CORRIM REPORT - Module D1
Life Cycle Assessment of Softwood Plywood Production in the US Pacific Northwest

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Information contained in this report is based on new survey data (2012) and supersedes information in the original Phase I report (Wilson and Sakimoto 2004). 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 Softwood Plywood 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

This report provides an update of the life cycle inventory (LCI) data for structural plywood produced in the Pacific Northwest (PNW) region of the U.S. Softwood plywood producers were invited to provide input and output data for the production year 2012. The collected data were from mills that accounted for 75 percent of the total production output in the PNW region that year.

The new primary data covered the gate-to-gate manufacturing inputs, outputs and on-site emissions. Production-weighted average values were determined based on the functional unit of one thousand square feet (MSF) 3/8-inch basis (0.885 m^3). An updated life cycle assessment (LCA) from cradle-to-gate required secondary data for the forestry operations, electricity, resin and thermal energy production. These data were assessed using SimaPro 8.0+, a LCA software package, and using the 'Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts' (TRACI) model.

The results of this study will contribute to the environmental product declaration (EPD) for North American softwood plywood and will assure compliance with the data quality requirements of the relevant classification standard the Product Category Rule (PCR) for North American Structural and Architectural Wood Products.

Nine plywood manufacturing plants in the PNW were surveyed. 2.468 million cubic meters (m^3) (2.789 million (MSF) 3/8-inch basis in 2012, representing 75 percent of the total production in the PNW region. A unit process approach was taken in modeling the LCI of manufacturing plywood. The plywood process was defined in terms of six sub-unit processes—bucking and debarking, block conditioning, peeling and clipping, drying, lay-up and pressing, and trimming and sawing.

As expected, the major use of electricity and heat (generated with fuel) were the drying and pressing sub-unit processes and to a lesser extent the conditioning process. The same was true of emissions. Plywood production required 2.2 GJ of thermal energy, of which, 98 percent was generated from wood biomass. The electricity use per cubic meter of plywood is 145 kWh. Roundwood requirement per cubic meter of finished plywood was 640 kg.

Carbon dioxide (CO_2), a greenhouse gas of international interest, is generated by combustion of fuels. Since a major portion of the heat generation for the production of plywood was based upon wood biomass; this type of fuel contributed 74 percent the total CO_2 emissions (cradle to gate) but since the combustion of biomass is consider carbon neutral this impact is greatly lessened by the growing of trees that remove CO_2 from the atmosphere resulting in global warming potential of 143 kg of CO_2 eq.

The quality of the data for the PNW plywood LCA is considered very good. Based on the amount of data from the nine plants from each region, and comparison of values from previous LCIs on plywood, established the validity of the data. Additional data analysis (i.e., mass and energy balances), as well as regional comparisons, further supported the integrity of our findings. The unit process approach for modeling the LCA of plywood should prove useful for modeling other similar processes such as laminated veneer lumber (LVL) production, which uses green and dry veneer to produce product.

Acknowledgments

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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

List of figures

List of tables

1. Background

This document is part of a project to update the life cycle inventories for major wood products produced in the United States (U.S.). Softwood structural plywood manufacturing data were collected for the production years 2012 from mills in the US Pacific Northwest (PNW) and the US Southeast (SE). Only results for the PNW region are reported here, unless otherwise noted. This report also includes updated data for the thermal energy production (boiler operations).The updated LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare 2011). These updates are necessary for the development of environmental product declarations (EPD), which will be based on this document. This report builds on previous CORRIM LCI reports (Puettmann, et al. 2013, Wilson and Sakimoto 2004) . This report 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 wood product EPD. This report does not include comparative assertions. The study reports LCIA results for both mass and economic allocation to produce one cubic meter of finished softwood plywood.

2. Goal and scope of work

The goal of this work was to document energy and material inputs, outputs and emissions associated with the production of structural plywood in PNW region of the U.S. The data were obtained through a survey of manufacturers, in a process consistent the Consortium for Research on Renewable Industrial Materials (CORRIM) guidelines and following International Organization for Standardization (ISO) protocols (ISO 2006) and the PCR (FPInnovations 2015).

The scope of this study is cradle-to-gate, and covers the impacts of input materials, fuels, and electricity through to the plywood product at the mill gate, and associated emissions and waste. The logs used for plywood production are obtained from the forest resource base in the PNW region of the U.S. (Johnson, et al. 2005). The report does not consider how the product is used.

3. Description of plywood industry in the US Pacific Northwest (PNW)

The total production of softwood plywood in the PNW region was 2.468 million cubic meters (m^3) (2.789 million (MSF) 3/8 inch basis in 2012 (APA 2013). The surveyed mills (n=9) located in the PNW produced 1.854 million m^3) (2.096 million MSF, 3/8-inch basis), which represents 75 percent of the total production located in this region for the production year 2012. The individual mills in the PNW region had a production output of about 40,710-240,000 m^3) (46,000- 270,000 MSF, 3/8-inch basis). The responding mills reported start-up dates from the 1950s to 1999. The mills employed 338 persons based on a production-weighted average. Plywood manufactures in the U.S. are members of the American Panel Association (APA), a trade association, and potential survey recipients were identified by APA personnel. Most softwood plywood mills are located in either PNW or SE regions of the U.S., due to proximity to the resource (veneer logs).

3.1 Typical emission control measures

Common emission control devices are regenerative thermal oxidizers (RTOs) for the reduction of volatile organic compounds (VOC's) and electrostatic precipitators (ESPs) for the removal of particulate matter or particle pollution (PM). Regenerative thermal oxidizers can remove more than 99.9 percent of VOCs, but release nitrogen oxides by burning natural gas or liquefied petroleum gas. Electrostatic precipitators are used to collect particulate matter (PM) pollution but are not effective in reducing volatile organic compounds (VOC's) or hazardous air pollutants (HAP) emissions (Milota 2000). The surveyed mills reported the installation and use of five RTOs and two ESPs between 2000 and 2012.

3.2 General types of wastes and emissions

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

4. Product description

Softwood plywood is a wood-based building structural panel that is commonly used in the U.S. for commercial and residential construction. The characteristics of plywood are based on the cross-oriented layers of peeled veneers, which are glued together with thermoset resins (FPL 2010).

Although plywood is produced in different grades and thickness, a commonly-used unit of volume in the industry is one thousand square feet (MSF) 3/8-inch basis (0.885 cubic meters) (Briggs 1994).

Softwood plywood has had a long tradition as a structural building material for both commercial and residential construction. Plywood is used as structural sheathing for roof, wall and flooring, and for sub-flooring applications in home construction, furniture, and cabinet panels. Plywood is also used as a component in other engineered wood products and systems in applications such as prefabricated I-joists, box beams, stressed-skin panels, and panelized roofing. Plywood is a panel product built up wholly or primarily of sheets of veneer called plies (Figure 1). Softwood plywood in the U.S. is produced by peeling logs into veneer sheets, drying the veneer, applying resin (phenol-formaldehyde) to the veneer sheets, and sheets are typically stacked with alternating grain orientation. The veneer stacks are put into a hot press where pressure and heat are used to provide contact and curing, and the cured panel is then removed and sawn to standard sizes, with 1.22 × 2.44 meters (4 × 8 feet) sheets being the most common. Plywood is made from various species. Softwood plywood falls into the North American Industry Classification System (NAICS) Code 321212, softwood veneer and plywood manufacturing.

