CORRIM REPORT - Life Cycle Assessment of Cross Laminated Timbers Produced in Oregon

Maureen Puettmann
WoodLife Environmental Consultants
Corvallis, OR
www.woodlifeconsulting.com
maureen.puettmann@woodlifeconsulting.com

Arijit Sinha, Associate Professor
Dept. of Wood Science and Engineering
Oregon State University
Corvallis, OR
arijit.sinha@oregonstate.edu

Indroneil Ganguly, Assistant Professor
School of Environmental and Forest Sciences
University of Washington
Seattle, WA
indro@uw.edu

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CORRIM
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ABBREVIATIONS

APA	American Panel Association
BF	Board foot
CtoG	Cradle-to-gate
Cubic foot	ft^3
Cubic meter	m^3
EPDs	Environmental Product Declarations
FBC	Fluidized Bed Combustors
GtoG	Gate-to-gate
GWP	Global Warming Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MF	Melamine formaldehyde resin
MSR	Machine Stressed Lumber
PCR	Product Category Rules
odkg	oven dry weight of wood in kilograms
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
tkm	metric tonne - kilometers

GLOSSARY OF TERMS[1]

Allocation – A way of dividing emissions and resource use among the different products of a process. The partitioning can be made on weight basis, energy content, or economic value.
Cradle-to-gate – LCA model which includes upstream part of the product life cycle, i.e. all steps from raw material extraction to product at factory gate.
Declared Unit[2] - Quantity of a wood building product for use as a reference unit, e.g. mass, volume, for the expression of environmental information needed in information modules.
Functional Unit – expresses the function of studied product in quantitative terms and serves as basis for calculations. It is the reference flow to which other flows in the LCA are related. It also serves as a unit of comparison in comparative studies.
Life cycle assessment (LCA) – Method for the environmental assessment of products covering their lifecycle from raw material extraction to waste treatment
Life cycle inventory (LCI) – LCA study that goes as far as an inventory analysis, but does not include impact assessment.
Life cycle impact assessment (LCIA) – Phase of an LCA study during which the environmental impacts of the product are assessed and evaluated.
Machine Stressed Rated Lumber – is intended for broad range of engineered applications were low variability in strength and stiffness properties is primary product considerations[3].
Product Category Rules (PCR)[4] – Set of specific rules, requirements and guidelines for the development of type III environmental declarations for one or more product categories (ISO 14025)
System boundary[5] – A set of criteria that specifies which unit processes are part of a product system (adapted from ISO 104044)

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[1] Baumann, H. and A-M. Tillman. 2004. The Hitch Hiker's Guide to LCA – An orientation in life cycle assessment methodology and application. Studentlitteratur AB, Lund, Sweden

[2] FP Innovations. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD), For North American Structural and Architectural Wood Products June 2015.

[3] http://www.wwpa.org/western-lumber/structural-lumber/structural-lumber-overview.

[4] FP Innovations. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD), For North American Structural and Architectural Wood Products. June 2015.

[5] FP Innovations. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD), For North American Structural and Architectural Wood Products. June 2015.

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1 INTRODUCTION

The use of all products carries an inherent environmental impact. It is difficult to live today without purchasing or using a product that contains resources that were extracted, produced with energy, and were moved during their life cycle by some means of transportation. What we can do, is identity materials that carry less of this “environmental burden” inherently by means of their resource to produce. Wood products have shown consistently in life cycle assessments to have less of environmental burdens when compared to equivalent fossil-based materials (www.corrim.org; www.FPInnovations.ca).

The forest products industry is consistently challenged regarding its environmental sustainability. The greatest challenges with respect to practices center on the extraction of forest resources with questions about carbon stores and flows in the forest environment. Life cycle assessment (LCA) can address these concerns with quantitative results that can demonstrate how wood products in fact, store more carbon than they emit throughout their life cycle (https://corrim.org/latest-reports/).

This LCA report is part of a Market and Environmental Assessment of cross laminated timber (CLT) production in the Olympic Peninsula: Mid-Rise non-residential construction application study[6]. This report is a stand-alone LCA of CLT produced in Oregon, by DR Johnson, located in Riddle, Oregon. The LCA follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015) that will provide the guidance for preparation of North American Environmental Product Declarations (EPD). This report does not include comparative assertions.

2 LIFE CYCLE ASSESSMENT

Life-cycle assessment (LCA) has evolved as an internationally accepted method to analyze complex impacts and outputs of a product or process and the corresponding effects they might have on the environment. LCA is an objective process to evaluate a product’s life cycle by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials uses and releases on the environment; and to evaluate and implement opportunities to effect environmental improvements. LCA studies can evaluate full product life cycles, often referred to as “cradle to grave”, or incorporate only a portion of the products life cycle, referred to as “cradle-to-gate”, or “gate-to-gate”. This study can be categorized as a cradle-to-gate LCA as it includes forestry operations though the manufacturing of CLT ready to be shipped at the mill gate.

[6] Ganguly, I., I. Easin, and K. Simonen. 2015. Proposal: Market and Environmental Assessment of CLT Production in the Olympic Peninsula: Mid-Rise Non-Residential Construction Application. 2015 McIntire-Stennis Research Proposal.

As defined by the International Organization for Standardization (ISO 2006), LCA is a multiphase process consisting of a 1) Goal and Scope Definition, 2) Life Cycle Inventory (LCI), 3) Life Cycle Impact Assessment (LCIA), and 4) Interpretation (Figure 1). These steps are interconnected, and their outcomes are based on goals and purposes of a study.

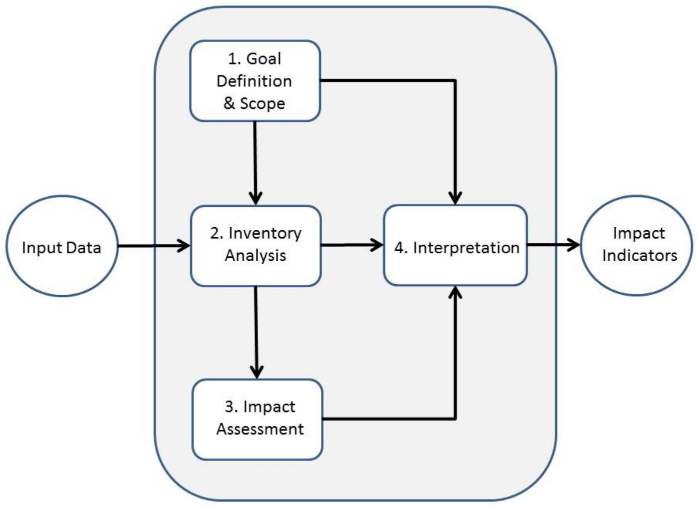

Figure 1 Steps involved in a life cycle assessment.

An LCA begins with a project goal, scope, functional unit, system boundaries, any assumptions and study limitations, method of allocation, and the impact categories that will be used.

The key component is the LCI which is an objective, data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases occurring within the system boundaries. It is this information which provides a quantitative basis for comparing wood products, their manufacturing processes and, most importantly from the forest industry point of view, wood products performance against competitors who use other resources to create alternative products.

The LCIA process characterizes and assesses the effects of environmental releases identified in the LCI into impact categories such as global warming, acidification, carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog.

The life cycle interpretation is a phase of LCA in which the findings of either the LCI or the LCIA, or both, are evaluated in relation to the defined goal and scope to reach conclusions and recommendations. This final step in a LCA involves an investigation of significant environmental aspects (e.g., energy use, greenhouse gases), their contributions to the indicators under consideration, and which unit processes in the system are generating the emissions. For example, if the results of a LCIA indicate a particularly high value for the global warming potential indicator, the analyst could refer to the inventory to determine which environmental flows are contributing to the high value, and which unit processes contribute to those outputs. This is also used as a form of *quality control*, and the results can be used to refine the scope definition to focus on the more important unit processes. This step also supports arriving at more certain conclusions and supportable recommendations.

