution

Three life cycle stages were used in the overall cradle to gate assessment of PNW glulam. Their contribution to impact categories varied depending if either a mass or economic allocation was applied. Table 22 shows how the allocation of burdens differed from a mass allocation methodology versus an economic. Based on an economic allocation, the glulam takes 100 percent of the burdens regarding environmental impacts, whereas lamstock takes 86 percent of the burden when using an economic approach.

As is the case with wood products in general, the manufacturing phase of glulam production requires most of the inputs and results in higher environmental impact contributions for GWP and Ozone Depletion (Table 23). When an economic allocation approach was used, the impact category contribution from glulam and lamstock manufacturing increases; this subsequently lowers the contribution from the forestry operations stage. Forestry operations contributed 4.08 percent of the total primary energy burden and 13.13 percent of the overall impact from cradle to gate GWP using mass allocation. These numbers are reduced to 3.84 percent and 11.56 percent accordingly using an economic approach, while energy use rises for both lamstock and glulam production and GWP contribution rises for lamstock production. Primary energy consumption also shows the same trend as impact category burdens increase from manufacturing using an economic approach and contributions from forestry operations decrease.

Table 22 Economic allocation methodology versus mass allocation

Glulam Process	**Mass**	**Economic**
Glulam	88%	100%
Co-Products	12%	0%
Total	100%	100%
Lamstock Process		
Lumber, Rough Green	50.10%	85.98%
Chips, Green	24.40%	11.48%

Bark, Green	6.10%	0.61%
Hog Fuel, Green	13.80%	1.37%
Sawdust, Green	5.60%	0.56%
Total	100%	100%

Table 23 Life cycle stages contribution analysis per 1 m ^{3} Glued-Laminated Timber, PNW (mass and economic allocation)

Impact Category	Unit	Mass Allocation			Economic Allocation		
		Forestry Operations	Lamstock Production	Glulam Production	Forestry Operations	Lamstock Production	Glulam Production
Global warming	kg CO_2 eq.	13.13%	40.85%	46.02%	11.56%	44.24%	44.20%
Acidification	SO_2 eq.	17.15%	41.60%	41.25%	15.45%	43.98%	40.57%
Eutrophication	kg N eq.	32.45%	36.13%	31.42%	29.50%	39.31%	31.19%
Ozone Depletion	kg CFC-11 eq.	5.14%	8.96%	85.93%	4.63%	10.67%	84.67%
Smog	kg O_3 eq	26.26%	37.87%	35.87%	23.92%	40.43%	35.66%
Primary Energy		Forestry Operations	Lamstock Production	Glulam Production	Forestry Operations	Lamstock Production	Glulam Production
Total	MJ	4.08%	68.17%	27.75%	3.84%	68.23%	27.94%
Non-renewable fossil	MJ	12.61%	41.58%	45.81%	11.13%	44.73%	44.14%
Non-renewable nuclear	MJ	1.49%	42.29%	56.21%	1.32%	44.05%	54.62%
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	0.45%	32.37%	67.18%	0.33%	35.32%	64.33%
Renewable, biomass	MJ	0.00%	83.70%	16.30%	0.00%	83.52%	16.48%
Material Resources Consumption (non-fuel resources)		Forestry Operations	Lamstock Production	Glulam Production	Forestry Operations	Lamstock Production	Glulam Production
Non-renewable materials	kg	0.07%	0.15%	99.78%	0.07%	0.15%	99.78%
Renewable materials	kg	0.00%	53.73%	46.27%	0.00%	53.70%	46.30%
Fresh water	L	3.10%	82.75%	14.15%	2.90%	82.66%	14.45%
Waste generated		Forestry Operations	Lamstock Production	Glulam Production	Forestry Operations	Lamstock Production	Glulam Production
Solid waste	kg	2.64%	43.43%	53.93%	2.37%	44.77%	52.86%

9.3 Substance Contribution Analysis

The impact indicators presented in the LCIA results (Table 17) in this report do not show how each of the substance releases (Table 13) within each of the life cycle stages contributes to individual impact indicators. Highlighting particular substances can result in a more focused approach to making process improvements therefore saving time and money. Table 24 lists the level of contribution of the 3 main GHG emissions (fossil CO_2, CH_3, and N_2O) to global warming potential (GWP) of the three life cycle stages for glulam manufacturing. Both mass and economic allocation results are presented. The level of contribution for acidification and eutrophication are shown in Tables 25 and 26.

Table 24 Substance contribution analysis to Global Warming Potential (kg CO_2 eq.) by life cycle stage, total percent basis and values are displayed per 1 m^3

		Mass Allocation				Economic Allocation			
GWP substances	Compartment type	TOTAL	Forestry Operations	Lamstock	Glulam	TOTAL	Forestry Operations	Lamstock	Glulam
Total of all compartments		100.00%	15.19	47.26	53.24	100.00%	15.19	58.15	58.11
Carbon dioxide, fossil (CO_2)	Air	93.47%	14.50	43.83	49.80	93.57%	14.50	54.13	54.36
Methane (CH_4)	Air	5.94%	0.53	3.09	3.25	5.86%	0.53	3.63	3.54
Dinitrogen monoxide (N_2O)	Air	0.43%	0.10	0.23	0.17	0.43%	0.10	0.28	0.18
Remaining substances	Air	0.16%	0.05	0.11	0.02	0.15%	0.05	0.12	0.02

Table 25 Substance contribution analysis to Acidification (kg SO_2 eq.) by life cycle stage, total percent basis and values are displayed per 1 m^3

		Mass Allocation				Economic Allocation			
Substances	Compartment type	TOTAL	Forestry Operations	Lamstock	Glulam	TOTAL	Forestry Operations	Lamstock	Glulam
Total of all compartments		100.00%	0.209	0.507	0.503	100.00%	0.209	0.595	0.549
Sulfur dioxide	Air	43.92%	0.010	0.249	0.276	44.11%	0.010	0.285	0.301
Nitrogen oxides	Air	49.92%	0.184	0.233	0.192	49.58%	0.184	0.277	0.209
Ammonia	Air	0.40%	0.000	0.004	0.001	0.38%	0.000	0.004	0.001
Remaining substances	Air	5.76%	0.015	0.021	0.034	5.93%	0.015	0.028	0.037

Table 26 Substance contribution analysis to Eutrophication (kg N eq.) by life cycle stage, total percent basis and values are displayed per 1 m^3

		Mass Allocation				Economic Allocation			
Substances	Compartment type	TOTAL	Forestry Operations	Lamstock	Glulam	TOTAL	Forestry Operations	Lamstock	Glulam
Total of all compartments		100.00%	0.015	0.017	0.015	100.00%	0.015	0.020	0.016
Nitrogen oxides	air	82.66%	1.16E-02	1.47E-02	1.21E-02	82.85%	1.16E-02	1.75E-02	1.33E-02
Ammonia	air	0.66%	1.56E-05	2.40E-04	5.27E-05	0.63%	1.56E-05	2.49E-04	5.75E-05
BOD5, Biological Oxygen Demand	water	4.58%	1.55E-04	6.03E-04	1.38E-03	4.78%	1.55E-04	7.91E-04	1.50E-03
COD, Chemical Oxygen Demand	water	3.33%	2.94E-04	6.61E-04	5.95E-04	3.45%	2.94E-04	8.24E-04	6.49E-04
Phosphate	water	6.02%	2.76E-03	3.66E-05	6.17E-06	5.49%	2.76E-03	4.64E-05	6.74E-06
Ammonia	water	2.57%	2.47E-04	5.06E-04	4.43E-04	2.66%	2.47E-04	6.33E-04	4.83E-04
Other substances		0.19%	1.57E-07	6.85E-05	1.78E-05	0.13%	1.57E-07	4.91E-05	1.94E-05

9.4 Completeness, Sensitivity and Consistency Checks

Evaluating a LCA's completeness, sensitivity, and consistency can offer confidence and reliability of the LCA results. The completeness check process verifies whether information from the life cycle phases of a 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, lamstock production, and glulam 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, land, and final waste disposals. All input and output data were found to be complete and no data gaps were identified.

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 to this LCA to make certain consistency was applied to the assumptions made, methods used, models, data quality including data sources, and data accuracy, age, time-related coverage, technology, and geographical coverage.

Sensitivity analysis can be applied to the LCA to determine changes in results due to variations in assumptions, methods, and data. A sensitivity check was performed on this LCA contrasting the mass and economic allocation methods. This LCA used a mass allocation method, similar to previous LCA's on wood products. To stay within conformance with the updated PCR (FPInnovations 2015), an economic allocation was required on the data. In this instance, a mass allocation of emissions is being compared with an economic allocation of emissions based on the value of the end products in the glulam LCI. This allocation was also used for the lumber (lamstock) LCI outputs since lumber has the highest value of all the end products during that particular stage. It was assumed that the final glulam produced takes 100% of the environmental burdens since it is the only end product with any economic value. The difference in the allocation methodologies are shown in Table 27 below.

Table 27 Sensitivity analysis of mass allocation versus economic allocation methodologies

Impact Indicator	Mass	Economic	% Change
Global Warming	115.68	131.45	13.63%
Acidification Potential	1.2187	1.3525	10.98%
Eutrophication Potential	0.0466	0.0512	9.87%
Ozone Depletion Potential	1.35E-08	1.50E-08	10.66%
Smog Potential	24.935	27.378	9.80%

10. Conclusion, Limitations and Recommendations

The cradle to gate LCA for glued-laminated timbers includes the LCI of the forest resource (management, harvest and extraction), the LCI of lamstock (lumber manufacturing), and the LCI of glued-laminated timber production in the PNW. These LCIs rely on primary survey data and secondary data sources. The survey results in this study were representative of glued-laminated timber in the PNW region and their corresponding production processes. Timber volumes reported were consistent with trade association production data.

To produce one cubic meter of finished glulam in the PNW, it took 1.93 m^3 of roundwood. The roundwood produced 1.14 m^3 of lamstock for the production of 1 m^3 of glulam (oven dry mass without resin) and 72 kg of coproduct (sawdust, trimming, shavings). A small supplemental amount of wood fuel was purchased in the PNW for glulam production, but mostly self-generated fuel was used in both the

glulam manufacturing and lamstock manufacturing processes. Self-generated fuel used in the production of the lamstock material is reported in more detail in the PNW lumber manufacturing report (Milota 2015).

Emissions from the forest resources LCI are small relative to manufacturing emissions. The glulam manufacturing process has some onsite emissions from end jointing and face bonding of laminations because of the resins involved. Glulam manufacturing produced a larger percentage of the entire system emissions than lamstock production and consequently consumed the highest level of energy inputs. Most of the energy consumed during the glulam production stage was from non-renewable fossil fuels (53%). The total system (forestry, lamstock, and glulam processes) used renewable biomass for 63 percent of its energy needs in the PNW which was a significant increase since the last report (Puettmann et al. 2013).

The TRACI impact method does not count the contribution of wood-derived CO_2 emissions from burning wood fuel in the boiler towards the global warming impact estimate. This is consistent with the current U.S. EPA ruling on wood emissions from stationary sources, which considers the CO_2 taken up by the forest ecosystem when the tree grew as balancing any CO_2 emissions when it is burned. Under the TRACI method, combustion of fossil fuels generates CO_2 and other air emissions that contribute to the global warming impact. Using the TRACI method, 116 kg CO_2e were released in the production of 1 m^3 of PNW glulam, whereas the same 1 m^3 of glulam stores 938 kg CO_2e.