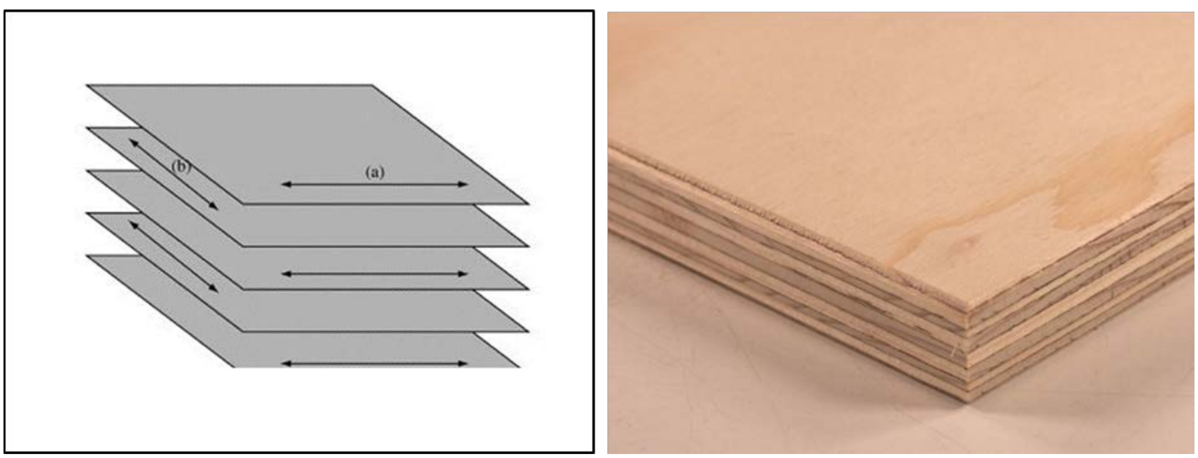

Figure 1 Arrangement of veneer plies in plywood (L) and the finished product (R)

4.1 Density Calculation

Roundwood entering the facility was measured by volume, by cunit[1], or board feet[2] (BF) based on commonly used scaling methods such as Doyle, Scribner, or by green ton weight. Measurement method varied by region and species. Log scaling methods were used by twelve mills and log weight by five mills (PNW and SE regions combined).

As documented in the literature, the scaling methods assume the yield of sawn lumber based on the dimensions of the logs but do not accurately measure the actual wood input to the mills (Briggs 1994). Therefore, factors for the conversion from the scaled amounts to the actual wood input were calculated based on the ratio of the wood input stated in green tons. For the Doyle scale a 2.5 conversion factor was developed; for the Scribner scale the factor was 3.2 and for cunit the value was 5.0.

To ensure consistency with the literature, the veneer recovery ratio (VRR) of the individual mills was calculated based on the actual wood input. According to the literature, the VRR has been historically between 2.5 and 3.0 SF 3/8 inch per BF (Briggs 1994). The calculated VRR for the surveyed mill was in the range between 2.8 and 4.5. The average wood density per functional unit was calculated based on the reported wood species mix (Table 1).

Table 1 Calculation of wood mass from logs for plywood production in the PNW region

Wood Species	Contribution (%)	Density[1] (lb/ft^3)	Weighted Average Density		Mills Reporting a Value (n)
			(lb/ft^3)	(kg/m^3)	
Douglas-fir	77.40	28.09	21.74	348.26	9
True fir	12.84	25.59	3.29	52.65	4
Western larch	4.19	29.96	1.26	20.12	3
Pine	2.48	31.52	0.78	12.52	4
Spruce	1.64	26.22	0.43	6.91	4
Hemlock	0.82	26.22	0.22	3.46	2
Grand fir	0.62	21.85	0.13	2.16	1
Total	100.00		27.85	446.07	

[1]Density according Wood Handbook, 2010

4.2 Functional and declared unit

The survey results were compiled to calculate production-weighted average values of the inputs and emissions associated with the production of one MSF 3/8-inch basis of plywood. In accordance with the PCR (2015), the declared unit for plywood is one cubic meter[3] (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). The analysis does not take the declared unit to the stage of being an installed building product, no service life is assigned.

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[1] One cunit is 100 cubic feet Briggs, D.G. 1994. *Forest products measurements and conversion factors: With special emphasis on the US Pacific Northwest*. College of Forest Resources, University of Washington Seattle, WA.

[2] 12" x 12" x 1" ibid.

[3] 1.0 cubic meter = 1,130 square feet 3/8" thick.

4.3 Intended audience

The primary audience for the LCA report includes the American Wood Council, Canadian Wood Council, North American softwood plywood manufacturers, and other LCA practitioners.

4.4 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 2006) guidelines and principles and compliance with the Wood Products PCR (FPInnovations 2015).[4]

4.5 System boundary

The system boundary begins with the planting, growth and harvest of trees in the PNW region of the U.S. (Johnson, et al. 2005) and ends with plywood packaged to leave the mill gate (Figure 2). The production stage for plywood includes an extraction module (A_1), a transportation module (A_2), and a manufacturing module (A_3). The extraction module includes forest regeneration and stand management, and harvesting. 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 (A_2) from the woods to the mill is accounted for with the plywood manufacturing (A_3). The plywood manufacturing module (A_3) was modeled as a multi- unit process separating log yard operations and primary log breakdown with the production and final packaging of the plywood product. Outputs to the system boundary include 1 m^3 of plywood ready to be shipped, air and water emissions, solid waste and co-products. The co-products are not tracked once they leave the system boundary.

[4] If the LCA is used to develop an Environmental Product Declaration (EPD), internal and/or external critical review would be required.