3 DESCRIPTION OF PRODUCT

Cross-laminated timber (CLT) is a multi-layered structural wood product constructed of large panels made from solid wood and glued together in alternating directions of their fibers (Figure 2). CLT panels consist of an odd number of layers (usually, three to seven,) and may be sanded or prefinished before shipping. While at the mill, CLT panels are cut to size, including door, and window openings, with state-of-the art Computer Numerical Controlled (CNC) routers, capable of making complex cuts with high precision. Panels are lightweight yet very strong, with superior acoustic, fire, seismic, and thermal performance. CLT is easy to install and generating almost no waste onsite (Figure 3).

Figure 2 Cross laminated timber assembly and verification grade stamp (https://www.apawood.org/).

A *B*

Figure 3 Installation of DR Johnson CLT panels at the Albina yard, Portland, Oregon (A). Photo credit, Kevin Cheung WWPA 2016. Installation of CLT Panels at Western Oregon University, Monmouth, OR (B), Photo credit Nicole Larsen.

DR Johnson (DRJ) CLT is manufactured with Douglas-fir-Larch lumber in accordance with the V1 or custom grade of ANSI/APA PRG 320 (Figure 2). DRJ CLT panels can be used in floor, roof, and wall applications, and is manufactured with nominal width of 0.305-3.05 meters (1-10 feet), thicknesses of 10.48- 24.45 centimeters (4-1/8 to 9-5/8 inches), and lengths up to 12 meters (42 feet). DRJ CLT is certified by the American Panel Association (APA) under standards listed in Table 1.

Table 1 Standards for DR Johnson cross-laminated timbers[7].

CLT Qualifications: per ANSI/APA PRG 320-2012 (8.1-8.6)		
Lumber	**Grading rules/manufacturing standards**	
Adhesives	AITC 405	
End Joints	ANSI/APA A190.1-2012	Section 12.1.1 to 12.1.3
Face Joints	ANSI/APA A190.1-2012	Section 12.1.1 to 12.1.2
CLT Panel Dimensions	ANSI/APA PRG 320-2012	Section 5
CLT Panel Structural Performance	ANSI/APA PRG 320-2012	Section 7.2 and 8.5
Standard method of test for surface burning characteristics of building materials	ASTM E84-15b	
Standard test methods for fire tests of building construction and materials	ASTM E119-16	

[7] Riddle Laminators/DR Johnson Lumber. 2015. Quality Manual: Glulams and CLT. Version 1.3 August 11, 2015. 24pp.

Cross laminated timber is produced from 2x4-12, #2 and #3 MSR[8] graded lumber dried to 12 percent (+/- 3%) moisture, oven dry basis. The production begins with the lumber entering a sorting line where it is planed to 1-3/8 inch. The lumber is then sorted by grade and moisture content. The lumber is then vertically finger jointed using a melamine-based resin (Figure 4). The finger joint lumber is cured in a radio frequency dryer. After a final quality check, the finger joint lumber is moved to assembly trays. Assembly of a 3-layer CLT panel would include higher quality lumber pieces placed as a first layer, then a melamine glue is applied, then a lower grade lumber is layered perpendicular to the first, followed by another glue application and another layer of higher grade lumber. CLT panels can be constructed in this manner to produce 3, 5, or 7-layer panels. Once the panel is assembled it is pressed using pneumatic cylinders to 110 psi for approximately 30 minutes (Figure 5). Panels exit the press and are lifted by forklift to a Hundegger CNC machine (Figure 6). Finally, the panel is sanded, wrapped and shipped directly to the construction site (Figure 7).

Figure 4 Lumber at the CLT facility is finger-jointed using MF resin and dried using radio frequency dryers.

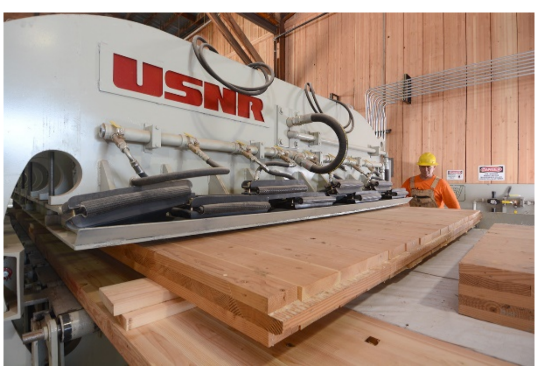

Figure 5 USNR CLT Pneumatic press for 3, 5, and 7 (max 10.5" thickness) panels (<10' wide, max length 24'. Photo credit, DR Johnson, OregonCLT.com.

[8] MSR – Machine Stressed Rated Lumber is intended for broad range of engineered applications were low variability in strength and stiffness properties is primary product considerations. http://www.wwpa.org/western-lumber/structural-lumber/structural-lumber-overview.

Figure 6 Hundegger (CNC machine). Photo source www.hundegger.de .

3.1 GOAL AND SCOPE

The goal of this study was to determine energy and material inputs and outputs associated with the production of CLT produced by DR Johnson, Riddle, Oregon, USA. The data were obtained by surveying DR Johnson. Surveys were consistent with CORRIM[9] protocols for performing LCI's of wood products, follow ISO14040/140444 standards for conducting LCA (ISO 2006b, ISO 2006c), and meet the requirements of the PCR for North American Structural and Architectural Wood Products (FPInnovations 2015).

The scope of this study was to develop a cradle-to-gate LCA to produce CLT using upstream process wood production process common to practices and technology in the Pacific Northwest U.S. It covers the impact in terms of material flow, energy type and use, emissions to air and water, solid waste production, and water impacts for the CLT process on a per unit volume basis of 1.0 cubic meter (m^3). Data for the LCA are based on gate-to-gate inputs and outputs obtained directly from the manufacturer, previously published data for gate-to-gate softwood lumber production (Milota 2015)[10] and cradle-to-gate forest resources LCI's (Oneil and Puettmann 2017)[11].

3.2 INTENDED AUDIENCE

The primary audience for the LCA report are the manufacturer and the users CLT panels for construction and other applications.

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[9] CORRIM – Consortium for Research on Renewable Industrial Materials has derived life cycle inventory (LCI) data for major wood products and wood production regions in the United States (U.S.)

[10] Milota, Mike. 2015. Life cycle assessment for the production of Pacific Northwest softwood lumber. Module B CORRIM Final Report. December 2015. 73 pp. https://corrim.org/latest-reports/.

[11] Oneil, E. and M. Puettmann. 2017. A lifecycle analysis of forest resources of the Pacific Northwest, USA. For. Prod. J. 67(5/6).

3.3 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 (ISO 2006)[12] guidelines and principles and compliance with the Wood Products PCR (FPInnovations 2015)[13].

3.4 Functional and declared unit

In accordance with the PCR, the declared unit for CLT is one cubic meter (1.0 m^3). A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building product cannot be stated (FPInnovations 2015). For conversion of units from the U.S. industry measure, 1.0 m^3 is equal to 35.31 ft^3. All input and output data were allocated to the declared unit of product based on the mass of products and co-products in accordance with standards for conducting LCA's (ISO 2006). As the analysis does not take the declared unit to the stage of being an installed building product, no service life is assigned.

3.5 System boundaries

The system boundary begins with regeneration in the forest and ends with CLT product (Figure 7). The system boundary includes forest operations (A_1), which may include site preparation and planting seedlings, fertilization and thinning, final harvest with the transportation of logs (A_2) to the primary breakdown facility, lumber production (A_3), transportation of lumber (A_2) to CLT manufacturing site, and onsite production of CLT (A_3) (Figure 7). Seedlings and the fertilizer and electricity it took to grow trees were considered as inputs to the system boundary. The CLT production complex was modeled as a single unit process. The study recognized seven steps (A_3) necessary to make CLT. Excluded from the system boundaries are fixed capital equipment and facilities, transportation of employees, land use, delivery of CLT to construction site, construction, maintenance, use, and final disposal.

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[12] ISO. 2006. Environmental management - life-cycle assessment - requirements and guidelines. ISO 14044. International Organization for Standardization, Geneva, Switzerland, pp. 54 pp.

[13] FPInnovations. 2015. Product Category Rules (PCR) North American Structural and Architectural Wood Products. Available online at https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Documents/pcr-v2.pdf; last accessed May 2016.