Carbon is released as CO_2 during all life cycle stages. The majority of the emissions are released during the production of glued-laminated timbers. This is consistent with most wood product manufacturing life cycles. In summary, glulam attains a positive carbon balance (sequesters carbon) in its production. This type of information is valuable for industry members trying to promote wood based products and users that are looking for environmentally friendly products.

Limitations to this study are related to the data provided to us by manufacturers. Use of fork lifts and equipment that utilized gasoline and other fuels may have not been accurately reported; resulting in under reporting of fuel use on site. Variability in amount of usage could contribute to manufacturers not being able to track these numbers.

Recommendations for future LCA studies would be to follow the amount of co-products (trimmings and shavings) being used for fuel in a boiler, and to see how this affects environmental impacts. The use of biogenic derived fuels replaces fossil fuel use and would lessen the need for electricity or fossil fuels for heat generation. It would also reduce the current waste stream of any wood waste to landfills or being transported offsite. Focusing more on the impacts of cold cure techniques versus radio frequency curing could provide further indications if the reduced amount of resin during radio frequency curing offsets the reduction in electricity used from cold curing. Electricity and fuel use for each individual process within the glulam manufacturing stage was not available, so there remains some uncertainty to which processes consumed the most energy.

11. Critical Review

11.1 Internal Review

An internal review of this report was conducted by Dr. Maureen Puettmann, WoodLife Environmental Consultants. The purpose of the internal review is to check for errors and for conformance with the PCR prior to external review.

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 (FPInnovations 2015).

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13. Appendix I: Economic Allocation

Economic allocation of environmental burdens is another methodology that attaches a certain percentage of the air, water, or land emissions based on the average market value of all end products or processes at the gate. The declared unit for this report is 1 m^3 of finished glulam at the gate, wrapped and ready for shipment. The economic allocation is determined by the value of the products that have been produced at this stage of the life cycle. The only end products in this system process are the finished glulam, minimal waste and scraps that are used for hog fuel. Intrinsic value cannot be placed upon the other co-products and therefore 100 percent of the environmental burdens are allocated to the finished 1 m^3 of PNW glulam.

13.1 Cradle to Gate LCI results – Economic Allocation

Life-cycle inventory results for glulam are presented by three life cycle stages, 1) forestry operations, 2) lamstock production, and glulam production (Table 28 – Table 30). Results in Table 29 and 30 show values to 10^{-4} kg/m^3. A full list of all emissions appears in appendix II (Tables 35 and 36).

Most of the raw material consumption used for energy production occurs during either glulam or lamstock manufacturing with only a miniscule portion arising from forestry operations (Table 28). Table 28 lists the raw material consumption of energy inputs per m^3 of glulam in the PNW. For fossil fuels, coal is consumed in the largest amounts with 21.79 kg/m^3. Coal is mainly used for off-site electricity production. The highest consumption rates are for wood fuel with all processes consuming a total of 159.89 kg/m^3. Wood fuel is used for on-site thermal energy and for lumber drying.

Table 28 Primary energy inputs to produce 1 m^3 of Glued-Laminated Timber, PNW (economic allocation)

Fuel	Total	Forestry Operations	Lamstock Production	Glulam Production
	kg/m^3			
Coal, in ground kg	2.18E+01	2.63E-01	9.22E+00	1.23E+01
Gas, natural, in ground kg	1.23E+01	2.55E-01	6.18E+00	5.86E+00
Oil, Crude, in ground kg	1.55E+01	4.46E+00	6.39E+00	4.62E+00
Uranium oxide, in ore kg	4.59E-04	6.16E-06	2.05E-04	2.48E-04
Total Non-Renewable	4.95E+01	4.98E+00	2.18E+01	2.28E+01
Wood waste kg	1.60E+02	0.00E+00	1.34E+02	2.63E+01

Table 29 lists the cradle to gate air emissions generated as a result of glulam production. Glulam manufacturing generates air emissions like CO_2 from electricity powered equipment during the jointing, bonding, planning, and finish/fabrication stages. Production also generates particulate emissions like PM_{10} (less than 10 µm in size) during resizing, drying, trimming, and planing. Air emissions including Hazardous Air Pollutants (HAPs)s are a result of resin use during face bonding and curing and particulate matter during resizing (jointing, planning, finishing). Recorded emissions of formaldehyde and methanol are used as a measure of the amount of Hazardous Air Pollutants (HAPs).

Mills reported acetaldehyde, acrolein, formaldehyde, methanol, phenol, propionaldehyde (or propanal), and VOCs as a measure of HAPs released.

Table 29 Emissions to air released per 1 m^3 of Glued-Laminated Timber, PNW (economic allocation)

Air Emission[1]	Total	Forestry Operations	Lamstock Production	Glulam Production
	kg/m^3			
Acetaldehyde	0.0244	0.0001	0.0243	0.0000
Acrolein	0.0011	0.0000	0.0011	0.0000
Aldehydes, unspecified	0.0008	0.0002	0.0003	0.0003
Ammonia	0.0027	0.0001	0.0021	0.0005
Benzene	0.0002	0.0001	0.0000	0.0000
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0042	0.0001	0.0022	0.0020
Carbon dioxide	0.1134	0.0534	0.0505	0.0094
Carbon dioxide, biogenic	278.06	0.012	233.64	44.40
Carbon dioxide, fossil	122.99	14.50	54.13	54.36
Carbon monoxide	0.0070	0.0000	0.0002	0.0068
Carbon monoxide, biogenic	0.5515	0.0000	0.4279	0.1236
Carbon monoxide, fossil	0.3942	0.1318	0.1469	0.1155
Dinitrogen monoxide	0.0019	0.0003	0.0009	0.0006
Formaldehyde	0.0268	0.0001	0.0023	0.0245
HAPs	0.3436	0.0000	0.0008	0.3428
Heat, waste	0.5691	0.0000	0.4786	0.0904
Hydrocarbons, unspecified	0.0001	0.0000	0.0001	0.0001
Hydrogen chloride	0.0115	0.0001	0.0050	0.0064
Hydrogen fluoride	0.0014	0.0000	0.0006	0.0008
Isoprene	0.0165	0.0003	0.0054	0.0108
Magnesium	0.0001	0.0000	0.0000	0.0001
Methane	0.2806	0.0198	0.1311	0.1297
Methane, biogenic	0.0035	0.0000	0.0029	0.0006
Methane, fossil	0.0275	0.0015	0.0139	0.0121
Methanol	0.0202	0.0000	0.0200	0.0002
Nitrogen oxides	0.9580	0.2628	0.3960	0.2993
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0381	0.0088	0.0133	0.0160
Organic substances, unspecified	0.0030	0.0000	0.0005	0.0025
Particulates, < 10 um	0.1344	0.0000	0.0623	0.0721
Particulates, < 2.5 um	0.0310	0.0000	0.0274	0.0035
Particulates, > 10 um	0.0245	0.0000	0.0245	0.0001
Particulates, > 2.5 um, and < 10um	0.0199	0.0081	0.0062	0.0057
Particulates, unspecified	0.0353	0.0014	0.0148	0.0190
Phenol	0.6130	0.0000	0.0001	0.6129
Propanal	0.0002	0.0000	0.0002	0.0000
Propene	0.0003	0.0002	0.0001	0.0000
Radionuclides (Including Radon)	0.0007	0.0000	0.0003	0.0004

Air Emission[1]	Total	Forestry Operations	Lamstock Production	Glulam Production
Sulfur dioxide	0.5967	0.0100	0.2854	0.3012
Sulfur monoxide	0.0345	0.0146	0.0052	0.0147
Sulfur oxides	0.0333	0.0000	0.0178	0.0156
VOC, volatile organic compounds	0.3664	0.0071	0.2748	0.0846
Wood (dust)	0.1040	0.0000	0.0900	0.0141

[1] Due to large amount of air emissions, total emissions less than 10^{-4} are not shown. A complete list can be found in Appendix II.

Most of the waterborne emissions reported are produced on-site as shown in Table 30. Unspecified suspended solids are a result of upstream processes like natural gas production.

Table 30 Emissions to water released per 1 m^3 of Glued-Laminated Timber, PNW (economic allocation)

Water Emission[1]	Total	Forestry Operations	Lamstock Production	Glulam Production
	kg/m^3			
Aluminium	0.0060	0.0014	0.0026	0.0020
Ammonia	0.0017	0.0003	0.0008	0.0006
Ammonia, as N	0.0002	0.0000	0.0000	0.0002
Barium	0.0820	0.0198	0.0358	0.0263
Benzene	0.0002	0.0000	0.0001	0.0001
Benzoic acid	0.0001	0.0000	0.0001	0.0000
BOD5, Biological Oxygen Demand	0.0490	0.0031	0.0158	0.0300
Boron	0.0004	0.0001	0.0002	0.0001
Bromide	0.0232	0.0036	0.0109	0.0087
Calcium	0.2440	0.0546	0.0613	0.1281
Calcium, ion	0.1043	0.0000	0.1015	0.0028
Chloride	3.9158	0.6144	1.8294	1.4721
Chromium	0.0001	0.0000	0.0001	0.0000
COD, Chemical Oxygen Demand	0.0353	0.0059	0.0165	0.0130
Fluoride	0.0017	0.0015	0.0001	0.0000
Formaldehyde	0.0027	0.0000	0.0000	0.0027
Iron	0.0133	0.0029	0.0059	0.0045
Lithium	0.0425	0.0013	0.0148	0.0265
Lithium, ion	0.0158	0.0000	0.0153	0.0005
Magnesium	0.0681	0.0107	0.0318	0.0256
Manganese	0.0003	0.0000	0.0001	0.0001
Oils, unspecified	0.0029	0.0004	0.0013	0.0012
Phenol	0.0009	0.0000	0.0000	0.0009
Phosphate	0.0012	0.0012	0.0000	0.0000
Silver	0.0002	0.0000	0.0001	0.0001
Sodium	0.7735	0.1732	0.1942	0.4060
Sodium, ion	0.3306	0.0000	0.3216	0.0090
Solids, inorganic	0.0004	0.0000	0.0000	0.0004
Solved solids	1.4625	0.0000	1.4068	0.0556

Water Emission[1]	Total	Forestry Operations	Lamstock Production	Glulam Production
Strontium	0.0059	0.0009	0.0028	0.0022
Sulfate	0.0191	0.0014	0.0084	0.0093
Sulfur	0.0003	0.0000	0.0001	0.0001
Suspended solids, inorganic	0.0019	0.0000	0.0000	0.0019
Suspended solids, unspecified	3.5715	0.8022	0.9327	1.8366
Toluene	0.0002	0.0000	0.0001	0.0001
Waste water/m3	95.1951	0.0000	0.0001	95.1950
Zinc	0.0001	0.0000	0.0001	0.0000

[1] Due to large amount of air emissions, total emissions less than 10^{-4} are not shown. A complete list can be found in Appendix II.

13.2 Life Cycle Impact Assessment – Economic Allocation

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. All impacts are presented as equals. 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 31 provides the environmental impact by category for PNW glulam using an economic allocation. 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 31). Comparing glulam production to the total system environmental impact of question, the contribution of that process provides a percent of the total burden. For GWP, 44.2 percent of the CO_2 eq. emissions come from producing glulam in the PNW. Similar results are presented for acidification, eutrophication, and smog, representing 40.6, 31.2, and 35.7 percent contributions from glulam, respectively.