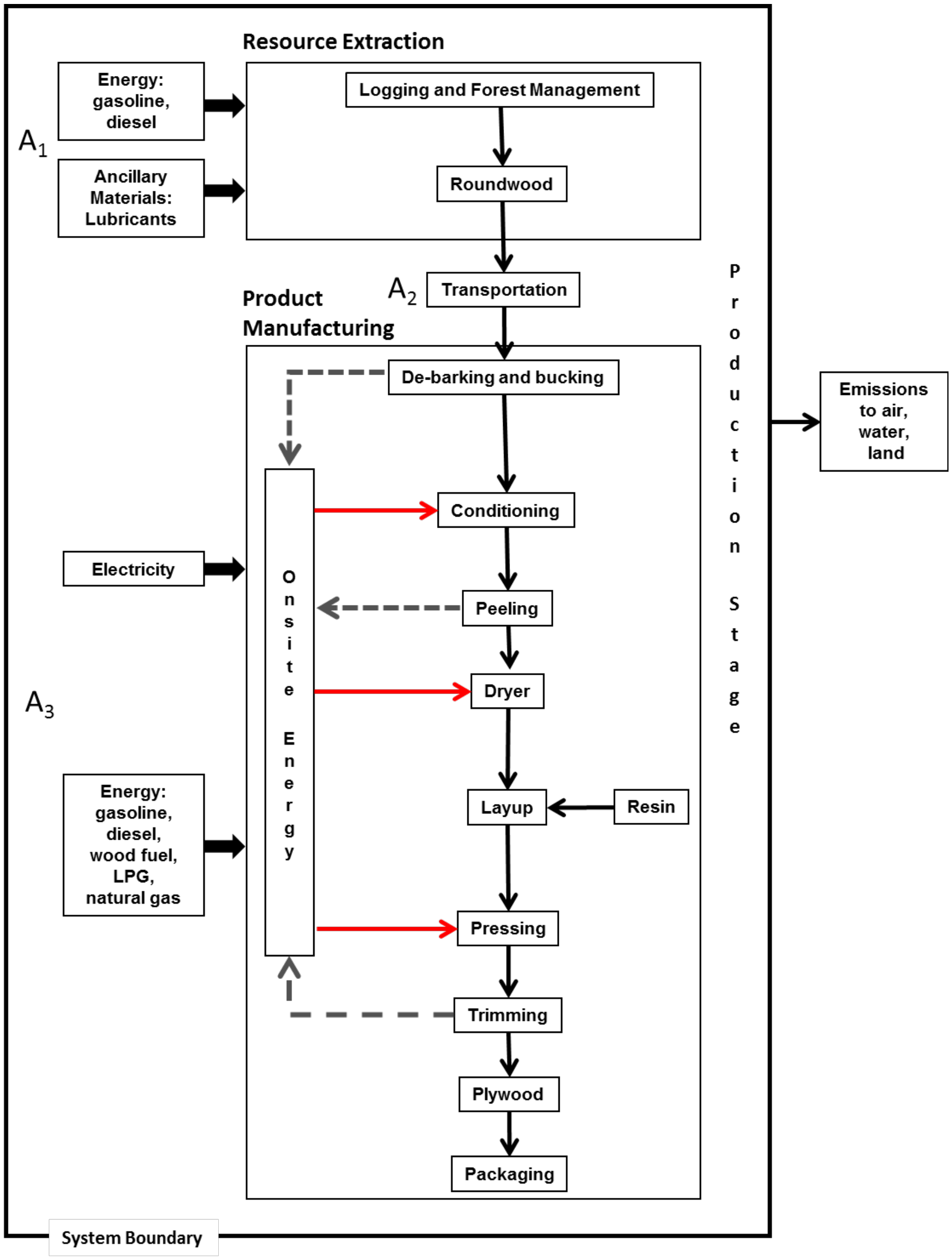

Figure 2 Processes included in the cradle to gate LCA for softwood plywood produced in the PNW region

5. Description of data and processes

As shown in Figure 2, the cradle-to-gate process for plywood production is considered to comprise wood resource (log) extraction, the transport of the logs to the mill, and the on-site plywood manufacturing process. These steps are described separately below.

5.1 Resource extraction

Consideration of the logs used in the production of softwood plywood in the PNW regions 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 (Table 2) come from the research of Johnson, et al. (2005), as updated in Puettmann, et al. (2013).

Table 2 Fuel consumption for PNW region forest resource management processes (regeneration, thinning, and harvest) (Puettmann, et al. 2013)

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

5.2 Transportation

The participating plywood mills reported transportation of raw materials and resources by truck and train (Table 3). The transportation distance of purchased hogged fuel, which is fuel for thermal energy production used for conditioning, drying and pressing was based on discussion with mill personnel and assumed to be 64.37 km (40 miles).

Table 3 Delivery distance of input materials for plywood production in the PNW region

Material	Transportation Method	Distance[1]		Mills Reporting a Value (n)	CVw[2] (%)
		(km)	(miles)		
Logs	Truck	103.67	64.42	8	44
Veneer	Truck	277.36	172.34	8	46
Veneer	Train	160.93	100.00	1	-
Resin	Truck	227.12	141.13	9	75
Wood fuel	Truck	64.37	40.00[3]	-	-

1All transportation distances are weight-averaged and one way.
2 Coefficient of variation (CVw) is a measure of the variability in the data. See Section 7 for further explanation.
3 Assumed value, based on discussion with mill personnel

5.3 Materials Flow

Most wood raw material for plywood production arrives in the form of roundwood (logs) (Table 4) and is converted to finished plywood on-site. In some instances, veneer (green or dry) can be a co-product as well as a purchased a raw material for plywood production. Table 4 list the wood inputs and outputs from plywood production on oven dry mass basis. Unaccountable wood made up 9 percent of the output and could be a result of many factors including waste stream accounting and wood moisture content discrepancies.

Table 4 Mass balance of raw materials, co-products and products in the plywood manufacturing process for in the PNW region[1], unallocated

Input	Unit	Quantity per MSF 3/8 inch	Unit	Quantity per m^3
Roundwood (logs)	lb	1.63E+03	kg	8.37E+02
Purchased veneer (dry)	lb	8.11E+01	kg	4.16E+01
Purchased veneer (green)	lb	5.83E+01	kg	2.99E+01
Total	**lb**	**1.77E+03**	**kg**	**9.08E+02**
Output				
Plywood[2]	lb	8.70E+02	kg	4.46E+02
Hogged fuel	lb	2.54E+02	kg	1.30E+02
Peeler core	lb	1.40E+02	kg	7.18E+01
Clippings (green)	lb	1.67E+02	kg	8.56E+01
Veneer downfall	lb	7.49E+00	kg	3.84E+00
Panel trim	lb	6.85E+01	kg	3.51E+01
Sawdust	lb	1.59E+01	kg	8.14E+00
Wood waste boiler/ Ash	lb	1.22E+01	kg	6.27E+00
Wood waste	lb	2.64E+01	kg	1.35E+01
Sold veneer (dry)	lb	4.17E+01	kg	2.14E+01
Lay up scrap	lb	1.11E+01	kg	5.66E+00
Unaccounted wood	lb	1.57E+02	kg	8.06E+01
Total	**lb**	**1.77E+03**	**kg**	**9.08E+02**

[1]All weights are on an oven-dry basis.
[2]Plywood density is based on weighted density of wood species mix (dry).

5.4 Manufacturing operations

The softwood plywood manufacturing process was modeled using six unit processes. These processes are described in Table 5. Additional details of the plywood manufacturing process can be found in the Wood Handbook (2010), Puettmann et al. (2013), or Wilson and Sakimoto (2004).