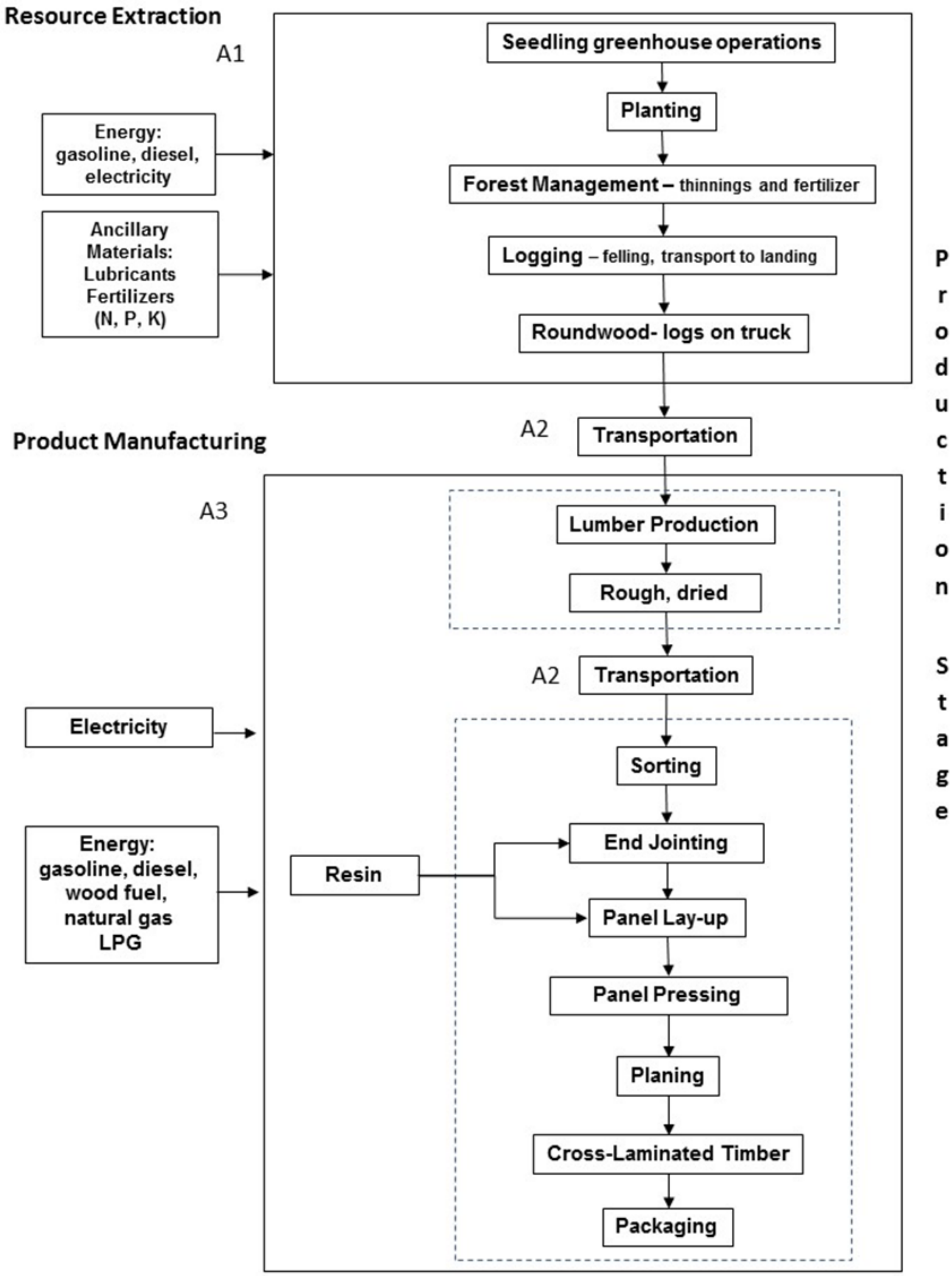

Figure 7 System boundary for cradle-to-gate CLT manufacturing.

4 LIFE CYCLE INVENTORY

4.1 GATE-TO-GATE LCI

The CLT production LCI is based on 2016 data collected from DR Johnson, Riddle Laminators, Riddle, Oregon (https://oregonclt.com). Production is based on a 120,000 cubic feet (ft^3) (10 x 24-foot panels) of CLT per year. A weighed average of three panel sizes presents the 120,000 ft^3/year and is shown in Table 2.

Table 2 Panel sizes and allocation for a weighted average CLT panel.

CLT Panel Thickness	Allocation of Panels	ft^3/panel	ft^3/year	m^3/year	Panels/year	Bf [14]/year
3-Layer Panel	30%	82.5	36,000	1,019.41	436.36	741,701
5-Layer Panel	60%	137.5	72,000	2,038.81	523.64	1,483,402
7-Layer Panel	10%	192.5	12,000	339.80	62.34	247,234
TOTAL	100%		120,000	3,398.02	1,022.34	2,472,336

4.1.1 CLT OUTPUTS

Cross laminated timber is the main product in the manufacturing process. On a mass basis, 83 percent of the input wood material is applied to the CLT product (Table 3). To stay within conformance with the PCR an economic allocation would have to be applied to the main product and coproducts as well as the feedstock production, in this case input wood material. It is assumed that of the CLT product has a value greater than 10 times the value of the coproducts (shavings, waste, off specs and end cuts). Therefore, no allocation was assigned to the coproducts allowing 100 percent of the burden allocated to CLT. In this report, we also present all results using a mass allocation for reference to several wood product LCAs that have been published (www.corrim.org).

[14] ft^3/bf = 0.049 (actual)

Table 3 Outputs to Technosphere in the LCA model.

Primary product	Unit	Amount/m³	Mass Allocation	Economic Allocation
CLT	m³	1		
CLT	odkg[15]	544.68	83%	100%
Wood Portion	odkg	537.23		
Resin portion	kg	7.45		
Coproducts				
Planar shavings	odkg	22.43	3.4%	0%
Finger joint waste	odkg	6.05	0.9%	0%
Hundegger waste	odkg	7.12	1.1%	0%
CLT off spec and end cuts	odkg	75.98	11.6%	0%

4.1.2 Transportation Inputs

The transportation of logs from the forest roadside after harvest is the first transportation process for CLT manufacturing (Table 4). Lumber is transported from a sawmill facility to CLT manufacturing. Resin is transported both by road and by barge. All transportation distances are reported in Table 4.

Table 4 Delivery distances (one-way) for resources and materials for CLT manufacturing.

Material delivered to mill	Unit	Amount	Mode of Transport
Logs to sawmill	mile (km)	67 (108)	Road
Lumber to CLT	mile (km)	169 (272)	Road
Resin	mile (km)	8,937 (14,373)	Barge
Resin	mile (km)	227 (365)	Road
Hardener	mile (km)	486 (782)	Road
Wrapping material – Packaging CLT	mile (km)	200 (322)	Road

4.1.3 Forest Resources Inputs

The wood extraction stage (A1) provides estimates of the yield and emissions associated with management of representative timber producing acres for the area west of the Cascade Mountains in Washington and Oregon, in what is commonly called the Pacific Northwest (PNW) Douglas-fir region. Data for resource extraction is based on the cradle-to-gate LCA by Oneil and Puettmann (2017) and adjusted where necessary to represent only Douglas-fir. This region is dominated by temperate coniferous rainforests comprised mainly of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), with other species such as spruce *(Picea spp.),* true firs (*Abies* ssp.) and western redcedar (*Thuja plicata*) making up a smaller component

[15] odkg = oven dry mass in kilograms

of the harvested softwood volume. Only the harvest of Douglas-fir timber is considered in the LCA on CLT. Harvest are predominately from large private and industrial landowners (Oneil and Puettmann 2017). The gate-to-gate process for PNW forest operations considers landscape level impacts and the potential impacts to soil carbon and biodiversity are outside the scope of this analysis. Under a mass allocation approach, roundwood harvested and delivered from the roadside was ???? and 1.86 m3/m3 of CLT using an economic allocation.

4.1.4 LUMBER INPUTS

Douglas-fir kiln dried rough saw lumber in the wood input for CLT (Table 5). Lumber is produced in Oregon follows processes outlined by Milota (2015). Rough dry lumber is delivered by truck 169 miles from supplier located in Mill City, Oregon to the CLT facility. The weighted average amount of wood only in a CLT panel is 537 kg/m^3 requiring a total of 649 kg of oven dry rough lumber or 1.21 cubic meters. In the economic allocation model, 100 percent of the input lumber is burdened to the CLT, while under a mass allocation model, only 83 percent of the 649 kg of lumber input would be assigned to CLT.