Overall, the manufacture of PNW glulam is 61 percent energy self-sufficient with its use of renewable biomass for thermal energy and lamstock drying. Energy from non-renewable fossil fuels, non-renewable nuclear and renewable energy represented 34.1, 2.8, and 2.0 percent of the total primary energy, respectively. Glulam manufacturing (includes all fuel and resin upstream processes) consumes 27.9 percent of the total primary energy consumption using an economic allocation.

Table 31 Economic allocation methodology for the environmental performance of 1 m^3 Glued-Laminated Timber, PNW

Impact category	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Global warming potential (GWP)	kg CO_2 equiv	131.45	15.19	58.15	58.11
Acidification Potential	kg SO_2 equiv	1.353	0.209	0.595	0.549
Eutrophication Potential	kg N equiv	0.051	0.015	0.020	0.016
Ozone depletion Potential	kg CFC-11 equiv	1.50E-08	6.94E-10	1.60E-09	1.27E-08
Smog Potential	kg O_3 equiv	27.38	6.55	11.07	9.76
Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Total Primary Energy Consumption	MJ	5,472.16	210.04	3,733.40	1,528.71
Non-renewable fossil	MJ	1,865.71	207.63	834.54	823.54
Non-renewable nuclear	MJ	154.22	2.04	67.93	84.24
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	108.62	0.36	38.37	69.88
Renewable, biomass	MJ	3,343.61	0.00	2,792.56	551.05
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Non-renewable materials	kg	9.374	0.007	0.014	9.353
Renewable materials	kg	510.70	0	592.42	510.70
Fresh water	L	489.22	14.17	404.38	70.67
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Lamstock Production**	**Glulam Production**
Solid waste	kg	9.84	0.23	4.41	5.20

13.3 Carbon – Economic Allocation

Using the same method applied for mass allocation, 131 kg CO_2e were released in the production of 1 m^3 of PNW glulam. That same 1 m^3 of glulam stores 255 kg of carbon[7] or 938 kg CO_2 eq.[8], resulting in more carbon storage in the product then released during manufacturing (cradle to gate) (Table 32). There was a 15 kg CO_2 eq. difference between mass and economic allocation methods.

Table 32 Carbon balance per 1 m^3 of Glued-Laminated Timber, PNW (economic allocation)

	kg CO_2 equivalent
Released forestry operations	15.19
Released lumber manufacturing	58.15
Released glulam manufacturing	58.11
CO_2 eq. stored in product	937.69

[7] Assuming a 50% carbon content

[8] 511 OD kg of wood in glulam × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO_2/kmole/12 kg carbon/kmole) = 937.69 kg CO_2 eq.

14. Appendix II: Emissions

14.1 Cradle to Gate LCI Air Emissions (mass allocation)

Table 33 Air emissions released per 1 m^3 of Glued-Laminated Timbers, PNW (mass allocation)

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
2,4-D	kg	2.24E-11	x	1.07E-12	2.14E-11
2-Chloroacetophenone	kg	4.15E-11	3.24E-12	1.97E-11	1.85E-11
2-Methyl-4-chlorophenoxyacetic acid	kg	4.18E-13	x	1.99E-14	3.98E-13
5-methyl Chrysene	kg	1.82E-10	2.53E-12	7.45E-11	1.05E-10
Acenaphthene	kg	4.22E-09	5.87E-11	1.73E-09	2.44E-09
Acenaphthylene	kg	2.07E-09	2.88E-11	8.46E-10	1.20E-09
Acetaldehyde	kg	2.40E-02	6.04E-05	2.39E-02	3.64E-05
Acetochlor	kg	3.11E-10	x	1.48E-11	2.96E-10
Acetophenone	kg	8.89E-11	6.94E-12	4.23E-11	3.96E-11
Acrolein	kg	1.12E-03	7.31E-06	1.10E-03	2.14E-05
Alachlor	kg	3.06E-11	x	1.46E-12	2.91E-11
Aldehydes, unspecified	kg	6.79E-04	1.81E-04	1.89E-04	3.08E-04
Ammonia	kg	2.60E-03	1.32E-04	2.02E-03	4.44E-04
Ammonium chloride	kg	2.16E-05	3.27E-07	9.28E-06	1.20E-05
Anthracene	kg	1.74E-09	2.42E-11	7.11E-10	1.00E-09
Antimony	kg	1.56E-07	2.07E-09	6.09E-08	9.31E-08
Arsenic	kg	3.55E-06	6.55E-08	1.45E-06	2.03E-06
Atrazine	kg	6.06E-10	x	2.88E-11	5.77E-10
Barium	kg	2.22E-08	x	2.22E-08	x
Bentazone	kg	2.47E-12	x	1.18E-13	2.35E-12
Benzene	kg	1.42E-04	7.36E-05	4.28E-05	2.56E-05
Benzene, chloro-	kg	1.30E-10	1.02E-11	6.20E-11	5.81E-11
Benzene, ethyl-	kg	1.16E-08	4.35E-11	1.10E-08	5.13E-10
Benzo(a)anthracene	kg	6.63E-10	9.20E-12	2.71E-10	3.83E-10
Benzo(a)pyrene	kg	3.15E-10	4.37E-12	1.29E-10	1.82E-10
Benzo(b,j,k)fluoranthene	kg	9.11E-10	1.27E-11	3.72E-10	5.26E-10
Benzo(g,h,i)perylene	kg	1.81E-10	3.11E-12	5.45E-11	1.23E-10
Benzo(ghi)perylene	kg	4.30E-11	x	3.69E-11	6.15E-12
Benzyl chloride	kg	4.15E-09	3.24E-10	1.97E-09	1.85E-09
Beryllium	kg	1.89E-07	3.22E-09	7.69E-08	1.09E-07
Biphenyl	kg	1.41E-08	1.96E-10	5.75E-09	8.13E-09
Bromoform	kg	2.31E-10	1.81E-11	1.10E-10	1.03E-10
Bromoxynil	kg	5.42E-12	x	2.58E-13	5.16E-12
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	3.81E-03	8.97E-05	1.93E-03	1.79E-03
Butadiene	kg	4.35E-06	3.08E-06	6.50E-07	6.27E-07
Cadmium	kg	7.26E-07	1.60E-08	3.17E-07	3.94E-07
Carbofuran	kg	4.63E-12	x	2.20E-13	4.41E-12
Carbon dioxide	kg	1.11E-01	5.34E-02	4.93E-02	8.63E-03

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Carbon dioxide, biogenic	kg	2.69E+02	1.15E-02	2.29E+02	4.07E+01
Carbon dioxide, fossil	kg	1.08E+02	1.45E+01	4.38E+01	4.98E+01
Carbon disulfide	kg	1.75E-07	6.02E-11	1.74E-07	3.43E-10
Carbon monoxide	kg	6.42E-03	6.32E-06	1.44E-04	6.27E-03
Carbon monoxide, biogenic	kg	5.32E-01	x	4.19E-01	1.13E-01
Carbon monoxide, fossil	kg	3.46E-01	1.32E-01	1.09E-01	1.06E-01
Chloride	kg	4.41E-10	8.80E-12	1.30E-10	3.03E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	5.49E-09	x	2.61E-09	2.88E-09
Chlorine	kg	8.91E-08	x	4.03E-08	4.88E-08
Chloroform	kg	3.50E-10	2.73E-11	1.66E-10	1.56E-10
Chlorpyrifos	kg	3.56E-11	x	1.70E-12	3.39E-11
Chromium	kg	2.57E-06	4.70E-08	1.07E-06	1.45E-06
Chromium VI	kg	6.54E-07	9.09E-09	2.67E-07	3.78E-07
Chrysene	kg	8.28E-10	1.15E-11	3.38E-10	4.78E-10
Cobalt	kg	1.19E-06	8.95E-08	4.95E-07	6.05E-07
Copper	kg	1.80E-08	8.07E-10	7.47E-09	9.71E-09
Cumene	kg	1.62E-07	2.45E-12	1.62E-07	1.40E-11
Cyanazine	kg	5.34E-12	x	2.54E-13	5.09E-12
Cyanide	kg	1.48E-08	1.16E-09	7.05E-09	6.60E-09
Dicamba	kg	3.15E-11	x	1.50E-12	3.00E-11
Dimethenamid	kg	7.43E-11	x	3.54E-12	7.08E-11
Dimethyl ether	kg	3.05E-06	x	1.17E-09	3.05E-06
Dinitrogen monoxide	kg	1.67E-03	3.27E-04	7.83E-04	5.63E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	3.14E-11	2.89E-13	4.19E-12	2.69E-11
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	3.68E-14	x	3.60E-20	3.68E-14
Dipropylthiocarbamic acid S-ethyl ester	kg	5.09E-11	x	2.42E-12	4.85E-11
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1.34E-09	4.28E-10	4.85E-10	4.31E-10
Ethane, 1,2-dibromo-	kg	8.00E-12	5.56E-13	4.25E-12	3.20E-12
Ethane, 1,2-dichloro-	kg	2.37E-10	1.85E-11	1.13E-10	1.06E-10
Ethane, chloro-	kg	2.49E-10	1.94E-11	1.18E-10	1.11E-10
Ethene, tetrachloro-	kg	3.68E-07	5.93E-09	1.48E-07	2.14E-07
Ethene, trichloro-	kg	6.60E-09	x	2.11E-11	6.58E-09
Ethylene oxide	kg	5.78E-08	x	5.59E-08	1.84E-09
Fluoranthene	kg	5.88E-09	8.17E-11	2.40E-09	3.40E-09
Fluorene	kg	7.54E-09	1.05E-10	3.08E-09	4.35E-09
Fluoride	kg	1.37E-06	6.33E-07	3.42E-07	3.91E-07
Formaldehyde	kg	2.47E-02	9.36E-05	2.22E-03	2.24E-02
Furan	kg	4.04E-11	5.25E-13	1.62E-11	2.36E-11
Glyphosate	kg	6.68E-11	x	3.18E-12	6.36E-11
HAPs	kg	3.15E-01	x	8.12E-04	3.14E-01
HAPS, unspecified	kg	1.27E-05	x	1.27E-05	x
Heat, waste	MJ	5.52E-01	x	4.69E-01	8.29E-02