Table 5 Description of the production flow of plywood and the associated inputs and outputs of each unit process

Production Process		Inputs	Outputs
1. Debarking	Logs are bucked (cut to length) on the log yard. Logs are debarked.	• Logs • Diesel • Electricity	• Debarked logs • Wood waste
2. Conditioning	Conditioning of debarked logs with hot water or steam	• Debarked logs • Thermal energy • Water	• Conditioned logs
3. Peeling and Clipping	Logs are peeled in the lathe to make veneer. Veneer is clipped to size and sorted by moisture content	• Conditioned logs • Electricity	• Veneer (green) • Peeler cores • Veneer clippings and trim (downfall)
4. Drying	Veneers are dried to 4-6% MC. The re-drying rate for processed veneer is 2-18%, according to the surveys	• Veneer (green) • Thermal energy • Electricity	• Veneer (dry)• Water vapor • Air emissions
5. Layup and Pressing	The resin is applied on the veneers, and the veneers are cross-laminated in a mat, and the mat is pressed	• Veneer (dry) • Resin • Thermal heat • Electricity	• Plywood • Layup scrap • Water vapor • Air emissions
6. Trimming, sawing, packaging	The plywood panels are sawn to appropriate dimensions. Packaging material consist of wrapping, strapping, and spacers	• Plywood • Electricity • LPG	• Sawn plywood • Plywood trim • Sawdust • Wood waste

Survey respondents provided data from 2012 on the material and resource inputs to plywood manufacturing at the mill (Table 6), and outputs such as product, co-products, and air emissions (Table 7). The data were production-weight averaged and are reported below per cubic meter (m^3) of finish plywood produced. Emissions listed and amount reported in Table 7 do not represent all the emissions and quantities used in the LCI model. For example, some of the emissions listed in Table 7 are wood boiler emissions. These emissions were omitted or changed to avoid double accounting of boiler emissions from use of U.S. wood boiler process. Tables 10 and 11 explain the allocation of air emissions to processes as reported in the survey and emissions used for the boiler.

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 products facilities are required to report as surrogates for all

HAPs. These are methanol, acetaldehyde, formaldehyde, propionaldehyde (propanal), acrolein, and phenol. All HAPS are included in this LCI and a complete list of air emission are found in Tables 27 and 29 in the Appendix I and II of this report. There were no cut-offs used in the impact assessment therefore a complete list of all air emissions are reported.

Table 6 Summary of survey responses of inputs to the plywood manufacturing process in the PNW region, unallocated

Materials[1]	Unit	Quantity per m^3	Mills Reporting a Value (n)	CVw[4] (%)
Roundwood (logs)	m3	1.87E+00		
	kg	8.37E+02	9	45
Bark	kg	1.12E+02	7	133
Phenol-formaldehyde resin	kg	1.17E+01	9	49
Extender and fillers[2]	kg	2.04E+00	9	119
Catalyst[2]	kg	3.17E-01	9	110
Soda ash[2]	kg	2.86E-01	5	97
Veneer (purchased)				
Veneer (dry)	kg	4.16E+01	9	162
Veneer (green)	kg	2.99E+01	9	210
Water				
Municipal water	L	2.84E+02	7	97
Well water	L	2.16E+00	7	149
Recycled water	L	2.17E+01	4	136
Total water consumption	L	3.07E+02	8	82
Electricity				
Electricity[3]	kWh	1.45E+02	8	27
Fuel				
Hogged fuel (produced)	kg	1.20E+02	8	97
Hogged fuel (purchased)	kg	4.18E+01	9	150
Wood waste	kg	2.18E+01	6	134
Natural gas	m^3	1.27E+00	9	141
Liquid petroleum gas	L	2.13E+00	8	43
Gasoline	L	4.03E-02	9	162
Diesel	L	1.84E+00	8	72
Packaging Materials				
Cardboard	kg	1.02E-01	7	85
Steel strapping	kg	1.51E-02	6	118
Plastic strapping	kg	8.04E-02	5	102

[1] All materials are given as oven-dry or solid weight.
[2] These materials were not included in the LCI analysis based on the 2 percent exclusion rule.
[3] One outlier identified and excluded in production-weighted industry average value.
[4] Coefficient of variation (CVw) is a measure of the variability in the data. See Section 7 for further explanation.

Table 7 Summary of survey responses of outputs from the plywood manufacturing process in the PNW region

Product	Unit	Quantity per m^3	Mills Reporting a Value (n)	CVw[3] (%)
Plywood[1]	kg	4.58E+02		
Co-products				
Bark	kg	1.12E+02	7	133
Sawdust	kg	8.14E+00	6	154
Peeler core	kg	7.18E+01	5	70
Veneer downfall	kg	3.84E+00	3	306
Solid Waste				
Wood Waste	kg	1.35E+01	7	144
Ash	kg	6.27E+00	7	111
Air Emissions[2]				
Acetaldehyde	kg	1.62E-02	8	132
Acetone	kg	1.11E-02	1	
Acrolein	kg	3.61E-03	4	87
CH_4	kg	1.31E+02	7	522
CO	kg	1.80E+00	8	109
CO_2 (biogenic)	kg	3.33E+02	8	57
Dust	kg	1.01E-01	2	139
Formaldehyde	kg	8.90E-03	8	49
Methanol	kg	4.20E-02	8	58
NOx	kg	3.38E-01	8	76
Particulate, PM 2.5	kg	1.85E-01	7	104
Particulate, PM 10	kg	2.47E-01	9	126
Phenol	kg	5.81E-04	4	91
Propionaldehyde	kg	4.92E-03	1	
SO_2	kg	3.63E-02	8	65
VOC	kg	1.70E-01	9	62

[1] Plywood density is based on weighted density of wood species mix (dry) and 80 percent of resin, filler, catalyst and soda ash input. The 20 percent less of the resin formula is based on the mass loss in the production process and during the condensation reaction in the curing process (Wilson and Sakimoto 2004).
[2] Emission values based on survey results (include estimated, measured and permitted values).
[3] Coefficient of variation (CVw) is a measure of the variability in the data. See Section 7 for further explanation.

In the survey, mills were asked to report the portion of the energy inputs (electrical and thermal) and outputs (waste and emissions) used in each process step in plywood manufacturing. Some mills reported electrical usage (Table 8) and air emissions (Table 9) by production step; however, no data were provided on the breakdown of thermal energy usage between processes. Therefore, thermal energy for each process (10) was calculated using the same allocations used in previous reports (Puettmann, et al. 2013, Wilson and Sakimoto 2004).

Table 8 Summary of survey responses on the allocation of electrical energy to the manufacturing steps for plywood production the PNW region

Production Stage	Survey[1] (%)	Allocation		
		(%)[2]	kWh per MSF 3/8 inch	MJ per m^3
Debarking	11.24	13.60	17.46	71.05
Conditioning	12.26	14.62	18.78	76.38
Peeling and Clipping	13.37	15.73	20.20	82.18
Veneer Drying	29.79	32.15	41.29	167.97
Layup and Pressing	15.62	17.98	23.09	93.94
Trimming and Sawing	3.56	5.92	7.60	30.93
Overhead[3]	14.16			
Total	100.00	100.00	128.43	522.45

[1] Allocation on production steps are based on responses from two mills.
[2] Weighted allocation of "overhead" electrical load to all production stages.
[3] Overhead includes electricity usage of emission control devices because the energy usage was only documented by one mill.