Table 5 Lumber inputs to the CLT manufacturing process(unallocated) .

Lumber Inputs	Unit	Amount/m^3
Lumber	m^3	1.21
Lumber	odkg	648.81
Lumber delivery by truck	tkm	176.46

4.1.5 RESIN INPUTS

Melamine formaldehyde resin is used for both finger jointing and face bonding. The manufacturer is AkzoNobel, which produced a low emission, melamine 2-part clear glue. It is LEED Gold certified and approved for interior and exterior use. The resins mixture is sourced both locally and internationally and requires both road and ocean modes of transport (Table 6).

Table 6 Resin inputs to the CLT manufacturing process (unallocated).

Resin Inputs	Unit	Amount/m^3
MF resin	kg	7.45
MF resin transport - ship	tkm	107.10
MF resin transport - Truck	tkm	2.72

4.1.6 *ENERGY INPUTS*

Energy requirements come from electricity, natural gas, and diesel fuel at the DR Johnson CLT facility (Table 7). Electricity was modeled using the Northwest Power Pool Grid which includes coal, biomass, petroleum, geothermal, natural gas, nuclear, hydroelectric, wind, and other energy sources (NWPP 2010)[16]. The source of fuel used to generate electricity help determine the type and amount of impact in the overall LCA. The proportional breakdown of electricity used for CLT is shown in Figure 8. Non-renewable fossil represents nearly 60 percent of the fuel source, where hydro, wind, solar, and geothermal comprise about 41 percent of the electricity fuel sourcing.

Table 7 On-site energy use for CLT manufacturing process (unallocated).

Energy Inputs	Unit	Amount/ m^3
Electricity	kWh	98.90
Natural gas	m^3	4.18
Diesel	L	0.05

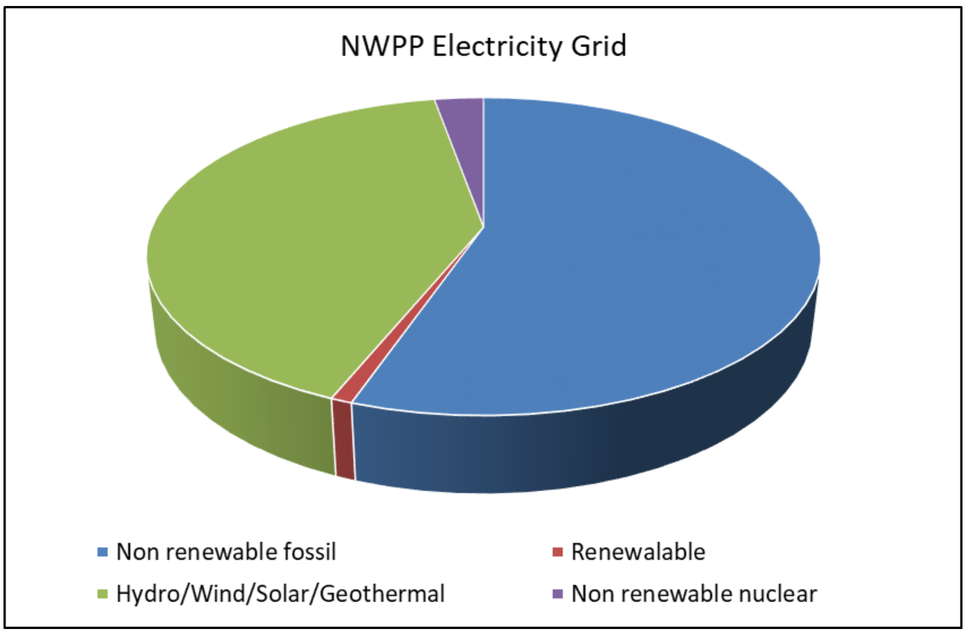

Figure 8 Fuel used in eelectricity production for the Pacific Northwest (NWPP 2010) for CLT manufacturing.

[16] IEA Statistics for Electricity/Heat in Mexico in 2009 /2011/International Energy

ANCILLARY MATERIALS INPUTS

Much of the machinery, both mobile and stationary, require hydraulic fluids, lubricants, antifreeze, and packaging. These amounts per cubic meter of CLT produced are in Table 8.

Table 8 Ancillary material inputs in the CLT manufacturing process (unallocated).

Ancillary Inputs	Unit	Amount/ m^3
Hydraulic fluid	L	0.0006
Lubricants	L	0.0022
Antifreeze	L	0.0002
Lumber wrap	m^2	0.0406
Lumber wrap	kg	0.3800
Consumables Transportation	tkm	0.1223

4.2 CRADLE-TO-GATE LCI

The cradle-to-gate LCI model was developed by linking the CLT gate-to gate production model to a western softwood lumber gate-to-gate LCI model (Milota 2015) which was then linked to a gate-to-gate LCI model of Pacific Northwest forestry operations (Oneil and Puettmann 2017). Western softwood lumber production includes transportation of logs to the sawmill, log yard, sawmilling, drying, and packaging processes. Forestry operations includes average harvesting scenarios, reforestation operations including seedling growth, planting, pile and burn of logging residue, herbicide and fertilizer applications, and transportation of the logs to the roadside. Western softwood rough dry lumber represents the lumber grades presented in section 4 of this report as input into the CLT manufacturing gate-to-gate model. Both mass and economic allocation models are reported.

5 LIFE CYCLE IMPACT ASSESSMENT

5.1 LCIA METHODOLOGY

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 9. Environmental impacts are determined using the TRACI method (Bare et al. 2011)[17]. These five impact

[17] Bare, J. C. 2011. TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Techn. Environ Policy. 21 January 2011.

categories are reported and consistent with the requirements of the wood products PCR (FPInnovations 2015).

Table 9 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 sulfur dioxide equivalent for releases of acid forming chemicals such as sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of SO_2 is used as a reference unit.	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photo-chemically oxidized. Smog forming potential of O_3 is used as a reference unit.	Photochemical smog
Releases to air potentially resulting in eutrophication of water bodies	Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit.	Eutrophication

Each impact indicator is a measure of an aspect of a potential impact. This LCIA does not make value judgments about the impact indicators, meaning 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.

The Cumulative Energy Demand[18] (CED) impact method was used for summarizing primary energy (coal, oil, natural gas, nuclear, biomass, hydro, and other renewables). The primary fuels are further categorized into non-renewable fossil, non-renewable nuclear, non-renewable biomass, renewable biomass, hydroelectric, and other (wind, solar, geothermal). The CED impact method was adjusted to include the mill residues used for heat energy in the western softwood lumber model. Table 10 summarizes the source and scope of each impact category reported in this report.

Table 10 Impact category sources and scope.

Impact category	Unit	Method	Level of site specificity
Global warming	kg CO_2 eq	TRACI 2.1 v1.01	Global
Smog	kg SO_2 eq	TRACI 2.1 v1.01	North America
Acidification	kg N eq	TRACI 2.1 v1.01	North America
Ozone depletion	kg CFC-11 eq	TRACI 2.1 v1.01	North America
Eutrophication	kg O_3 eq	TRACI 2.1 v1.01	North America
Total energy	MJ	CED	Global
Non-renewable fossil	MJ	CED	Global
Non-renewable nuclear	MJ	CED	Global
Renewable woody biomass	MJ	CED - modified	Global
*Other renewables**	MJ	CED	Global

∗ solar, wind, hydro, geothermal

5.2 LCIA Results

5.2.1 Cradle-to-gate LCIA Results

Environmental performance results for global warming potential (GWP), acidification, eutrophication, ozone depletion and smog, calculated using the TRACI impact method are reported in Table 11. Cumulative Energy Demand impact method results are also reported in Table 11 as total energy and energy generated from non-renewables, renewables, wind, hydro, solar, and nuclear fuels.