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Hexane	kg	4.02E-07	3.10E-11	4.02E-07	1.77E-10
Hydrazine, methyl-	kg	1.01E-09	7.87E-11	4.79E-10	4.49E-10
Hydrocarbons, unspecified	kg	1.25E-04	1.89E-06	5.36E-05	6.93E-05
Hydrogen	kg	1.83E-08	x	1.50E-08	3.25E-09
Hydrogen chloride	kg	1.02E-02	1.47E-04	4.23E-03	5.82E-03
Hydrogen fluoride	kg	1.25E-03	1.72E-05	5.08E-04	7.22E-04
Hydrogen sulfide	kg	1.43E-11	2.84E-13	4.19E-12	9.78E-12
Indeno(1,2,3-cd)pyrene	kg	5.05E-10	7.02E-12	2.06E-10	2.92E-10
Iron	kg	2.16E-08	x	2.16E-08	x
Isophorone	kg	3.44E-09	2.69E-10	1.64E-09	1.53E-09
Isoprene	kg	1.45E-02	2.88E-04	4.25E-03	9.92E-03
Kerosene	kg	1.05E-05	1.56E-07	4.45E-06	5.94E-06
Lead	kg	3.04E-05	7.30E-08	2.42E-05	6.14E-06
Magnesium	kg	9.11E-05	1.27E-06	3.72E-05	5.26E-05
Manganese	kg	6.67E-06	9.74E-08	4.06E-06	2.52E-06
Mercaptans, unspecified	kg	1.27E-06	9.98E-08	6.02E-07	5.70E-07
Mercury	kg	1.07E-06	1.31E-08	5.65E-07	4.93E-07
Metals, unspecified	kg	7.87E-07	3.26E-14	2.95E-08	7.57E-07
Methane, biogenic	kg	3.39E-03	x	2.88E-03	5.10E-04
Methane, bromo-, Halon 1001	kg	9.48E-10	7.41E-11	4.51E-10	4.23E-10
Methane, chlorodifluoro-, HCFC-22	kg	4.80E-13	x	4.65E-13	1.53E-14
Methane, chlorotrifluoro-, CFC-13	kg	4.56E-12	x	4.41E-12	1.45E-13
Methane, dichloro-, HCC-30	kg	2.79E-06	9.99E-08	1.14E-06	1.55E-06
Methane, dichlorodifluoro-, CFC-12	kg	1.52E-09	5.18E-10	5.31E-10	4.68E-10
Methane, fossil	kg	2.75E-01	2.14E-02	1.23E-01	1.30E-01
Methane, monochloro-, R-40	kg	3.14E-09	2.45E-10	1.49E-09	1.40E-09
Methane, tetrachloro-, CFC-10	kg	1.47E-08	5.18E-11	1.26E-10	1.45E-08
Methanol	kg	1.99E-02	x	1.97E-02	2.26E-04
Methyl ethyl ketone	kg	2.31E-09	1.81E-10	1.10E-09	1.03E-09
Methyl methacrylate	kg	1.18E-10	9.26E-12	5.64E-11	5.28E-11
Metolachlor	kg	2.46E-10	x	1.17E-11	2.34E-10
Metribuzin	kg	1.14E-12	x	5.42E-14	1.08E-12
Naphthalene	kg	9.12E-06	1.86E-08	7.63E-06	1.47E-06
Nickel	kg	7.58E-06	1.13E-06	3.26E-06	3.19E-06
Nitrogen oxides	kg	8.69E-01	2.63E-01	3.32E-01	2.74E-01
Nitrogen, total	kg	1.22E-05	1.21E-05	1.53E-07	2.86E-11
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	3.30E-02	8.78E-03	9.63E-03	1.46E-02
N-Nitrodimethylamine	kg	1.48E-09	x	4.72E-12	1.47E-09
Organic acids	kg	7.95E-08	1.20E-09	3.41E-08	4.42E-08
Organic substances, unspecified	kg	2.78E-03	7.14E-07	5.23E-04	2.26E-03
Other Organic	kg	3.22E-05	x	2.73E-05	4.84E-06
PAH, polycyclic aromatic hydrocarbons	kg	1.87E-05	1.32E-05	2.77E-06	2.69E-06
Paraquat	kg	4.97E-12	x	2.37E-13	4.73E-12

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Parathion, methyl	kg	3.75E-12	x	1.79E-13	3.58E-12
Particulates	kg	2.35E-05	x	5.72E-10	2.35E-05
Particulates, < 10 um	kg	1.27E-01	x	6.10E-02	6.61E-02
Particulates, < 2.5 um	kg	2.83E-02	x	2.51E-02	3.24E-03
Particulates, > 10 um	kg	1.91E-02	x	1.91E-02	5.83E-05
Particulates, > 2.5 um, and < 10um	kg	1.81E-02	8.06E-03	4.84E-03	5.18E-03
Particulates, unspecified	kg	3.12E-02	1.45E-03	1.23E-02	1.74E-02
Pendimethalin	kg	2.55E-11	x	1.22E-12	2.43E-11
Permethrin	kg	2.30E-12	x	1.09E-13	2.19E-12
Phenanthrene	kg	2.24E-08	3.11E-10	9.14E-09	1.29E-08
Phenol	kg	5.62E-01	7.41E-12	1.04E-04	5.62E-01
Phenols, unspecified	kg	4.01E-07	5.19E-08	1.73E-07	1.77E-07
Phorate	kg	1.18E-12	x	5.60E-14	1.12E-12
Phosphate	kg	2.80E-07	2.77E-07	3.49E-09	x
Phthalate, dioctyl-	kg	4.33E-10	3.38E-11	2.06E-10	1.93E-10
Polycyclic organic matter, unspecified	kg	1.16E-11	x	1.12E-11	3.69E-13
Potassium	kg	3.82E-06	x	3.82E-06	x
Propanal	kg	1.84E-04	1.76E-10	1.83E-04	1.18E-06
Propene	kg	2.87E-04	2.03E-04	4.29E-05	4.14E-05
Propylene oxide	kg	2.43E-09	x	2.43E-09	x
Pyrene	kg	2.73E-09	3.80E-11	1.12E-09	1.58E-09
Radionuclides (Including Radon)	kg	5.79E-04	8.75E-06	2.49E-04	3.22E-04
Selenium	kg	1.09E-05	1.60E-07	4.44E-06	6.31E-06
Simazine	kg	1.61E-11	x	7.68E-13	1.54E-11
Sodium	kg	8.82E-08	x	8.82E-08	x
Styrene	kg	1.48E-10	1.16E-11	7.05E-11	6.60E-11
Sulfur	kg	7.54E-08	0x	3.59E-09	7.19E-08
Sulfur dioxide	kg	5.35E-01	1.00E-02	2.49E-01	2.76E-01
Sulfur monoxide	kg	3.21E-02	1.46E-02	4.05E-03	1.34E-02
Sulfur oxides	kg	2.71E-02	x	1.29E-02	1.43E-02
Sulfur, total reduced	kg	2.73E-07	x	2.73E-07	x
Sulfuric acid, dimethyl ester	kg	2.84E-10	2.22E-11	1.35E-10	1.27E-10
Tar	kg	4.96E-10	9.90E-12	1.46E-10	3.40E-10
t-Butyl methyl ether	kg	2.07E-10	1.62E-11	9.87E-11	9.24E-11
Terbufos	kg	4.01E-11	x	1.91E-12	3.82E-11
TOC, Total Organic Carbon	kg	5.85E-08	x	2.79E-09	5.57E-08
Toluene	kg	4.57E-05	3.22E-05	6.91E-06	6.56E-06
Toluene, 2,4-dinitro-	kg	1.66E-12	1.30E-13	7.90E-13	7.40E-13
Trichloroethane	kg	5.47E-08	x	5.47E-08	x
Vinyl acetate	kg	4.50E-11	3.52E-12	2.14E-11	2.01E-11
VOC, volatile organic compounds	kg	3.52E-01	7.06E-03	2.67E-01	7.75E-02
Wood (dust)	kg	9.66E-02	x	8.37E-02	1.29E-02
Xylene	kg	3.18E-05	2.24E-05	4.80E-06	4.57E-06
Zinc	kg	2.60E-07	2.24E-07	2.94E-08	6.47E-09

14.2 Cradle to Gate LCI Water Emissions (mass allocation)

Table 34 Water emissions release per 1 m^3 of Glued- Laminated Timbers, PNW (mass allocation)

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
2,4-D	kg	9.61E-13	x	4.57E-14	9.15E-13
2-Hexanone	kg	6.23E-07	1.11E-07	2.68E-07	2.44E-07
2-Methyl-4-chlorophenoxyacetic acid	kg	1.79E-14	x	8.53E-16	1.71E-14
2-Propanol	kg	5.44E-10	x	2.56E-10	2.88E-10
4-Methyl-2-pentanone	kg	4.01E-07	7.15E-08	1.73E-07	1.57E-07
Acetaldehyde	kg	6.08E-08	x	5.89E-08	1.93E-09
Acetochlor	kg	1.33E-11	x	6.34E-13	1.27E-11
Acetone	kg	9.54E-07	1.70E-07	4.11E-07	3.73E-07
Acidity, unspecified	kg	2.06E-10	x	3.81E-13	2.05E-10
Acids, unspecified	kg	1.70E-07	1.85E-10	1.26E-07	4.38E-08
Alachlor	kg	1.31E-12	x	6.24E-14	1.25E-12
Aluminium	kg	5.24E-03	1.45E-03	1.99E-03	1.80E-03
Aluminum	kg	1.03E-06	x	1.03E-06	x
Ammonia	kg	1.53E-03	3.17E-04	6.49E-04	5.68E-04
Ammonia, as N	kg	1.75E-04	9.28E-11	1.37E-09	1.75E-04
Ammonium, ion	kg	1.08E-04	6.99E-08	8.58E-05	2.19E-05
Antimony	kg	3.15E-06	9.01E-07	1.19E-06	1.06E-06
Arsenic	kg	1.77E-05	5.16E-06	3.64E-06	8.92E-06
Arsenic, ion	kg	6.61E-06	x	6.41E-06	2.04E-07
Atrazine	kg	2.60E-11	x	1.24E-12	2.47E-11
Barium	kg	7.09E-02	1.98E-02	2.70E-02	2.41E-02
Bentazone	kg	1.06E-13	x	5.04E-15	1.01E-13
Benzene	kg	1.60E-04	2.85E-05	6.89E-05	6.26E-05
Benzene, 1-methyl-4-(1-methylethyl)-	kg	9.53E-09	1.70E-09	4.10E-09	3.73E-09
Benzene, ethyl-	kg	9.00E-06	1.61E-06	3.88E-06	3.52E-06
Benzene, pentamethyl-	kg	7.15E-09	1.27E-09	3.08E-09	2.80E-09
Benzenes, alkylated, unspecified	kg	2.76E-06	7.91E-07	1.04E-06	9.30E-07
Benzo(a)pyrene	kg	3.24E-08	x	2.93E-08	3.14E-09
Benzoic acid	kg	9.68E-05	1.73E-05	4.17E-05	3.79E-05
Beryllium	kg	1.21E-06	2.58E-07	5.01E-07	4.53E-07
Biphenyl	kg	1.79E-07	5.12E-08	6.75E-08	6.02E-08
BOD5, Biological Oxygen Demand	kg	4.27E-02	3.11E-03	1.21E-02	2.75E-02
Boron	kg	3.18E-04	5.34E-05	1.29E-04	1.36E-04
Bromide	kg	2.04E-02	3.64E-03	8.80E-03	8.00E-03
Bromoxynil	kg	1.40E-13	x	6.67E-15	1.33E-13
Cadmium	kg	2.74E-06	8.59E-07	5.46E-07	1.33E-06
Cadmium, ion	kg	1.66E-06	x	9.50E-07	7.06E-07
Calcium	kg	2.21E-01	5.46E-02	4.90E-02	1.17E-01
Calcium, ion	kg	8.56E-02	x	8.30E-02	2.59E-03
Carbofuran	kg	1.98E-13	x	9.45E-15	1.89E-13
CFCs, unspecified	kg	5.44E-10	x	2.56E-10	2.88E-10