Table 9 Summary of survey responses on the allocation of air emissions from the manufacturing steps for plywood production the PNW region

Substance	Allocation %			
	Boiler	Veneer Drying	Layup and Pressing	Trimming and Sawing
Acetaldehyde	23	45	26	6
Acetone	0	76	21	3
Acrolein	33	33	33	0
CH4	69	31	0	0
CO	81	19	0	0
CO2	81	19	0	0
Dust	7	9	48	36
Formaldehyde	49	19	26	6
Methanol	11	18	46	26
NOx	72	28	0	0
Particulate, PM 2.5	37	24	26	13
Particulate, PM10	35	23	28	13
Phenol	13	17	31	39
Propionaldehyde	33	26	40	0
SO2	79	21	0	0
VOC	33	18	41	8

The removal of water from wood in the drying process consumed the greatest proportion of energy use (76%) (Table 10). Conditioning and pressing used 10 and 15 percent, respectively. On the other hand, 98 percent of the mills energy (electricity generation not included) was generated by wood fuel.

Table 10 Allocation of thermal energy to the manufacturing steps for plywood production in the PNW region

Fuel Type	Conditioning	Drying	Pressing	Total	Fraction
	MJ/m³				
Wood fuel[1]	2.31E+02	1.80E+03	3.53E+02	2.39E+03	98%
Natural gas[2]	5.35E+00	4.17E+01	8.17E+00	5.52E+01	2%
Total	2.37E+02	1.84E+03	3.61E+02	2.44E+03	100%
Percent %[3]	9.7	75.5	14.8	100	

[1]Includes hogged fuel self-generated and purchased, saw dust, panel trim and veneer downfall. Energy content 20.93 MJ/kg (Puettmann et al., 2014) 67% efficiency (Wilson et al., 2004).
[2]Energy content natural gas 54.45 MJ/kg (Puettmann et al. 2014), 80% efficiency (Wilson et al. 2004).
[3]Allocation per Wilson and Sakimoto (2004).

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

5.5 Resin

Phenol formaldehyde (PF) is the most commonly used adhesive system in plywood manufacture. It is a thermoset (cured by heating) adhesive that provides a waterproof and irreversible bond between the veneers. The life cycle inventory to produce phenol-formaldehyde (PF) resin covers its cycle from in ground resources through the production and delivery of input chemicals and fuels, through to the manufacturing of a resin as shipped to the customer (Wilson 2009). It examines the use of all resources, fuels and electricity and all emissions to air, water and land; it also includes feedstock of natural gas and crude oil used to produce the chemicals. The inputs to produce 1.0 kg of neat (PF) resin (47% solids) consist of the two primary chemicals: 0.244 kg of phenol and 0.209 kg of methanol, and a lesser amount of sodium hydroxide (0.061 kg), and 0.349 kg of water. Electricity is used for running fans and pumps, and for operating emissions control equipment. Natural gas is used for boiler fuel and emission control equipment, and propane fuel is used in forklifts.

5.6 Equipment: Type and fuel consumption

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 are used for debarking, peeling lathes, materials conveying and trims saws. The veneer driers and pressing steps are powered by steam from the boiler, which is fueled by wood residues. The emissions controls equipment is powered by electricity or natural gas. Lifts for transporting products and materials in the mill are powered by liquefied propane gas.

5.7 Energy use and generation

Energy for producing plywood comes from electricity, diesel, liquid propane gas (LPG), wood fuel, and steam. The electricity is used to operate the debarker, bucker, lathe, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, and saws throughout the production process. Electricity was used in all processes. Diesel fuel use is attributed solely to log loaders for debarking, therefore, all diesel use was allocated to this process. Forklift trucks used small amounts of LPG throughout the mill therefore, this fuel use was assigned evenly over the all unit processes (16.67%)

5.7.1 Wood-based fuels

Wood-based by-products are commonly used in the plywood industry to produce heat for the thermal energy intense processes like conditioning, drying and hot pressing (Figure 2). The boiler and the emission control processes were considered separately. Wood fuel represented 98 percent of the total heat energy with natural gas making up the 2 percent difference. 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 11).

Table 11 Wood boiler process parameters used in PNW plywood production (Puettmann and Milota 2017)

Inputs – Materials and Fuels	Value	Unit/m^3
Bark, Plywood mill, US, PNW	3.55E-01	kg
Wood waste, Plywood mill, US, PNW	3.59E-02	kg
Veneer clippings green, softwood, Plywood mill, US, PNW	1.39E-01	kg
Veneer downfall, softwood, Plywood mill, US, PNW	1.47E-02	kg
Lay-up scrap, softwood, Plywood mill, US, PNW	1.78E-02	kg
Panel trim from formatting, Plywood mill, US, PNW	1.66E-01	kg
Sawdust from formatting, Plywood mill, US, PNW	2.58E-02	kg
Wood fuel, unspecified/RNA (purchased fuel)	2.45E-01	kg
Transport, combination truck, diesel powered/US,	1.58E-02	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
CORRIM Wood ash, at boiler, at mill, kg, RNA	2.00E-02	kg

[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

Outputs - 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
Formaldehyde	1.26E-05	kg
HAPs	6.27E-06	kg
Hydrogen chloride	1.17E-06	kg
Lead	1.75E-07	kg
Mercury	1.83E-09	kg
Methane, biogenic	2.23E-05	kg
Methanol	7.95E-06	kg
Nitrogen oxides	1.10E-03	kg
Particulates, < 10 um	4.71E-04	kg
Particulates, < 2.5 um	1.39E-04	kg
Phenol	6.21E-07	kg
Propanal	5.14E-08	kg
Sulfur dioxide	7.71E-05	kg
VOC, volatile organic compounds	8.76E-04	kg
Dinitrogen monoxide	2.93E-06	kg
Naphthalene	5.77E-08	kg
Other Organic	2.11E-07	kg
Outputs - Emissions to water		
Suspended solids, unspecified	8.35E-07	kg
BOD5, Biological Oxygen Demand	2.10E-06	kg

5.7.2 Electricity use summary

The source of fuel used to generate the electricity used in the manufacturing process is very important in determining the type and amount of impact in the LCA. The breakdown of electricity for the Pacific Northwest by fuel source is given in Table 12. The dominant form of electricity generation in the region was natural gas at 32 percent with coal and hydro representing 30 and 22 percent of the regions electricity. Other sources making of the difference is nuclear at 8 percent, biomass, wind, geothermal representing 1, 2, and 2 percent respectively. In the CORRIM Phase I PNW plywood report (Wilson and Sakimoto 2004), the dominant form of electricity generation for the region was hydro, representing 74 percent.