5.2.1.1 Economic Allocation

The economic LCIA is based on 100 percent of the upstream inputs allocated to the CLT finished product. There is no waste wood product sent to a landfill and the wood waste generated by

[18] Cumulative Energy Demand (CED), based on the method published by Ecoinvent version 2.0 and expanded by PRé Consultants for raw materials available in the SimaPro 7 database.
Frischknecht R., Jungbluth N., et.al. (2003). Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000, Swiss Centre for LCI. Duebendorf, CH, www.ecoinvent.ch

finger jointing, planning, and the Hundegger is sent for energy or to other wood processing facilities such as particleboard. It is assumed the value of the coproducts is less than 10 percent of the value of CLT therefore, 100 percent of the burdens are allocation to CLT. Lumber production was also modeled using an economic allocation (Milota 2015)

Results in Table 11 are presented for forestry operations (regeneration, management, and final harvest), softwood lumber production (transport of logs, lumber sawing, drying, and packaging), and CLT production. For GWP, 57 percent of the CO_2 equivalent emissions come from manufacturing the CLT. Lumber production and forestry operations account for 28 and 16 percent of the global warming impact, respectively.

Energy calculations are from the CED impact assessment methods (Table 11). Cross laminated timber manufacturing consumed 31 percent of the total cradle-to-gate energy, with lumber production consuming 63 percent and forestry operations 5 percent. Renewable biomass fuels represented the greatest proportion of energy consumed (51%) for total cradle-to-gate energy use. Non-renewable fossil fuels represented 49 percent of the total primary energy. Non-renewable nuclear and renewable (solar/hydro/wind/etc.) represent less than 0.5 percent of the total primary energy. Overall, the manufacture of CLT in Oregon is around 50 percent energy self-sufficient with its *on-site use* of renewable biomass for the lumber production process when an economic allocation is used. Table 12 reports the three life cycle stages on percentage basis. Figure 9 shows the contribution of each life cycle stage to each TRACI impact category and total energy (CED impact method). An important to note for Figure 9; CLT represents 57 percent of the global warming potential impacts (GWP), while lumber production used 63 percent of the total energy. There is normally a direct correlation between energy use and GWP. Nearly half the energy used to produce softwood is from renewable biomass fuel and is considered carbon neutral. The CO_2 emission from combustion of the biomass fuel is not included in the GWP totals in Tables 11 and 12 and Figure 9. The calculated global warming impact is limited to anthropogenic emissions of fossil carbon and does not include biogenic CO_2 emissions. Therefore, a higher energy demand is reported with a low carbon impact.

Producing 1 m^3 of CLT results in the production of 206 kg of greenhouse gases, on a CO_2 equivalent basis, of which 57 percent can be traced to the CLT manufacturing (includes resin and transportation of all materials and resources) process. The calculated global warming impact is limited to anthropogenic emissions of fossil carbon and does not include biogenic CO_2 emissions.

Table 11 Cradle-to-gate LCIA results for 1 m^3 of CLT (Economic Allocation).

Impact category	Unit	Total	CLT Manufacturing	Lumber Production	Forestry Operations
			A2 & A3		A1
Global warming	kg CO2 eq	206.26	116.75	57.26	32.25
Smog	kg O3 eq	41.98	11.57	12.27	18.14
Acidification	kg SO2 eq	2.27	0.96	0.62	0.69
Eutrophication	kg N eq	0.11	0.05	0.02	0.04
Ozone depletion	kg CFC-11 eq	0.0	2.08E-06	8.43E-09	2.90E-08
Total Energy	MJ	**5,839.96**	**1,832.03**	**3,706.50**	**301.43**
Non-renewable, fossil	MJ	2,954.8	1,803.69	847.01	301.19
Non-renewable, nuclear	MJ	24.71	24.45	0.03	0.23
Renewable, biomass	MJ	2,859.65	0.62	2,859.03	0.00
Renewable, wind, solar, geothermal	MJ	0.84	0.84	0.00	0.00
Renewable, water	MJ	2.86	2.43	0.43	0.00

Table 12 Allocation of cradle-to-gate LCIA results for 1 m^3 of CLT (Economic Allocation).

Impact category	Total	CLT Manufacturing	Lumber Production	Forestry Operations
		A2 & A3		A1
Global warming	100%	57%	28%	16%
Acidification	100%	42%	27%	31%
Eutrophication	100%	47%	20%	33%
Smog	100%	28%	29%	43%
Ozone depletion	100%	98%	0%	1%
Total Energy	100%	**31%**	**63%**	**5%**
Non-renewable, fossil	100%	61%	29%	10%
Non-renewable, nuclear	100%	99%	0%	1%
Renewable, biomass	100%	0%	100%	0%
Renewable, wind, solar, geothermal	100%	100%	0%	0%
Renewable, water	100%	85%	15%	0%

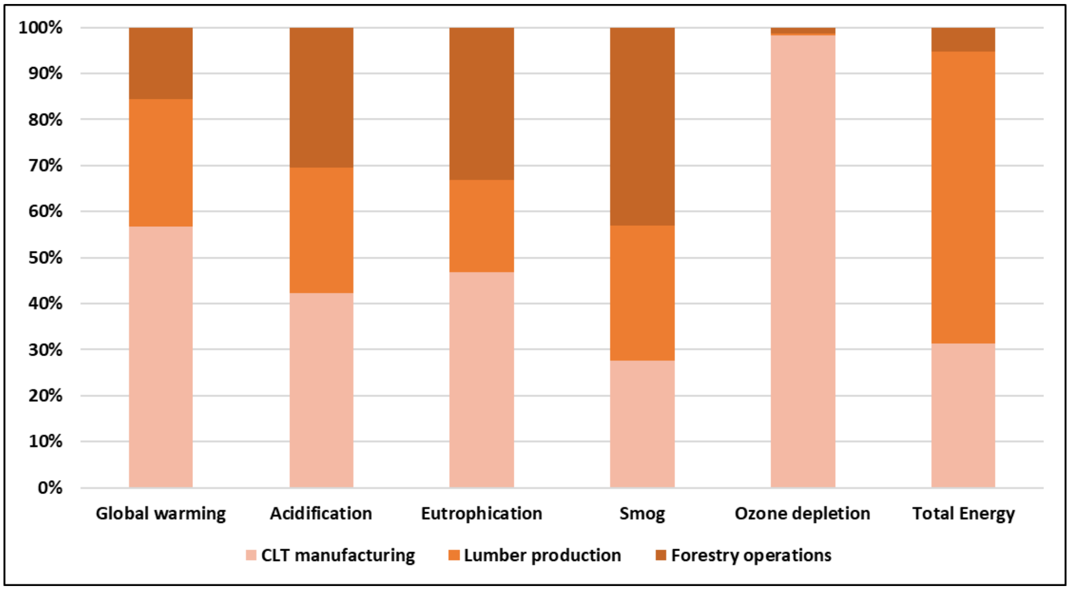

Figure 9 Cradle-to-gate impact assessment results showing contribution by life cycle stage (CLT manufacturing, lumber production, and forestry operations) (Economic Allocation)(A1-A3).

5.2.1.2 Mass Allocation

Using the mass allocation approach, both lumber CLT production impacts are allocated to the main product and coproducts according to their mass, not the economic value. In CLT production that resulted in 83 percent of the mass of the input material (Lumber production) was allocated to CLT. The remaining 17 percent of the input material and all associated upstream impacts remained with the coproducts. Furthermore, all energy, materials, and resin consumed onsite would be allocated based on the mass of the products, 83 and 17 percent for CLT and coproducts, respectively. See Milota (2015) for differences in mass and economic allocation LCA results for lumber production.

Results in Table 13 are presented for forestry operations (regeneration, management, and final harvest), softwood lumber production (transport of logs, lumber sawing, drying, and packaging), and CLT production. Using the mass allocation model, 61 percent of the CO_2 equivalent emissions come from manufacturing the CLT. Lumber production and forestry operations account for 27 and 12 percent of the global warming impact, respectively.

The mass allocation model lowered the total energy consumption by 19 percent. Cross laminated timber manufacturing consumed 32 percent of the total cradle-to-gate energy (17% lower of the economic allocation), with lumber production consuming 64 percent and forestry operations 4 percent. Renewable biomass fuels represented the greatest proportion of energy consumed (51%) for total cradle-to-gate energy use. Non-renewable fossil fuels represented 49 percent of the total primary energy. Non-renewable nuclear and renewable (solar/hydro/wind/etc.) represent less than 0.5 percent of the total primary energy. Table 14 reports the three life cycle stages on percentage basis. Figure 10 shows the contribution of each life cycle stage to each TRACI impact category and total energy (CED impact method).