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
Chloride	kg	3.45E+00	6.14E-01	1.48E+00	1.35E+00
Chlorpyrifos	kg	1.53E-12	x	7.27E-14	1.45E-12
Chromate	kg	1.11E-08	x	1.95E-11	1.11E-08
Chromium	kg	1.13E-04	3.87E-05	3.89E-05	3.49E-05
Chromium III	kg	2.29E-05	3.04E-06	6.27E-06	1.36E-05
Chromium VI	kg	4.67E-07	1.60E-07	1.64E-07	1.44E-07
Chromium, ion	kg	9.10E-06	x	8.82E-06	2.76E-07
Cobalt	kg	2.11E-06	3.77E-07	9.10E-07	8.27E-07
COD, Chemical Oxygen Demand	kg	3.10E-02	5.89E-03	1.32E-02	1.19E-02
Copper	kg	1.84E-05	5.16E-06	3.78E-06	9.44E-06
Copper, ion	kg	6.56E-06	x	6.25E-06	3.07E-07
Cumene	kg	3.89E-07	x	3.89E-07	x
Cyanazine	kg	2.29E-13	x	1.09E-14	2.18E-13
Cyanide	kg	3.72E-06	1.23E-09	3.35E-06	3.63E-07
Decane	kg	2.78E-06	4.96E-07	1.20E-06	1.09E-06
Detergent, oil	kg	8.75E-05	1.44E-05	3.83E-05	3.48E-05
Dibenzofuran	kg	1.81E-08	3.23E-09	7.81E-09	7.10E-09
Dibenzothiophene	kg	1.52E-08	2.78E-09	6.54E-09	5.94E-09
Dicamba	kg	1.35E-12	x	6.42E-14	1.28E-12
Dimethenamid	kg	3.18E-12	x	1.52E-13	3.03E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	1.32E-12	x	6.27E-14	1.25E-12
Disulfoton	kg	7.86E-14	x	3.74E-15	7.48E-14
Diuron	kg	2.21E-14	x	1.05E-15	2.10E-14
DOC, Dissolved Organic Carbon	kg	7.17E-07	5.67E-13	7.17E-07	1.95E-11
Docosane	kg	1.02E-07	1.82E-08	4.39E-08	3.99E-08
Dodecane	kg	5.28E-06	9.41E-07	2.27E-06	2.06E-06
Eicosane	kg	1.45E-06	2.59E-07	6.25E-07	5.68E-07
Fluorene	kg	1.14E-12	x	1.10E-12	3.62E-14
Fluorene, 1-methyl-	kg	1.09E-08	1.94E-09	4.67E-09	4.25E-09
Fluorenes, alkylated, unspecified	kg	1.60E-07	4.58E-08	6.04E-08	5.39E-08
Fluoride	kg	1.64E-03	1.54E-03	5.27E-05	4.26E-05
Fluorine	kg	8.22E-08	2.26E-08	3.15E-08	2.81E-08
Formaldehyde	kg	2.46E-03	x	x	2.46E-03
Furan	kg	9.40E-12	x	9.40E-12	x
Glyphosate	kg	2.86E-12	x	1.36E-13	2.73E-12
Hexadecane	kg	5.76E-06	1.03E-06	2.48E-06	2.25E-06
Hexanoic acid	kg	2.00E-05	3.57E-06	8.63E-06	7.84E-06
Hydrocarbons, unspecified	kg	9.44E-09	7.10E-13	9.41E-09	2.44E-11
Iron	kg	1.15E-02	2.89E-03	4.50E-03	4.14E-03
Lead	kg	4.45E-05	9.96E-06	1.84E-05	1.61E-05
Lead-210/kg	kg	9.91E-15	1.77E-15	4.27E-15	3.88E-15
Lithium	kg	3.74E-02	1.25E-03	1.19E-02	2.42E-02
Lithium, ion	kg	1.52E-02	x	1.47E-02	4.60E-04
Magnesium	kg	5.99E-02	1.07E-02	2.58E-02	2.34E-02

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
Manganese	kg	2.57E-04	1.91E-05	1.01E-04	1.36E-04
Mercury	kg	6.92E-08	2.37E-08	2.35E-08	2.20E-08
Metallic ions, unspecified	kg	4.41E-06	8.67E-12	8.30E-09	4.40E-06
Methane, monochloro-, R-40	kg	3.84E-09	6.85E-10	1.65E-09	1.50E-09
Methyl ethyl ketone	kg	7.68E-09	1.37E-09	3.31E-09	3.00E-09
Metolachlor	kg	1.05E-11	x	5.01E-13	1.00E-11
Metribuzin	kg	4.88E-14	x	2.32E-15	4.64E-14
Molybdenum	kg	2.19E-06	3.91E-07	9.44E-07	8.58E-07
m-Xylene	kg	2.89E-06	5.15E-07	1.24E-06	1.13E-06
Naphthalene	kg	1.49E-06	3.10E-07	5.23E-07	6.55E-07
Naphthalene, 2-methyl-	kg	1.51E-06	2.69E-07	6.51E-07	5.91E-07
Naphthalenes, alkylated, unspecified	kg	4.53E-08	1.30E-08	1.71E-08	1.52E-08
n-Hexacosane	kg	6.37E-08	1.14E-08	2.74E-08	2.49E-08
Nickel	kg	2.16E-05	4.82E-06	8.82E-06	7.96E-06
Nickel, ion	kg	9.39E-15	x	5.64E-15	3.75E-15
Nitrate	kg	8.32E-08	6.22E-14	1.16E-08	7.16E-08
Nitrate compounds	kg	1.26E-10	2.50E-12	3.69E-11	8.61E-11
Nitric acid	kg	2.82E-07	5.62E-09	8.28E-08	1.93E-07
Nitrogen, total	kg	1.59E-05	1.74E-07	8.82E-06	6.92E-06
o-Cresol	kg	2.74E-06	4.89E-07	1.18E-06	1.07E-06
Octadecane	kg	1.42E-06	2.54E-07	6.13E-07	5.57E-07
Oils, unspecified	kg	2.50E-03	3.91E-04	1.03E-03	1.08E-03
Organic substances, unspecified	kg	4.60E-05	x	6.98E-08	4.59E-05
o-Xylene	kg	2.42E-12	x	2.34E-12	7.69E-14
Paraquat	kg	2.13E-13	x	1.01E-14	2.03E-13
Parathion, methyl	kg	1.61E-13	x	7.66E-15	1.53E-13
p-Cresol	kg	2.96E-06	5.28E-07	1.27E-06	1.16E-06
Pendimethalin	kg	1.09E-12	x	5.21E-14	1.04E-12
Permethrin	kg	9.84E-14	x	4.68E-15	9.37E-14
Phenanthrene	kg	1.95E-08	4.67E-09	7.82E-09	7.03E-09
Phenanthrenes, alkylated, unspecified	kg	1.88E-08	5.37E-09	7.09E-09	6.32E-09
Phenol	kg	8.28E-04	7.06E-06	7.25E-06	8.14E-04
Phenol, 2,4-dimethyl-	kg	2.67E-06	4.76E-07	1.15E-06	1.05E-06
Phenols, unspecified	kg	2.49E-05	1.51E-06	1.22E-05	1.12E-05
Phorate	kg	3.04E-14	x	1.45E-15	2.90E-14
Phosphate	kg	1.18E-03	1.16E-03	1.54E-05	2.59E-06
Phosphorus	kg	1.67E-07	x	7.78E-08	8.91E-08
Phosphorus compounds, unspecified	kg	5.64E-10	x	2.69E-11	5.37E-10
Phosphorus, total	kg	3.10E-07	x	3.10E-07	x
Process solvents, unspecified	kg	9.40E-10	x	9.40E-10	x
Propene	kg	1.43E-07	x	1.43E-07	x
p-Xylene	kg	2.42E-12	x	2.34E-12	7.69E-14
Radium-226/kg	kg	3.45E-12	6.15E-13	1.48E-12	1.35E-12
Radium-228/kg	kg	1.76E-14	3.15E-15	7.59E-15	6.90E-15
Selenium	kg	2.23E-06	1.99E-07	9.26E-07	1.11E-06

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
Silver	kg	2.00E-04	3.57E-05	8.61E-05	7.83E-05
Simazine	kg	6.91E-13	x	3.29E-14	6.58E-13
Sodium	kg	7.00E-01	1.73E-01	1.55E-01	3.72E-01
Sodium, ion	kg	2.71E-01	x	2.63E-01	8.22E-03
Solids, inorganic	kg	3.23E-04	1.43E-11	2.10E-10	3.23E-04
Solved solids	kg	1.20E+00	x	1.15E+00	5.10E-02
Strontium	kg	5.20E-03	9.27E-04	2.24E-03	2.03E-03
Styrene	kg	1.96E-12	x	1.66E-12	3.05E-13
Sulfate	kg	1.70E-02	1.38E-03	7.03E-03	8.56E-03
Sulfide	kg	1.46E-05	8.20E-07	1.17E-05	2.11E-06
Sulfur	kg	2.53E-04	4.51E-05	1.09E-04	9.89E-05
Sulfuric acid	kg	4.74E-06	x	1.52E-08	4.72E-06
Surfactants	kg	1.12E-10	x	1.08E-10	3.56E-12
Suspended solids, inorganic	kg	1.71E-03	x	x	1.71E-03
Suspended solids, unspecified	kg	3.23E+00	8.02E-01	7.42E-01	1.68E+00
Tar	kg	7.09E-12	1.42E-13	2.09E-12	4.87E-12
Terbufos	kg	1.04E-12	x	4.94E-14	9.89E-13
Tetradecane	kg	2.31E-06	4.12E-07	9.95E-07	9.05E-07
Thallium	kg	6.65E-07	1.90E-07	2.51E-07	2.24E-07
Tin	kg	1.58E-05	3.69E-06	6.39E-06	5.75E-06
Titanium	kg	3.52E-05	1.38E-05	5.48E-06	1.59E-05
Titanium, ion	kg	1.32E-05	x	1.28E-05	4.00E-07
TOC, Total Organic Carbon	kg	7.32E-07	x	7.30E-07	2.92E-09
Toluene	kg	1.51E-04	2.70E-05	6.51E-05	5.91E-05
Vanadium	kg	2.59E-06	4.62E-07	1.12E-06	1.01E-06
Waste water/m3	m3	8.72E+01	x	8.32E-05	8.72E+01
Xylene	kg	7.98E-05	1.45E-05	3.43E-05	3.11E-05
Yttrium	kg	6.43E-07	1.15E-07	2.77E-07	2.51E-07
Zinc	kg	1.27E-04	3.34E-05	4.86E-05	4.49E-05
Zinc, ion	kg	2.54E-07	x	1.34E-08	2.40E-07

14.3 Cradle to Gate LCI Air Emissions (economic allocation)

Table 35 Air emissions released per 1 m^3 of Glued-Laminated Timbers, PNW (economic allocation)