Table 12 Electric power generation by primary fuel sources as defined by the Western Electricity Coordinating Council (WECC) grid, 2008

Fuel source	kWh	Percent share, 2008
Natural gas, at power plant/US	0.318	32%
Hydropower, at power plant, unspecified/kwh/RNA	0.222	22%
Bituminous coal, at power plant/US	0.301	30%
Nuclear, at power plant/US	0.094	9%
Wind power plant, unspecified/kwh/RNA	0.024	2%
Geothermal, unspecified/kwh/RNA	0.019	2%
Biomass, at power plant/US	0.007	1%
Other	0.015	1%

5.8 Packaging

Materials used for packaging plywood for shipping are shown in (Table 13). Packing materials for PNW softwood plywood represent 1.21% of the cumulative mass of the model flow. The wooden spacers make up the bulk of this mass, representing 86 percent of the total packaging material. The wrapping material, strap protectors, and strapping made up, 8, 4, and 2 percent of the packaging by mass.

Table 13 Materials used in packaging and shipping per m^3, PNW plywood

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

6. Cut-off rules and other assumptions

The data collection, analysis, and assumptions followed protocols defined in the 'CORRIM Guidelines for Performing Life Cycle Inventories on Wood Products' (Puettmann, et al. 2014). Additional considerations included:

- All survey data contributed by participating plywood plants were production-weighted in comparison to the total surveyed production for the year 2012;
- For bark, hogged fuel, wood and wood waste (green) 50 percent moisture content (MC) on a dry basis was assumed. For saw dust and dry wood waste, 7 percent MC on a dry basis was assumed;
- The resin components were converted to the solid content based on the percentages stated in the surveys;
- The allocation of the fossil energy sources is based on the information provided by the mills;
- 100 percent of diesel fuel was assigned to the debarking process to address fuel use by mobile equipment on the log yard;

- 100 percent of gasoline was used for mobile equipment and was assigned to the six process units in the production process;
- 88 percent of liquid propane gas (LPG) was used for mobile equipment, 12 percent were used for emission control devices for exhaust air from the drying process;
- The density of plywood was assumed to be 458 kg/m^3. The wood only density of plywood was assumed to be 446 kg/m^3
- 45 percent of natural gas was used for emission control and 55 percent for the thermal energy and steam production. (Allocation based on information from two mills);
- Resin additives such as extender and fillers, catalysts and soda ash were excluded based on the 2 percent cut-off rule.
- Unaccounted wood mass of 8.87 percent was established by the difference between reported input and output based on the weighted wood material flows.

According to the PCR (FPInnovations 2015), 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 included all energy and mass flows for primary data.

In the primary surveys, manufacturers were asked to report total hazard air pollutants (HAPS) specific to their wood products manufacturing process: formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde. If applicable to the wood product, all HAPS are included in the LCI and are reported in Table 27 and Table 29. No cut-offs were applied in the impact assessment.

7. Data quality and variability

The data quality assurance procedures included a standardized outlier detection method, the reporting of the sample size as ‘Mills reporting a value (n)’ and the reporting of the data variation in form of the production-weighted coefficient of variation (CV_w). These methods have now been included in the ‘CORRIM Guidelines for Performing Life Cycle Inventories on Wood Products’ (Puettmann, et al. 2014).

In general, outliers are defined as extreme observations that can have a significant impact on calculated values. In case of the collected survey data, outliers could be values that are incorrectly reported because the true value is not known or the question was misunderstood. JMP Pro 11 statistical software was used to analyze the data set and identify possible outliers. Values identified as potential outliers were discussed with mill personnel, and excluded if they could not be verified.

The coefficient of variation (CV) describes the variability of the data series by dividing the standard deviation by the mean (Abdi 2010). To be consistent with the documented production-weighted average values (1), the weighted standard deviation (2) was calculated. Finally, the weighted CV_w (3) was calculated and documented for the individual values (NIST 1996, Toshkov 2012).

$$\bar{x}_w = \frac{\sum wx}{\sum w} \quad (1)$$

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

$$CV_w = \frac{Sd_w}{\bar{x}_w} \quad (3)$$

8. Life cycle inventory

8.1 Data collection

For the primary data collection, plywood mills in the PNW U.S. were invited to contribute detailed production data for the assessment. The survey instrument was based on the used one in a prior study (Wilson and Sakimoto 2004), but was updated for current conditions. The survey is included in Appendix III: Survey. Nine mills provided input and output data for the assessment from PNW representing 75 percent of the regional production for the 2012 calendar year. The PNW region is represented with mill data from Idaho, Oregon and Washington.

8.2 Primary and secondary data sources

In addition to the primary data collected by survey of the on-site plywood production process, several sources of secondary data were required to complete the cradle-to-date process and to connect with the relevant upstream processes (Table 14). Forest management and harvesting LCI data used in this study were derived from Johnson, et al. (2005). Adhesive data were sourced from Wilson (2009) and an update to the boiler LCI was provided by Puettmann and Milota (2017). Others secondary process data was taken from the USLCI database (NREL 2012).

Table 14 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
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
Phenol formaldehyde resin	CORRIM data resin production	2009

	obtained from the USLCI	
Packaging materials	USLCI data for “Low density polyethylene resin, at plant/RNA”; USCLI data for “High density polyethylene resin, at plant/RNA” USLCI data for “Kraft unbleached 100% rec.FAL” USLCI data for “Cardboard” CORRIM data for “Softwood lumber from dryer, m^3 / dry / PNW_US” USLCI data for “Recycled postconsumer PET flake/RNA”	1998-2015

8.3 Calculation rules

Calculation procedures of the *Forestry Operations* data are described by Puettmann, et al. (2013). The survey results for each unit process were converted to a production basis (e.g., logs used per m^3 of plywood produced) and production-weighted averages were calculated for each material. This approach provides plywood production data that represent a composite of the mills surveyed, but do not represent any mill. The USLCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 8.0+ (PreConsultants 2012) was used as the accounting program to track all of the materials, and their allocation among products and co-products.

Missing data were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were not averaged as zeros.

8.4 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% rule is applied based on a per unit basis, in this case per m^3 of plywood. 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. The mass allocation results can be found in subsequent sections, while economic allocation results are in Appendix I: Economic allocation.

8.5 Life cycle inventory results

Life cycle inventory data for plywood are presented separately for their *Total* values, and the component *Forestry Operations* and *Plywood Production*, which includes resin production. The plywood production phase is associated with most of the raw material energy consumption. Wood waste, primarily from the self-generated wood fuel, makes up most of the fuels used from cradle to gate followed by coal use at 10 percent.

Table 15 Cradle to gate raw material energy consumption per 1 m^3 of softwood plywood produced in the PNW region (mass allocation)

Fuel	Percent	Total	Forestry	Plywood

	Distribution of Total		Operations	Production
		kg/m³		
Coal, in ground	10%	2.92E+01	1.92E-01	2.90E+01
Gas, natural, in ground	7%	1.86E+01	1.72E-01	1.85E+01
Oil, crude, in ground	5%	1.45E+01	3.27E+00	1.12E+01
Uranium oxide, in ore	0%	6.17E-04	4.50E-06	6.13E-04
Wood waste[1]	78%	2.20E+02	0.00E+00	2.20E+02

[1]Included in total wood waste burned for energy is wet and dry co-products produced during debarking and trimming.