Producing 1 m^3 of CLT results in the production of 159 kg of greenhouse gases, on a CO_2 equivalent basis, of which 61 percent can be traced to the CLT manufacturing (includes resin and transportation of all materials and resources) process.

Table 13 Cradle-to-gate LCIA results for 1 m^3 of CLT (Mass Allocation).

Impact category	Unit	Total	CLT Manufacturing	Lumber Production	Forestry Operations
			A2 & A3		A1
Global warming	kg CO2 eq	158.67	97.06	42.71	18.90
Smog	kg O3 eq	1.72	0.80	0.52	0.41
Acidification	kg SO2 eq	0.09	0.04	0.02	0.02
Eutrophication	kg N eq	30.90	9.66	10.61	10.63
Ozone depletion	kg CFC-11 eq	1.75E-06	1.73E-06	9.29E-09	1.70E-08
Total Energy	MJ	**4,716.34**	**1,523.01**	**3,016.66**	**176.67**
Non-renewable, fossil	MJ	2,298.80	1,499.48	622.78	176.54
Non-renewable, nuclear	MJ	20.47	20.29	0.05	0.14
Renewable, biomass	MJ	2,394.08	0.52	2,393.57	0.00
Renewable, wind, solar, geothermal	MJ	0.70	0.70	0.00	0.00
Renewable, water	MJ	2.29	2.02	0.27	0.00

Table 14 Allocation of cradle-to-gate LCIA results for 1 m^3 of CLT (Mass Allocation).

Impact category	Total	CLT Manufacturing	Lumber Production	Forestry Operations
		A2 & A3		A1
Global warming	100%	61%	27%	12%
Acidification	100%	46%	30%	24%
Eutrophication	100%	51%	23%	26%
Smog	100%	31%	34%	34%
Ozone depletion	100%	98%	1%	1%
Total Energy	100%	**32%**	**64%**	**4%**
Non-renewable, fossil	100%	65%	27%	8%
Non-renewable, nuclear	100%	99%	0%	1%
Renewable, biomass	100%	0%	100%	0%
Renewable, wind, solar, geothermal	100%	0%	100%	0%
Renewable, water	100%	100%	0%	0%

Figure 10 Cradle-to-gate impact assessment results showing contribution by life cycle stage (CLT manufacturing, lumber production, and forestry operations) (Mass Allocation)(A1-A3).

5.2.2 GATE-TO-GATE LCIA RESULTS

The gate-to-gate results include those operations directly associated with the onsite production of CLT. Those stages considered in the gate-to-gate LCIA results are transportation of the resources to the facility, packaging material production, resin production, and energy used on-site to produce the CLT panels. Economic allocation results are in Table 15 and Table 16 and Figure 11 and represent 100 percent of the input streams. Tables 17 and 18 and Figure 12 are the mass allocation results where CLT encompasses 83 percent of all inputs.

Table 15 Gate-to-gate LCIA results for 1 m^3 of finish CLT (Economic Allocation).

Impact category	Unit per m³ of CLT	CLT GtoG Onsite Total	CLT Onsite Energy	Transport Lumber	Transport resin	Packaging Material	Resin
Global warming	kg CO2 eq	116.70	59.12	16.85	3.80	0.51	36.42
Acidification	kg SO2 eq	0.96	0.51	0.23	0.04	0.01	0.16
Eutrophication	kg N eq	0.0534	0.0068	0.0139	0.0022	0.0003	0.0302
Smog	kg O3 eq	11.56	3.32	5.96	1.11	0.05	1.12
Ozone depletion	kg CFC-11 eq	2.08E-06	8.57E+02	7.12E-10	0.00	3.94E-09	2.07E-06
Total Energy	MJ	**1,831.21**	**857.24**	**253.20**	**51.63**	**19.20**	**649.93**
Non-renewable, fossil	MJ	692.49	0.00	0.00	51.63	19.19	621.67
Non-renewable, nuclear	MJ	24.45	0.00	0.00	0.00	0.01	24.44
Renewable, biomass	MJ	0.00	0.00	0.00	0.00	0.00	0.62
Renewable, wind, solar, geothermal	MJ	0.00	0.00	0.00	0.00	0.00	0.84
Renewable, water	MJ	0.00	0.00	0.00	0.00	0.00	2.36

Table 16 Allocation of gate-to-gate LCIA results for 1 m^3 of finish CLT (Economic Allocation).

Impact category	CLT Onsite Energy	Transport Lumber	Transport resin	Packaging Material	Resin
Global warming	51%	14%	3%	0%	31%
Acidification	53%	24%	5%	1%	17%
Eutrophication	13%	26%	4%	1%	57%
Smog	29%	52%	10%	0%	10%
Ozone depletion	100%	0%	0%	0%	0%
Total Energy	**47%**	**14%**	**3%**	**1%**	**35%**
Non-renewable, fossil	48%	14%	3%	1%	34%
Non-renewable, nuclear	0%	0%	0%	0%	100%
Renewable, biomass	0%	0%	0%	0%	100%
Renewable, wind, solar, geothermal	0%	0%	0%	0%	100%
Renewable, water	0%	0%	0%	0%	100%

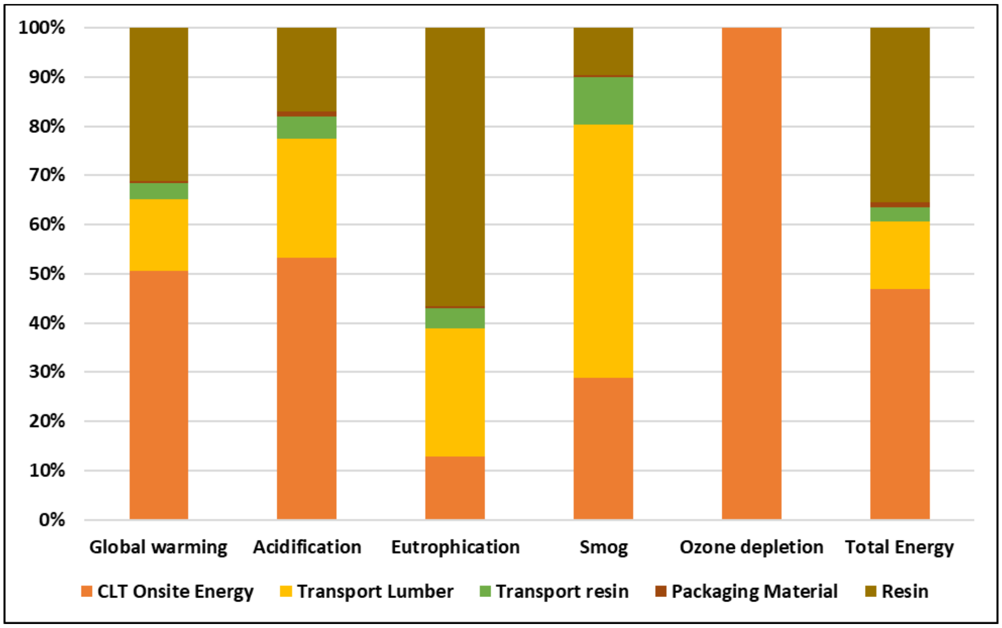

Figure 11 Gate-to-gate impact assessment results showing contribution by life cycle stage (CLT manufacturing, lumber production, and forestry operations) (Economic Allocation.)

Table 17 Gate-to-gate LCIA results for 1 m^3 of finish CLT (Mass allocation).