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
2,4-D	kg	2.47E-11	x	1.35E-12	2.33E-11
2-Chloroacetophenone	kg	4.75E-11	3.24E-12	2.41E-11	2.02E-11
2-Methyl-4-chlorophenoxyacetic acid	kg	4.60E-13	x	2.51E-14	4.35E-13
5-methyl Chrysene	kg	2.05E-10	2.53E-12	8.79E-11	1.15E-10
Acenaphthene	kg	4.76E-09	5.87E-11	2.04E-09	2.66E-09
Acenaphthylene	kg	2.33E-09	2.88E-11	9.99E-10	1.31E-09
Acetaldehyde	kg	2.44E-02	6.04E-05	2.43E-02	3.97E-05
Acetochlor	kg	3.42E-10	x	1.86E-11	3.23E-10
Acetophenone	kg	1.02E-10	6.94E-12	5.17E-11	4.32E-11
Acrolein	kg	1.14E-03	7.31E-06	1.11E-03	2.34E-05
Alachlor	kg	3.36E-11	x	1.84E-12	3.18E-11
Aldehydes, unspecified	kg	7.81E-04	1.81E-04	2.64E-04	3.37E-04
Ammonia	kg	2.72E-03	1.32E-04	2.10E-03	4.85E-04
Ammonium chloride	kg	2.43E-05	3.27E-07	1.09E-05	1.31E-05
Anthracene	kg	1.96E-09	2.42E-11	8.39E-10	1.10E-09
Antimony	kg	1.76E-07	2.07E-09	7.20E-08	1.02E-07
Arsenic	kg	4.00E-06	6.55E-08	1.71E-06	2.22E-06
Atrazine	kg	6.66E-10	x	3.63E-11	6.29E-10
Barium	kg	2.82E-08	x	2.82E-08	x
Bentazone	kg	2.72E-12	x	1.48E-13	2.57E-12
Benzene	kg	1.51E-04	7.36E-05	4.91E-05	2.79E-05
Benzene, chloro-	kg	1.49E-10	1.02E-11	7.58E-11	6.34E-11
Benzene, ethyl-	kg	1.45E-08	4.35E-11	1.39E-08	5.60E-10
Benzo(a)anthracene	kg	7.47E-10	9.20E-12	3.20E-10	4.18E-10
Benzo(a)pyrene	kg	3.55E-10	4.37E-12	1.52E-10	1.98E-10
Benzo(b,j,k)fluoranthene	kg	1.03E-09	1.27E-11	4.40E-10	5.74E-10
Benzo(g,h,i)perylene	kg	2.07E-10	3.11E-12	6.94E-11	1.34E-10
Benzo(ghi)perylene	kg	4.52E-11	x	3.85E-11	6.71E-12
Benzyl chloride	kg	4.75E-09	3.24E-10	2.41E-09	2.02E-09
Beryllium	kg	2.13E-07	3.22E-09	9.08E-08	1.19E-07
Biphenyl	kg	1.59E-08	1.96E-10	6.79E-09	8.88E-09
Bromoform	kg	2.65E-10	1.81E-11	1.34E-10	1.12E-10
Bromoxynil	kg	5.95E-12	x	3.25E-13	5.63E-12
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	4.21E-03	8.97E-05	2.17E-03	1.95E-03
Butadiene	kg	4.62E-06	3.08E-06	8.57E-07	6.84E-07
Cadmium	kg	8.13E-07	1.60E-08	3.68E-07	4.30E-07
Carbofuran	kg	5.09E-12	x	2.78E-13	4.81E-12
Carbon dioxide	kg	1.13E-01	5.34E-02	5.05E-02	9.42E-03
Carbon dioxide, biogenic	kg	2.78E+02	1.15E-02	2.34E+02	4.44E+01
Carbon dioxide, fossil	kg	1.23E+02	1.45E+01	5.41E+01	5.44E+01

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Carbon disulfide	kg	1.74E-07	6.02E-11	1.74E-07	3.75E-10
Carbon monoxide	kg	7.04E-03	6.32E-06	1.86E-04	6.84E-03
Carbon monoxide, biogenic	kg	5.52E-01	x	4.28E-01	1.24E-01
Carbon monoxide, fossil	kg	3.94E-01	1.32E-01	1.47E-01	1.15E-01
Chloride	kg	5.04E-10	8.80E-12	1.65E-10	3.30E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	6.48E-09	x	3.34E-09	3.14E-09
Chlorine	kg	1.05E-07	x	5.16E-08	5.32E-08
Chloroform	kg	4.01E-10	2.73E-11	2.03E-10	1.70E-10
Chlorpyrifos	kg	3.92E-11	x	2.14E-12	3.70E-11
Chromium	kg	2.88E-06	4.70E-08	1.26E-06	1.58E-06
Chromium VI	kg	7.37E-07	9.09E-09	3.16E-07	4.12E-07
Chrysene	kg	9.33E-10	1.15E-11	4.00E-10	5.22E-10
Cobalt	kg	1.34E-06	8.95E-08	5.93E-07	6.61E-07
Copper	kg	2.03E-08	8.07E-10	8.89E-09	1.06E-08
Cumene	kg	2.05E-07	2.45E-12	2.05E-07	1.53E-11
Cyanazine	kg	5.87E-12	x	3.20E-13	5.55E-12
Cyanide	kg	1.70E-08	1.16E-09	8.61E-09	7.21E-09
Dicamba	kg	3.46E-11	x	1.89E-12	3.27E-11
Dimethenamid	kg	8.17E-11	x	4.46E-12	7.72E-11
Dimethyl ether	kg	3.33E-06	x	1.49E-09	3.33E-06
Dinitrogen monoxide	kg	1.88E-03	3.27E-04	9.38E-04	6.15E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	3.47E-11	2.89E-13	5.07E-12	2.93E-11
Dioxins (unspec.)	kg	9.59E-15	x	9.59E-15	x
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	4.02E-14	x	4.60E-20	4.02E-14
Dipropylthiocarbamic acid S-ethyl ester	kg	5.59E-11	x	3.05E-12	5.29E-11
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1.57E-09	4.28E-10	6.68E-10	4.70E-10
Ethane, 1,2-dibromo-	kg	9.27E-12	5.56E-13	5.22E-12	3.49E-12
Ethane, 1,2-dichloro-	kg	2.72E-10	1.85E-11	1.38E-10	1.15E-10
Ethane, chloro-	kg	2.85E-10	1.94E-11	1.45E-10	1.21E-10
Ethene, tetrachloro-	kg	4.15E-07	5.93E-09	1.75E-07	2.34E-07
Ethene, trichloro-	kg	7.21E-09	x	3.07E-11	7.18E-09
Ethylene oxide	kg	7.27E-08	x	7.07E-08	2.01E-09
Fluoranthene	kg	6.63E-09	8.17E-11	2.84E-09	3.71E-09
Fluorene	kg	8.49E-09	1.05E-10	3.64E-09	4.75E-09
Fluoride	kg	1.47E-06	6.33E-07	4.07E-07	4.27E-07
Formaldehyde	kg	2.68E-02	9.36E-05	2.27E-03	2.45E-02
Furan	kg	4.55E-11	5.25E-13	1.92E-11	2.58E-11
Glyphosate	kg	7.34E-11	x	4.01E-12	6.94E-11
HAPs	kg	3.44E-01	x	8.29E-04	3.43E-01
HAPS, unspecified	kg	1.63E-05	x	1.63E-05	x
Heat, waste	MJ	5.69E-01	x	4.79E-01	9.04E-02
Hexane	kg	4.00E-07	3.10E-11	4.00E-07	1.93E-10
Hydrazine, methyl-	kg	1.15E-09	7.87E-11	5.86E-10	4.90E-10

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Hydrocarbons, unspecified	kg	1.40E-04	1.89E-06	6.27E-05	7.57E-05
Hydrogen	kg	2.27E-08	x	1.92E-08	3.55E-09
Hydrogen chloride	kg	1.15E-02	1.47E-04	4.98E-03	6.35E-03
Hydrogen fluoride	kg	1.40E-03	1.72E-05	5.99E-04	7.88E-04
Hydrogen sulfide	kg	1.63E-11	2.84E-13	5.34E-12	1.07E-11
Indeno(1,2,3-cd)pyrene	kg	5.69E-10	7.02E-12	2.44E-10	3.19E-10
Iron	kg	2.76E-08	x	2.76E-08	x
Isophorone	kg	3.94E-09	2.69E-10	2.00E-09	1.67E-09
Isoprene	kg	1.65E-02	2.88E-04	5.42E-03	1.08E-02
Kerosene	kg	1.18E-05	1.56E-07	5.20E-06	6.48E-06
Lead	kg	3.17E-05	7.30E-08	2.50E-05	6.70E-06
Magnesium	kg	1.03E-04	1.27E-06	4.40E-05	5.74E-05
Manganese	kg	7.23E-06	9.74E-08	4.38E-06	2.75E-06
Mercaptans, unspecified	kg	1.46E-06	9.98E-08	7.37E-07	6.23E-07
Mercury	kg	1.18E-06	1.31E-08	6.27E-07	5.38E-07
Metals, unspecified	kg	8.64E-07	3.26E-14	3.73E-08	8.26E-07
Methane	kg	2.81E-01	1.98E-02	1.31E-01	1.30E-01
Methane, biogenic	kg	3.50E-03	x	2.94E-03	5.57E-04
Methane, bromo-, Halon 1001	kg	1.09E-09	7.41E-11	5.51E-10	4.61E-10
Methane, chlorodifluoro-, HCFC-22	kg	6.04E-13	x	5.88E-13	1.67E-14
Methane, chlorotrifluoro-, CFC-13	kg	5.74E-12	x	5.58E-12	1.58E-13
Methane, dichloro-, HCC-30	kg	3.14E-06	9.99E-08	1.35E-06	1.69E-06
Methane, dichlorodifluoro-, CFC-12	kg	1.77E-09	5.18E-10	7.41E-10	5.10E-10
Methane, fossil	kg	2.75E-02	1.54E-03	1.39E-02	1.21E-02
Methane, monochloro-, R-40	kg	3.60E-09	2.45E-10	1.83E-09	1.53E-09
Methane, tetrachloro-, CFC-10	kg	1.61E-08	5.18E-11	1.74E-10	1.58E-08
Methanol	kg	2.02E-02	x	2.00E-02	2.47E-04
Methyl ethyl ketone	kg	2.65E-09	1.81E-10	1.34E-09	1.12E-09
Methyl methacrylate	kg	1.36E-10	9.26E-12	6.89E-11	5.77E-11
Metolachlor	kg	2.70E-10	x	1.47E-11	2.55E-10
Metribuzin	kg	1.25E-12	x	6.83E-14	1.18E-12
Naphthalene	kg	9.44E-06	1.86E-08	7.81E-06	1.61E-06
Nickel	kg	8.57E-06	1.13E-06	3.96E-06	3.48E-06
Nitrogen oxides	kg	9.58E-01	2.63E-01	3.96E-01	2.99E-01
Nitrogen, total	kg	1.23E-05	1.21E-05	1.94E-07	3.12E-11
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	3.81E-02	8.78E-03	1.33E-02	1.60E-02
N-Nitrodimethylamine	kg	1.61E-09	x	6.84E-12	1.61E-09
Organic acids	kg	8.93E-08	1.20E-09	3.99E-08	4.82E-08
Organic substances, unspecified	kg	3.00E-03	7.14E-07	5.38E-04	2.46E-03
Other Organic	kg	3.32E-05	x	2.79E-05	5.28E-06
PAH, polycyclic aromatic hydrocarbons	kg	1.98E-05	1.32E-05	3.66E-06	2.94E-06
Paraquat	kg	5.46E-12	x	2.98E-13	5.17E-12
Parathion, methyl	kg	4.13E-12	x	2.25E-13	3.90E-12
Particulates	kg	2.57E-05	x	7.25E-10	2.57E-05