Waterborne emissions are all off-site. No mill reported in the survey that they discharged process water. The water sprayed on logs is collected and recycled or soaks into the ground. Water used at the boiler and kilns is evaporated. A full list of emissions to water and to air by mass and economic allocation are in Appendix 1 and II of this report. Data are reported for forestry operations and plywood production, which encompasses resin production.

Cradle to gate solid emissions include ash generated at the boiler and the extraction of natural gas (Table 17 and Table 25). Commonly, waste is generated at the log-yard and cannot be sent to the boiler because it is mixed with dirt. No mills reported this type of waste in the surveys. In previous studies this amount as accounted for 4 percent of the total mass of the log entering the facility.

9. 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 et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (FPInnovations 2015).

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 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	Calculate total substances that can be photo-	Photochemical

resulting in smog	chemically oxidized. Smog forming potential of O_3 is used as a reference unit.	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

Table 17 provides the environmental impacts by category for plywood produced in the PNW region. Energy and material resource consumption values and the solid waste generated are also provided. Most of the energy consumption, and environmental impact, is associated with the plywood production phase. Most of the energy used in plywood production is derived from renewable biomass, i.e. wood processing residues.

Table 17 Environmental performance of 1 m^3 softwood plywood produced in the PNW region (mass allocation)

Impact Category	Unit	Total	Forestry Operations	Plywood Production
Global warming potential (GWP)	kg CO_2 eq.	1.43E+02	1.10E+01	1.32E+02
Acidification Potential	SO_2 eq.	1.60E+00	1.51E-01	1.45E+00
Eutrophication Potential	kg N eq.	6.16E-02	1.04E-02	5.12E-02
Ozone depletion Potential	kg CFC-11 eq.	1.01E-07	4.94E-10	1.01E-07
Smog Potential	kg O3 eq.	2.50E+01	4.73E+00	2.03E+01
Primary Energy Consumption				
Total	MJ	7.43E+03	1.65E+02	7.26E+03
Non-renewable fossil	*MJ*	2.44E+03	1.63E+02	2.28E+03
Non-renewable nuclear	*MJ*	2.35E+02	1.72E+00	2.33E+02
Renewable (solar, wind, hydroelectric, and geothermal)	*MJ*	1.48E+02	2.69E-01	1.48E+02
Renewable, biomass	*MJ*	4.61E+03	1.62E-03	4.61E+03
Material Resources Consumption (non-fuel resources)				
Non-renewable materials	kg	5.81E+00	9.09E-03	5.80E+00
Renewable materials	kg	6.40E+02	0.00E+00	6.40E+02
Fresh water	L	1.06E+03	1.05E+01	1.05E+03
Waste generated				
Solid waste	kg	1.18E+01	1.71E-01	1.16E+01

10. Treatment of biogenic carbon

Treatment of biogenic carbon here is consistent with the Intergovernmental Panel for Climate Change (IPCC 2007) inventory reporting framework, with no assumption that biomass combustion is carbon neutral but with net carbon emissions from biomass combustion accounted for under the Land-Use Change and Forestry (LUCF) Sector. Biogenic carbon emissions are ignored in energy emissions reporting for the product LCA to prevent double counting. This approach is consistent with the Norwegian Solid Wood Product PCR (Aasestad 2008) and the North American PCR (FPInnovations 2015). The default TRACI impact assessment method was used. This default method does not count the CO_2 emissions released during the combustion of woody biomass during production. Other emissions associated from wood combustion, e.g., methane or nitrogen oxides, do contribute to and are included in the GWP impact category.

The carbon balance was calculated based on the production-weighted LCI results and the upstream processes (Table 18). The wood in the product was assumed to have a carbon content of 50 percent (wood only). To convert the carbon into kg CO_2 equivalent the factor 3.664 was used. This factor is based on the molar weight of 12.011 and 15.9994 for carbon and oxygen, respectively (Puettmann, et al. 2014). The cradle to gate manufacturing of 1 m^3 PNW plywood resulted in 143 kg of CO_2 eq released, which is only 18 percent as much as is stored in the product.

Table 18 Carbon balance of one m^3 of softwood plywood produced in the PNW region

	kg CO_2 equivalent
Released during forestry operations	1.10E+01
Released during manufacture	1.32E+02
Stored in product	8.17E+02

11. 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.

11.1 Identification of the significant issues

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

11.2 Life cycle phase contribution analysis

As is the case with wood products in general, the product manufacturing phase of plywood production requires most of the inputs and results in most of the environmental impact (Table 19). When an economic allocation approach was used, the impact category contribution of the plywood manufacturing life cycle stage increases slightly, subsequently lowering the forestry operations stage. Forestry operations contributed much less to the overall impact from cradle to gate with eutrophication and smog having the highest contributions of 17 and 19 percent with a mass allocation and 14 and 16 percent using an economic approach. Primary energy consumption also shows the same trend as the impact categories with the economic approach increasing the manufacturing burden and lower forestry contributions.

Table 19 Life cycle stages contribution analysis for PNW plywood (mass and economic allocation)

Impact Category	Unit	Mass Allocation		Economic Allocation	
		Forestry Operations	Plywood Production	Forestry Operations	Plywood Production
Global warming potential (GWP)	kg CO_2 eq.	7.69%	92.31%	6.18%	93.82%
Acidification potential	SO_2 eq.	9.44%	90.56%	7.63%	92.37%
Eutrophication potential	kg N eq.	16.88%	83.12%	13.87%	86.13%
Ozone Depletion potential	kg CFC-11 eq.	0.49%	99.51%	0.39%	99.61%
Smog potential	kg O_3 eq	18.92%	81.08%	15.56%	84.44%
Primary Energy Consumption					
Total	MJ	2.22%	97.78%	1.77%	98.23%
Non-renewable fossil	*MJ*	*6.68%*	*93.32%*	*5.36%*	*94.64%*
Non-renewable nuclear	*MJ*	*0.73%*	*99.27%*	*0.58%*	*99.42%*
Renewable (solar, wind, hydroelectric, and geothermal)	*MJ*	*0.18%*	*99.82%*	*0.14%*	*99.86%*
Renewable, biomass	*MJ*	*0.00%*	*100.00%*	*0.00%*	*100.00%*
Material Resources Consumption (non-fuel resources)					
Non-renewable materials	kg	0.16%	99.84%	0.13%	99.87%
Renewable materials	kg	0.00%	100.00%	0.00%	100.00%
Fresh water	L	0.99%	99.01%	0.79%	99.21%
Waste Generated					
Solid waste	kg	1.45%	98.55%	1.16%	98.84%

11.3 Substance contribution analysis

The impact indicators presented in the LCIA results (Table 17 and Table 25) shows total impacts and the relative contributions of the life cycle stages. The data can be further examined to identify the various compounds that contribute to theses impact categories. Global warming potential (GWP) is an indicator that is often emphasized in LCA discussions but there are many individual gas emissions that contribute to GWP; furthermore, the relative importance of these gases to the greenhouse effect ('radiative efficiency') and their lifetimes in the atmosphere vary widely. In plywood production, it is the carbon dioxide emissions associated with fossil fuel combustion that contributes most the GWP indicator (Table 20).