Impact category	Unit per m^3 of CLT	CLT GtoG Onsite Total	CLT Onsite Energy	Transport Lumber	Transport resin	Packaging Material	Resin
Global warming	kg CO2 eq	96.85	49.07	13.94	3.16	0.47	30.21
Acidification	kg SO2 eq	0.80	0.42	0.19	0.04	0.01	0.14
Eutrophication	kg N eq	0.0443	0.0057	0.0115	0.0018	0.0003	0.0250
Smog	kg O3 eq	9.58	2.76	4.93	0.92	0.05	0.93
Ozone depletion	kg CFC-11 eq	1.73E-06	7.12E+02	7.12E-10	0.00	3.94E-09	2.07E-06
Total Energy	MJ	**1,521.34**	**711.51**	**210.16**	**42.86**	**17.68**	**539.14**
Non-renewable, fossil	MJ	1,497.89	711.51	210.16	42.86	17.67	515.70
Non-renewable, nuclear	MJ	20.28	0.0000	0.0000	0.0000	0.0089	20.27
Renewable, biomass	MJ	0.52					0.52
Renewable, wind, solar, geothermal	MJ	0.70					0.70
Renewable, water	MJ	1.96				0.0005	1.96

Table 18 Allocation of gate-to-gate LCIA results for 1 m^3 of finish CLT (Mass Allocation).

Impact category	CLT Onsite Energy	Transport Lumber	Transport resin	Packaging Material	Resin
Global warming	51%	14%	3%	0%	31%
Acidification	53%	24%	5%	1%	17%
Eutrophication	13%	26%	4%	1%	57%
Smog	29%	52%	10%	0%	10%
Ozone depletion	100%	0%	0%	0%	0%
Total Energy	**47%**	**14%**	**3%**	**1%**	**35%**
Non-renewable, fossil	48%	14%	3%	1%	34%
Non-renewable, nuclear	0%	0%	0%	0%	100%
Renewable, biomass	0%	0%	0%	0%	100%
Renewable, wind, solar, geothermal	0%	0%	0%	0%	100%
Renewable, water	0%	0%	0%	0%	100%

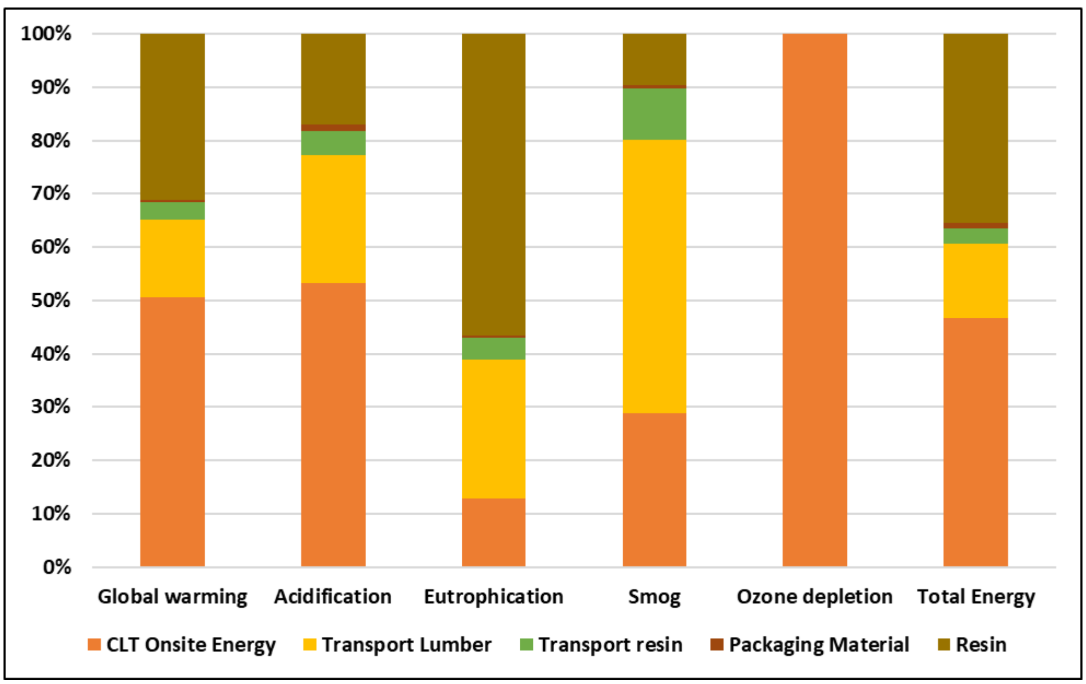

Figure 12 Gate-to-gate impact assessment results showing contribution by life cycle stage (CLT manufacturing, lumber production, and forestry operations) (Mass Allocation).

5.3 Biogenic Carbon Accounting

Treatment of biogenic carbon is consistent with the Intergovernmental Panel for Climate Change (IPCC 2006)[19] 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 is based on the PCR (FPInnovations 2015). This 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 during the combustion of woody biomass during production processes. Other emissions associated from wood combustion, e.g., methane or nitrogen oxides, are considered a greenhouse gas emission and are included in the global warming impact category. For a complete list of emissions factors for the TRACI global warming impact method, see Bare et al. (2011). Using this method, 206 kg CO_2eq were released in the production of 1 m^3 of CLT (ready for installation). That same 1 m^3 of CLT stores 985 kg CO_2eq based on the wood portion the finished panel 537 kg and a carbon content of 50% (Table 19). On a mass allocation basis, because the emissions allocated to CLT are less, the net emission is a negative 826 kg of CO_2 (Table 20).

Table 19 Net Cradle-to-gate carbon emissions (Economic Allocations).

Cradle-to-gate	kg CO_2 equivalent
Forestry operations	32
Lumber production	57
CLT manufacturing	117
CO_2 eq. stored in product[20]	-985
Net cradle-to-gate carbon emissions	-778

[19] IPCC 2006. Task Force on National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/faq/faq.html. Accessed October 2, 2012.

[20] To convert to CO2 in product, convert total wood to carbon (we assumed a carbon content of 50%) then divide by 44/12.

Table 20 Net Cradle-to-gate carbon emissions (Mass Allocations).

Cradle-to-gate	kg CO_2 equivalent
Forestry operations (A1)	19
Lumber production (A2 A3)	43
CLT manufacturing (A2 A3)	97
CO_2 eq. stored in product	-985
Net cradle-to-gate carbon emissions	-826

5.4 Other PCR Reporting Requirements

5.4.1 Economic Allocation

There is 999 kg of wood fiber consumed from cradle to gate to produce 1 cubic meter of finished CLT. The wood fiber begins as a log at the forest road. When it arrives at the mill, approximately halt ends up as finished rough lumber and the rest in co-products (chips, residues, and wood fuel). On average, the wood fuel represents about 22 percent of the co-product and is used for drying lumber. Total wood fiber represents all the wood consumed from cradle to gate to produce 1 m3 of CLT including wood fuel, stickers, etc.

The non-renewable resources are inputs in fuel productions and electricity production used at the lumber mill, CLT plant, resin production, and transportation. They can be inputs into diesel, gasoline, natural gas, oils, lubricants, and resin production.

Water consumed (50%) during lumber production was reported used in the log yard where logs are commonly sprayed on log decks to prevent staining and cracking of the logs. The water allocated to CLT production is from the resin production. Very little solid waste is generated from cradle to gate. Common reported waste is packing material and “dirty” wood waste generated in the log yard.

Table 21 Raw resource inputs and waste to produce 1 m^3 of CLT, cradle to gate (Economic Allocation).

	Unit	CLT Manufacturing	Lumber Production	Forestry Operations	Total
		A2 & A3		A1	
Renewable Resources					
Wood Fiber	kg			999.26	999.26
Non-Renewable Resources					
Coal, in ground	kg	22.42	9.95	0.40	32.78
Gas, natural, in ground	kg	14.85	4.92	0.44	20.21
Oil, crude, in ground	kg	9.16	6.92	5.83	21.91
Uranium oxide, in ground	kg	1.12E-04	6.13E-05	7.97E-06	1.81E-04
Uranium, in ground	kg	4.36E-05	3.22E-08	4.12E-07	4.41E-05
Water	L	381.20	417.99	29.50	828.68
Solid waste	kg	17.57	4.65	0.31	22.54

5.4.2 *MASS ALLOCATION*

There is less fiber allocated to CLT when a mass allocation is used (585kg). The non-renewable resources all were lower using a mass allocation approach.

Table 22 Raw resource inputs and waste to produce 1 m³ of CLT, cradle to gate (Mass Allocation).