Substance	Unit	Total	Forestry Operations	Lamstock Production	Glulam Production
Particulates, < 10 um	kg	1.34E-01	x	6.23E-02	7.21E-02
Particulates, < 2.5 um	kg	3.10E-02	x	2.74E-02	3.54E-03
Particulates, > 10 um	kg	2.45E-02	x	2.45E-02	6.36E-05
Particulates, > 2.5 um, and < 10um	kg	1.99E-02	8.06E-03	6.22E-03	5.65E-03
Particulates, unspecified	kg	3.53E-02	1.45E-03	1.48E-02	1.90E-02
Pendimethalin	kg	2.81E-11	x	1.53E-12	2.65E-11
Permethrin	kg	2.52E-12	x	1.38E-13	2.39E-12
Phenanthrene	kg	2.52E-08	3.11E-10	1.08E-08	1.41E-08
Phenol	kg	6.13E-01	7.41E-12	1.06E-04	6.13E-01
Phenols, unspecified	kg	4.54E-07	5.19E-08	2.09E-07	1.93E-07
Phorate	kg	1.29E-12	x	7.06E-14	1.22E-12
Phosphate	kg	2.81E-07	2.77E-07	4.43E-09	x
Phthalate, dioctyl-	kg	4.96E-10	3.38E-11	2.51E-10	2.10E-10
Polycyclic organic matter, unspecified	kg	1.46E-11	x	1.42E-11	4.03E-13
Potassium	kg	4.88E-06	x	4.88E-06	x
Propanal	kg	1.87E-04	1.76E-10	1.86E-04	1.29E-06
Propene	kg	3.05E-04	2.03E-04	5.66E-05	4.51E-05
Propylene oxide	kg	3.08E-09	x	3.08E-09	x
Pyrene	kg	3.08E-09	3.80E-11	1.32E-09	1.72E-09
Radionuclides (Including Radon)	kg	6.51E-04	8.75E-06	2.91E-04	3.51E-04
Selenium	kg	1.23E-05	1.60E-07	5.24E-06	6.89E-06
Simazine	kg	1.77E-11	x	9.68E-13	1.68E-11
Sodium	kg	1.13E-07	x	1.13E-07	x
Styrene	kg	1.70E-10	1.16E-11	8.61E-11	7.21E-11
Sulfur	kg	8.30E-08	x	4.53E-09	7.84E-08
Sulfur dioxide	kg	5.97E-01	1.00E-02	2.85E-01	3.01E-01
Sulfur monoxide	kg	3.45E-02	1.46E-02	5.21E-03	1.47E-02
Sulfur oxides	kg	3.33E-02	x	1.78E-02	1.56E-02
Sulfur, total reduced	kg	3.48E-07	x	3.48E-07	x
Sulfuric acid, dimethyl ester	kg	3.26E-10	2.22E-11	1.65E-10	1.38E-10
Tar	kg	5.67E-10	9.90E-12	1.86E-10	3.71E-10
t-Butyl methyl ether	kg	2.38E-10	1.62E-11	1.21E-10	1.01E-10
Terbufos	kg	4.41E-11	x	2.41E-12	4.17E-11
TOC, Total Organic Carbon	kg	6.43E-08	x	3.51E-09	6.08E-08
Toluene	kg	4.85E-05	3.22E-05	9.10E-06	7.16E-06
Toluene, 2,4-dinitro-	kg	1.90E-12	1.30E-13	9.65E-13	8.07E-13
Trichloroethane	kg	5.45E-08	x	5.45E-08	x
Vinyl acetate	kg	5.16E-11	3.52E-12	2.62E-11	2.19E-11
VOC, volatile organic compounds	kg	3.66E-01	7.06E-03	2.75E-01	8.46E-02
Wood (dust)	kg	1.04E-01	x	9.00E-02	1.41E-02
Xylene	kg	3.37E-05	2.24E-05	6.33E-06	4.99E-06
Zinc	kg	2.68E-07	2.24E-07	3.71E-08	7.06E-09

14.4 Cradle to Gate LCI Water Emissions (economic allocation)

Table 36 Water emissions released per 1 m^3 of Glued-Laminated Timbers, PNW (economic allocation)

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
2,4-D	kg	1.06E-12	x	5.77E-14	9.99E-13
2-Hexanone	kg	7.08E-07	1.11E-07	3.31E-07	2.66E-07
2-Methyl-4-chlorophenoxyacetic acid	kg	1.97E-14	x	1.08E-15	1.86E-14
2-Propanol	kg	6.42E-10	x	3.28E-10	3.14E-10
4-Methyl-2-pentanone	kg	4.56E-07	7.15E-08	2.13E-07	1.71E-07
Acetaldehyde	kg	7.65E-08	x	7.44E-08	2.11E-09
Acetochlor	kg	1.46E-11	x	7.99E-13	1.38E-11
Acetone	kg	1.08E-06	1.70E-07	5.06E-07	4.07E-07
Acidity, unspecified	kg	2.25E-10	x	5.53E-13	2.24E-10
Acids, unspecified	kg	2.09E-07	1.85E-10	1.61E-07	4.79E-08
Alachlor	kg	1.44E-12	x	7.87E-14	1.36E-12
Aluminium	kg	6.05E-03	1.45E-03	2.64E-03	1.97E-03
Aluminum	kg	1.32E-06	x	1.32E-06	x
Ammonia	kg	1.75E-03	3.17E-04	8.12E-04	6.20E-04
Ammonia, as N	kg	1.91E-04	9.28E-11	1.74E-09	1.91E-04
Ammonium, ion	kg	8.42E-05	6.99E-08	6.03E-05	2.39E-05
Antimony	kg	3.65E-06	9.01E-07	1.59E-06	1.16E-06
Arsenic	kg	1.95E-05	5.16E-06	4.56E-06	9.74E-06
Arsenic, ion	kg	8.20E-06	x	7.97E-06	2.23E-07
Atrazine	kg	2.85E-11	x	1.56E-12	2.70E-11
Barium	kg	8.20E-02	1.98E-02	3.58E-02	2.63E-02
Bentazone	kg	1.16E-13	0.00E+00	6.35E-15	1.10E-13
Benzene	kg	1.82E-04	2.85E-05	8.49E-05	6.83E-05
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.08E-08	1.70E-09	5.06E-09	4.07E-09
Benzene, ethyl-	kg	1.02E-05	1.61E-06	4.78E-06	3.84E-06
Benzene, pentamethyl-	kg	8.12E-09	1.27E-09	3.80E-09	3.05E-09
Benzenes, alkylated, unspecified	kg	3.20E-06	7.91E-07	1.39E-06	1.02E-06
Benzo(a)pyrene	kg	4.59E-08	x	4.25E-08	3.43E-09
Benzoic acid	kg	1.10E-04	1.73E-05	5.14E-05	4.13E-05
Beryllium	kg	1.38E-06	2.58E-07	6.32E-07	4.94E-07
Biphenyl	kg	2.07E-07	5.12E-08	9.00E-08	6.57E-08
BOD5, Biological Oxygen Demand	kg	4.90E-02	3.11E-03	1.58E-02	3.00E-02
Boron	kg	3.61E-04	5.34E-05	1.59E-04	1.48E-04
Bromide	kg	2.32E-02	3.64E-03	1.09E-02	8.73E-03
Bromoxynil	kg	1.54E-13	x	8.41E-15	1.46E-13
Cadmium	kg	3.00E-06	8.59E-07	6.85E-07	1.45E-06
Cadmium, ion	kg	1.95E-06	x	1.18E-06	7.70E-07
Calcium	kg	2.44E-01	5.46E-02	6.13E-02	1.28E-01
Calcium, ion	kg	1.04E-01	x	1.01E-01	2.83E-03
Carbofuran	kg	2.18E-13	x	1.19E-14	2.06E-13

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
CFCs, unspecified	kg	6.42E-10	x	3.28E-10	3.14E-10
Chloride	kg	3.92E+00	6.14E-01	1.83E+00	1.47E+00
Chlorpyrifos	kg	1.68E-12	x	9.16E-14	1.59E-12
Chromate	kg	1.22E-08	x	2.83E-11	1.21E-08
Chromium	kg	1.31E-04	3.87E-05	5.43E-05	3.81E-05
Chromium III	kg	2.57E-05	3.04E-06	7.79E-06	1.48E-05
Chromium VI	kg	5.45E-07	1.60E-07	2.29E-07	1.57E-07
Chromium, ion	kg	1.02E-05	x	9.89E-06	3.01E-07
Cobalt	kg	2.40E-06	3.77E-07	1.12E-06	9.02E-07
COD, Chemical Oxygen Demand	kg	3.53E-02	5.89E-03	1.65E-02	1.30E-02
Copper	kg	2.02E-05	5.16E-06	4.77E-06	1.03E-05
Copper, ion	kg	8.20E-06	x	7.87E-06	3.35E-07
Cumene	kg	4.93E-07	x	4.93E-07	x
Cyanazine	kg	2.52E-13	x	1.37E-14	2.38E-13
Cyanide	kg	5.26E-06	1.23E-09	4.86E-06	3.96E-07
Decane	kg	3.16E-06	4.96E-07	1.48E-06	1.19E-06
Detergent, oil	kg	9.91E-05	1.44E-05	4.68E-05	3.80E-05
Dibenzofuran	kg	2.06E-08	3.23E-09	9.63E-09	7.75E-09
Dibenzothiophene	kg	1.73E-08	2.78E-09	8.08E-09	6.48E-09
Dicamba	kg	1.48E-12	x	8.09E-14	1.40E-12
Dimethenamid	kg	3.50E-12	x	1.91E-13	3.31E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	1.45E-12	x	7.90E-14	1.37E-12
Disulfoton	kg	8.64E-14	x	4.72E-15	8.17E-14
Diuron	kg	2.43E-14	x	1.32E-15	2.29E-14
DOC, Dissolved Organic Carbon	kg	9.10E-07	5.67E-13	9.10E-07	2.13E-11
Docosane	kg	1.16E-07	1.82E-08	5.42E-08	4.36E-08
Dodecane	kg	5.99E-06	9.41E-07	2.80E-06	2.25E-06
Eicosane	kg	1.65E-06	2.59E-07	7.71E-07	6.20E-07
Fluorene	kg	1.43E-12	x	1.39E-12	3.95E-14
Fluorene, 1-methyl-	kg	1.23E-08	1.94E-09	5.76E-09	4.64E-09
Fluorenes, alkylated, unspecified	kg	1.85E-07	4.58E-08	8.06E-08	5.88E-08
Fluoride	kg	1.65E-03	1.54E-03	6.38E-05	4.65E-05
Fluorine	kg	9.49E-08	2.26E-08	4.16E-08	3.07E-08
Formaldehyde	kg	2.68E-03	x	x	2.68E-03
Furan	kg	1.20E-11	x	1.20E-11	x
Glyphosate	kg	3.15E-12	x	1.72E-13	2.98E-12
Hexadecane	kg	6.54E-06	1.03E-06	3.06E-06	2.46E-06
Hexanoic acid	kg	2.28E-05	3.57E-06	1.06E-05	8.56E-06
Hydrocarbons, unspecified	kg	1.21E-08	7.10E-13	1.20E-08	2.66E-11
Iron	kg	1.33E-02	2.89E-03	5.86E-03	4.52E-03
Lead	kg	5.11E-05	9.96E-06	2.36E-05	1.76E-05
Lead-210/kg	kg	1.13E-14	1.77E-15	5.26E-15	4.23E-15
Lithium	kg	4.25E-02	1.25E-03	1.48E-02	2.65E-02
Lithium, ion	kg	1.58E-02	x	1.53E-02	5.03E-04

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
Magnesium	kg	6.81E-02	1.07E-02	3.18E-02	2.56E-02
Manganese	kg	2.90E-04	1.91E-05	1.22E-04	1.49E-04
Mercury	kg	7.86E-08	2.37E-08	3.09E-08	2.40E-08
Metallic ions, unspecified	kg	4.81E-06	8.67E-12	1.20E-08	4.80E-06
Methane, monochloro-, R-40	kg	4.36E-09	6.85E-10	2.04E-09	1.64E-09
Methyl ethyl ketone	kg	8.73E-09	1.37E-09	4.08E-09	3.28E-09
Metolachlor	kg	1.16E-11	x	6.31E-13	1.09E-11
Metribuzin	kg	5.36E-14	x	2.93E-15	5.07E-14
Molybdenum	kg	2.49E-06	3.91E-07	1.16E-06	9.36E-07
m-Xylene	kg	3.28E-06	5.15E-07	1.53E-06	1.23E-06
Naphthalene	kg	1.62E-06	3.10E-07	5.96E-07	7.14E-07
Naphthalene, 2-methyl-	kg	1.72E-06	2.69E-07	8.02E-07	6.45E-07
Naphthalenes, alkylated, unspecified	kg	5.24E-08	1.30E-08	2.28E-08	1.66E-08
n-Hexacosane	kg	7.24E-08	1.14E-08	3.38E-08	2.72E-08
Nickel	kg	2.47E-05	4.82E-06	1.11E-05	8.69E-06
Nickel, ion	kg	1.13E-14	x	7.21E-15	4.09E-15
Nitrate	kg	9.30E-08	6.22E-14	1.49E-08	7.81E-08
Nitrate compounds	kg	1.44E-10	2.50E-12	4.71E-11	9.40E-11
Nitric acid	kg	3.22E-07	5.62E-09	1.06E-07	2.11E-07
Nitrogen, total	kg	1.91E-05	1.74E-07	1.14E-05	7.55E-06
o-Cresol	kg	3.12E-06	4.89E-07	1.46E-06	1.17E-06
Octadecane	kg	1.62E-06	2.54E-07	7.55E-07	6.07E-07
Oils, unspecified	kg	2.87E-03	3.91E-04	1.31E-03	1.18E-03
Organic substances, unspecified	kg	5.02E-05	x	1.01E-07	5.01E-05
o-Xylene	kg	3.04E-12	x	2.96E-12	8.39E-14
Paraquat	kg	2.34E-13	x	1.28E-14	2.21E-13
Parathion, methyl	kg	1.77E-13	x	9.66E-15	1.67E-13
p-Cresol	kg	3.36E-06	5.28E-07	1.57E-06	1.26E-06
Pendimethalin	kg	1.20E-12	x	6.57E-14	1.14E-12
Permethrin	kg	1.08E-13	x	5.90E-15	1.02E-13
Phenanthrene	kg	2.24E-08	4.67E-09	1.01E-08	7.68E-09
Phenanthrenes, alkylated, unspecified	kg	2.17E-08	5.37E-09	9.45E-09	6.90E-09
Phenol	kg	9.06E-04	7.06E-06	1.01E-05	8.88E-04
Phenol, 2,4-dimethyl-	kg	3.04E-06	4.76E-07	1.42E-06	1.14E-06
Phenols, unspecified	kg	2.77E-05	1.51E-06	1.40E-05	1.22E-05
Phorate	kg	3.35E-14	x	1.83E-15	3.16E-14
Phosphate	kg	1.18E-03	1.16E-03	1.95E-05	2.83E-06
Phosphorus	kg	2.09E-07	x	1.12E-07	9.73E-08
Phosphorus compounds, unspecified	kg	6.20E-10	x	3.38E-11	5.86E-10
Phosphorus, total	kg	3.97E-07	x	3.97E-07	x
Process solvents, unspecified	kg	1.20E-09	x	1.20E-09	x
Propene	kg	1.82E-07	x	1.82E-07	x
p-Xylene	kg	3.04E-12	x	2.96E-12	8.39E-14
Radium-226/kg	kg	3.92E-12	6.15E-13	1.83E-12	1.47E-12

Substance	Unit	Total	Forestry Operations	Lumber Production	Glulam Production
Radium-228/kg	kg	2.00E-14	3.15E-15	9.36E-15	7.53E-15
Selenium	kg	2.53E-06	1.99E-07	1.12E-06	1.21E-06
Silver	kg	2.27E-04	3.57E-05	1.06E-04	8.54E-05
Simazine	kg	7.60E-13	x	4.15E-14	7.18E-13
Sodium	kg	7.73E-01	1.73E-01	1.94E-01	4.06E-01
Sodium, ion	kg	3.31E-01	x	3.22E-01	8.97E-03
Solids, inorganic	kg	3.52E-04	1.43E-11	2.68E-10	3.52E-04
Solved solids	kg	1.46E+00	x	1.41E+00	5.56E-02
Strontium	kg	5.91E-03	9.27E-04	2.76E-03	2.22E-03
Styrene	kg	2.45E-12	x	2.11E-12	3.33E-13
Sulfate	kg	1.91E-02	1.38E-03	8.41E-03	9.34E-03
Sulfide	kg	1.98E-05	8.20E-07	1.67E-05	2.30E-06
Sulfur	kg	2.87E-04	4.51E-05	1.34E-04	1.08E-04
Sulfuric acid	kg	5.18E-06	x	2.20E-08	5.15E-06
Surfactants	kg	1.41E-10	x	1.37E-10	3.89E-12
Suspended solids, inorganic	kg	1.87E-03	x	x	1.87E-03
Suspended solids, unspecified	kg	3.57E+00	8.02E-01	9.33E-01	1.84E+00
Tar	kg	8.11E-12	1.42E-13	2.66E-12	5.31E-12
Terbufos	kg	1.14E-12	x	6.23E-14	1.08E-12
Tetradecane	kg	2.63E-06	4.12E-07	1.23E-06	9.87E-07
Thallium	kg	7.69E-07	1.90E-07	3.34E-07	2.44E-07
Tin	kg	1.82E-05	3.69E-06	8.18E-06	6.28E-06
Titanium	kg	3.82E-05	1.38E-05	6.96E-06	1.74E-05
Titanium, ion	kg	1.78E-05	x	1.74E-05	4.36E-07
TOC, Total Organic Carbon	kg	9.29E-07	x	9.26E-07	3.18E-09
Toluene	kg	1.72E-04	2.70E-05	8.03E-05	6.46E-05
Vanadium	kg	2.94E-06	4.62E-07	1.38E-06	1.11E-06
Waste water/m3	m3	9.52E+01	x	1.08E-04	9.52E+01
Xylene	kg	9.08E-05	1.45E-05	4.23E-05	3.40E-05
Yttrium	kg	7.30E-07	1.15E-07	3.41E-07	2.75E-07
Zinc	kg	1.46E-04	3.34E-05	6.38E-05	4.90E-05
Zinc, ion	kg	2.79E-07	x	1.71E-08	2.62E-07

15. Appendix III: List of Terms

Table 37 List of terms

Board foot	One board foot is equal to a 1-inch thick board, 12 inches in width, and 1 foot in length (1” x 12” x 1 ft).
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2 (biomass)	Carbon dioxide emitted from the combustion wood or biomass
CO_2 (fossil)	Carbon dioxide emitted from the combustion on fossil fuels
CO_2 (non-fossil)	Carbon dioxide emitted from the combustion of non-fossil fuels and may include wood or biomass
CORRIM	The Consortium for Research on Renewable Industrial Materials
cuft	Cubic feet
EPA	Environmental Protection Agency
Hogged fuel	Wood waste (shavings, trimmings, bark, planer shavings etc.) used to fire boiler or furnaces, often at the mill or plant at which the fuel was processed.
kg	Kilogram
in^2	Inches squared
kg/m^3	Kilogram per cubic meter
kWh	Kilowatt hour
L	Liter
lb	US pound
lb/ft^3	Pound per cubic foot (density), US
LCA	Life-cycle assessment
LCI	Life-cycle inventory
LCIA	Life-cycle impact assessment
m^3	Cubic meters
MBF	1000 board feet
MJ	Mega joules
mm	Millimeters
10^3m^3	1000 cubic meters
MMBF	Million board feet
NMVOC	Non methane volatile organic substances
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxide and nitrogen dioxide
Particulate matter	A general term used for a mixture of solid particles and liquid droplets found in the air.
PM10	Particulate matter less than 10 microns in diameter
PNW	Pacific Northwest region (boundaries defined in report)
SE	Southeast United States region (boundaries defined in report)
SO_2	Sulfur dioxide
VOC	Volatile organic compounds

16. Appendix IV: Unit Conversions

Table 38 Unit Conversion Factors

BTU =	1.054 E-03 MJ
BTU =	1,054.3 J
cubic foot =	7.482 gal
cubic inch =	0.0043 gal
cubic unit =	200 ft^3
cubic yard =	0.7645549 m^3
ft =	0.305 m
ft^3 =	2.832 E-02 m^3
gallon (US) =	3.785 liters
gal/MCF =	133.67 L/1000 m^3
J =	10^6 MJ
kWh/ft^3 =	127 MJ/m^3
kWh=	3,414.4 BTUs
kWh=	3.6 MJ
lb =	0.454 kg
lb/ft^3 =	16.02 kg/m^3
liter =	0.02642 gal (US)
m^3 =	35.32 ft^3
MBF =	2.3597 m^3
miles =	1.852 kilometers
tons (short) =	2,000 lb
tons (short) =	907.185 kg
tons (long) =	2240 lb

Table 39 Energy Content Conversion – (Higher Heating Values used for conversions)

Fuel	Unit	MJ/Unit	MJ.kg	Density	Density/Units
Coal	kg		26.4		
Diesel	L	38.68		0.85	kg/L
Gasoline	L	34.66		0.74	kg/L
Kerosene	L	37.68			
LPG	L	25.53		0.49	kg/L
Natural Gas[1]	m^3	36.6	46.8	0.70	kg/m^3
Residual Fuel Oil	L	41.81		0.96	kg/L
Wood waste	kg		20.9	450	kg/m^3

Table 40 Factors Used to Convert Nominal Board Feet to Actual Volume, Pacific Northwest Region Conversions

Lumber Dimension in x in	Mix %	Nominal Dimension in^2	Green Lumber			Dry Lumber			Glulam Beams		
			Actual Dimension in^2	Ratio Act/Nom	Weighted Average	Actual Dimension in^2	Ratio Act/Nom	Weighted Average	Actual Dimension in^2	Ratio Act/Nom	Weighted Average
2x4	24.3%	8.00	6.49	0.81	0.20	5.25	0.66	0.16	4.69	0.59	0.14
2x6	51.2%	12.00	10.16	0.85	0.43	8.25	0.69	0.35	7.69	0.64	0.33
2x8	15.6%	16.00	13.41	0.84	0.13	10.88	0.68	0.11	10.13	0.63	0.10
2x10	5.3%	20.00	16.87	0.84	0.04	13.88	0.69	0.04	13.13	0.66	0.03
2x12	3.2%	24.00	20.33	0.85	0.03	16.88	0.70	0.02	16.13	0.67	0.02
Total	**100%**				**0.83[1]**			**0.68**			**0.63**

[1] Conversion example: (1 BF, nominal of green lumber x 0.83)/12 = 1 cubic foot of actual volume of lumber

17. Appendix V: Glulam Survey

Glulam Survey