	Unit	CLT Manufacturing	Lumber Production	Forestry Operations	Total
		A2 & A3		A1	
Renewable Resources					
Wood Fiber	kg			585.30	585.30
Non-Renewable Resources					
Coal, in ground	kg	18.62	7.11	0.24	25.97
Gas, natural, in ground	kg	12.33	3.95	0.26	16.54
Oil, crude, in ground	kg	7.65	4.81	3.42	15.88
Uranium oxide, in ground	kg	9.29E-05	4.45E-05	4.67E-06	1.42E-04
Uranium, in ground	kg	3.62E-05	6.12E-08	2.42E-07	3.65E-05
Water	L	316.39	336.92	17.29	670.6
Solid waste	kg	14.59	3.46	0.18	18.23

6 CONCLUSIONS

6.1 ASSUMPTIONS

DR Johnson CLT production is new and several updates have been made to the manufacturing of CLT since data was collected, eg. installation of a Hundegger CNC machine. Assumptions were made about electricity, natural gas, and other fuels use allocated to CLT were needed. DR Johnson allocated 30 percent of the total on site electricity use to CLT production. 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. A contribution analysis was applied for the interpretation phase of this LCA study (Figures 9-12). Contribution analysis examines the contribution of life cycles stages, unit process contributions in a multi-unit manufacturing process, or specific substances which contribute to an impact category. In the study, CLT manufacturing contributed the greatest to the global warming impact category, while the softwood lumber production stage consumed the most energy (Figures 9 and 10). Natural gas use is the main contributor to the GWP value for CLT, while biomass represents 75 percent of the energy for lumber production. Reducing the amount of natural gas use at the CLT manufacuturing would help the the cradle to gate carbon footprint. Under current natural gas use, CLT production represents a negative carbon net emission of 784 kg CO2 eq.

Resin production also had a significant contribution to the GWP and eutrophication impact categories (Table) for CLT. In two impact categories, resin contributed 31 and 57 percent to GWP and eutrophication, respectively. The resin used in the production of DR Johnson CLT is a non-urea melamine-formaldehyde resin which has a larger impact for production than commonly used melamine-urea-formaldehyde resins commonly used in structure timbers in North America.

6.2 COMPLETENESS

Evaluating the LCA's completeness and consistency offers confidence in and the 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, softwood lumber production, and CLT manufacturing) 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 significant data gaps were identified. Both the forestry and lumber production processes used in this CLT manufacturing CLT are based on recent LCI primary data collected from logging operations and lumber producers in the PNW.

6.3 LIMITATIONS AND RECOMMENDATIONS

This study provides a comprehensive cradle-to-gate LCA of cross-laminated timber manufacturing in Oregon. The goal of this study was to develop a LCA that could be used to develop an EPD in accordance with the Wood PCR standards (FPInnovations 2015). This LCA incorporates the necessary scope to develop a "business-to-business" EPD in accordance with the Wood PCR (FPInnovations 2015). The EPD would only include the economic allocation results present in this report

This report is all inclusive in that it reports both cradle-to-gate LCI and the LCIA of CLT manufacturing. The cradle-to-gate LCA for CLT is representative of DR Johnson production CLT and energy inputs. Two allocation methods are reported, an economic and mass allocation. In the economic allocation, 100 percent of the CLT manufacturing impacts and upstream inputs were assigned to the CLT product. Under the mass allocation approach, 83 percent of the onsite and upstream burdens are assigned to the CLT product. As per the PCR, the wood feedstock input was also allocated on an economic or mass allocation. In general, a mass allocation approach will yield lower impacts values for the final product. In the case of CLT this can be significant because the lumber production allocation can change from a 50 percent to a 86 percent for mass and economic allocation, respectively. In addition, lumber prices are volatile and changes in an economic value can change significantly over a year.

The CLT manufacturing stage drives most of the environmental impacts from cradle-to-gate. This is primarily due to resin production and CLT onsite energy consumption, primarily natural gas. Softwood lumber production consumes most of the energy, due to drying of the lumber prior to transport. Life cycle impact categories are mostly driven by the type of fuel used and if a material is produced using non-renewable or renewable resources. The majority of the biomass fuel is used during softwood lumber production, while fossil fuels remain the main energy source during CLT production as seen by the global warming impact. Wood waste is generated during CLT manufacturing (~17% of input) and is used for energy at DR Johnson lumber mill (not associated with CLT manufacturing) or sold to particleboard manufacturing offsite. No wood waste is burned on site or sent to landfill.

Carbon is released as CO_2 during all life cycle stages. Cross laminated timber stores 985 kg CO_2 eq. and releases from cradle-to-gate 206 and 159 kg CO_2 eq for economic and mass allocation, respectively. In summary, CLT stores more carbon than is released in its production – a finding worthy of communicating to users of this product.

Recommendations for continuing LCA coverage of CLT include, but not limited to:

1) modeling use and end-of-life life cycle phases,

2) evaluate alternative equivalent building structures,

3) investigate the influence of substituting the use of renewable biomass fuel on fossil fuels on site at CLT production,

4) evaluate transportation impacts for both the lumber and resin,

5) evaluate domestically produced resin,

6) re-survey DR Johnson for co-product production and electricity use.

Presenting results for CLT on cubic meter basis does not indicate the reduction benefit of not using non-renewable fossil-based building materials. Performing a LCA using a functional unit such as a square meter or entire structure built with CLT versus a concrete or steel framed structure will show the real benefits of CLT. Figure 13 shows how CLT can displace carbon emissions when compared to other structural components and assemblies. In a square meter of wall assembly, CLT with an interior gypsum covering displaces 119 kg of CO_2. While concrete and steel wall assemblies emit 39 and 7 kg of CO_2, respectively. Although the results presented in Figure 13 are preliminary, they do show that less carbon is emitted and subsequently stored when wood is included in building structures.

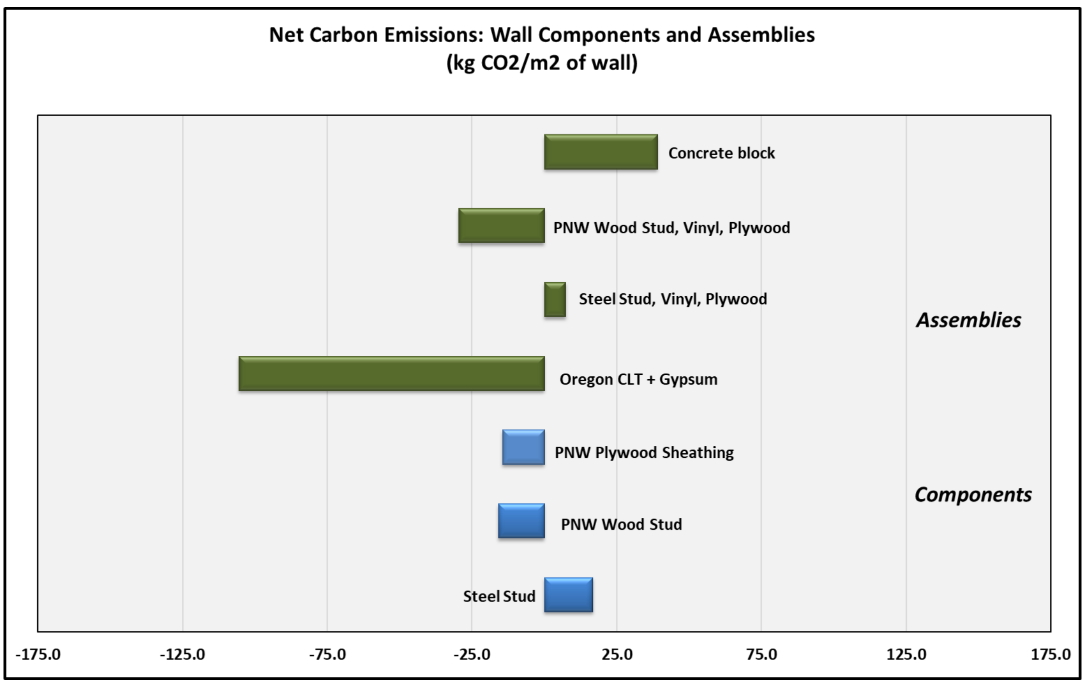

Figure 13 Net carbon emission for four assemblies and three components for a square meter of wall[21].

[21] Figure 13 is based on preliminary results (Puettmann and Lippke, unpolished work) and only included in this report for information purposes only. If this report is used to produce an EPD, Figure 13 will be removed.