Table 20 Substance contribution analysis to Global Warming Potential of plywood production in the PNW region, cradle-to-gate (mass allocation)

Substance	Total Emissions (kg)	CO_2 Equivalence factor[1]	CO_2 Equivalent (kg)	Contribution to Total GWP
Carbon dioxide, fossil	1.32E+02	1	1.32E+02	91.97%
Dinitrogen monoxide	2.43E-03	298	7.23E-01	0.50%
Methane	3.81E-01	25	9.53E+00	6.65%
Total global warming potential (GWP)			1.43E+02	

[1]100 year basis (IPCC 2007)

11.4 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. 2014) and the PCR (FPInnovations 2015) in the assumptions made, methods used, models, data quality including data sources, and data accuracy, age, time-related coverage, technology, and geographical coverage.

In addition to reporting primary data variability estimates, showing allocation of inputs to the various process steps, and showing separate sets of results for economic and mass allocation, a sensitivity analysis can be performed by comparing the effect of mass or economic allocation (Table 21). Plywood manufacture includes several steps in which a significant mass of by-products result. Is some cases the relative value of the co-product to the product is high, e.g. veneer that is sold rather than used to make plywood on-site (Table 21). However, in other cases the co-product is of much lower value than the main product, e.g. the peeler core. In no case are the co-products more valuable than the main product that ends up in the final plywood; thus, economic allocation associates more of the input and environmental consequences (about 25% more) on the plywood product than does mass allocation (Table 22).

Table 21 Allocation by relative mass and economic value to the products and coproducts in each step of plywood manufacturing in the PNW region

Step	Product and *co-products*	Quantity	Unit	Mass allocation	Economic allocation[1]
Debarking	Debarked logs	1.0000	kg	85.67%	99.47%
	Bark	*0.1550*	*kg*	*13.25%*	*0.49%*
	Wood waste	*0.0126*	*kg*	*1.08%*	*0.04%*
Conditioning	Conditioned logs	1.0000	kg	100.00%	100.00%
Peeling	Green veneer	1.0000	kg	72.65%	76.00%
	Green veneer that is sold	*0.0441*	*kg*	*3.21%*	*3.00%*
	Peeler core	*0.1480*	*kg*	*10.75%*	*3.00%*
	Veneer downfall	*0.0079*	*kg*	*0.57%*	*0.00%*
	Veneer clippings	*0.1760*	*kg*	*12.82%*	*18.00%*
Drying	Dry veneer	1.0000	kg	96.19%	96.19%
	Dry veneer that is sold	*0.0396*	*kg*	*3.81%*	*3.81%*
Pressing	Rough plywood	1.0000	kg	99.38%	99.98%
	Lay-up scrap	*0.0063*	*kg*	*0.62%*	*0.02%*
Trimming	Trimmed plywood	1.0000	kg	73.65%	99.00%
	Plywood trimmings	*0.0724*	*kg*	*5.33%*	*0.00%*
	Sawdust	*0.0168*	*kg*	*1.24%*	*0.00%*
	Hog fuel	*0.2690*	*kg*	*19.78%*	*1.00%*
Packaging	Packaged plywood	1.0000	m^3	100.00%	100.00%

[1] Product and co-product values from Random Lengths (2012) and expert estimates

Table 22 Sensitivity of select impact indicators and energy consumption data to the allocation method for plywood produced in the PNW region

Impact Category	Unit	Mass Allocation	Economic Allocation	Difference
Global warming potential (GWP)	kg CO_2 eq.	1.43E+02	1.82E+02	27.60%
Acidification potential	SO_2 eq.	1.60E+00	2.02E+00	26.05%
Eutrophication potential	kg N eq.	6.16E-02	7.60E-02	23.37%
Ozone depletion potential	kg CFC-11 eq.	1.01E-07	1.26E-07	24.53%
Smog potential	kg O_3 eq	2.50E+01	3.09E+01	23.68%
Primary Energy Consumption				
Total	MJ	7.43E+03	9.41E+03	26.65%
Non-renewable fossil	*MJ*	*2.44E+03*	*3.10E+03*	*26.87%*
Non-renewable nuclear	*MJ*	*2.35E+02*	*3.02E+02*	*28.63%*
Renewable (solar, wind, hydroelectric, and geothermal)	*MJ*	*1.48E+02*	*1.92E+02*	*29.60%*
Renewable, biomass	*MJ*	*4.61E+03*	*5.82E+03*	*26.17%*

12. Discussion & Conclusions

A life cycle inventory (LCI) update was conducted for softwood plywood produced in the PNW region in the U.S. Gate-to-gate data were collected by survey for the production year 2012. These data were combined with secondary data to create a cradle-to-gate analysis.

The surveyed mills represented 75 percent of the total production in the PNW region. The input and output data are reported as production-weighted average values per functional unit of one MSF 3/8-inch basis (0.884 m^3).

The production of softwood plywood in the PNW required 1.66 m^3 of roundwood and 63 kg of purchased veneer (37 kg dry veneer and 26 kg green veneer) per functional unit (MSF 3/8 in). The total wood recovery of 51 percent was calculated based on the amount of wood inputs in roundwood and veneer to the output of wood in form of plywood (394 kg) and sold dry veneer (19 kg). The production of one MSF 3/8 in of softwood plywood required 2.2 GJ thermal energy. The production of the thermal energy was covered with 98 percent wood fuel and 2 percent natural gas. The allocation of the thermal energy need of the conditioning, drying and pressing process was allocated per Wilson and Sakimoto (2004) because of a lack of reporting by the participating mills. The total electricity consumption was 128 kWh per functional unit and was allocated to following processes; veneer drying (32%), layup and pressing (18%), peeling clipping (16%), conditioning (15%), debarking (13%), and trimming and sawing (6%).

The allocations to the individual production steps provided the basis for conducting a life cycle impact assessment with a unit process structure. SimaPro 8.0+, an LCA software package, running the TRACI 2.1 V1.01/US 2008 impact method was used to calculate the environmental impact associated with the production of softwood plywood in both regions. Primary data in form of the LCI figures and secondary data for the forestry, energy and other input material production were used. The results for the softwood plywood production in the PNW show a global warming potential of 129 kg CO_2 equivalent, acidification potential of 1.43 kg sulfur dioxide equivalent, eutrophication potential of 0.05kg nitrogen equivalent, and smog potential of 19.8 kg ozone equivalent. Softwood plywood produced in the PNW results in a net storage of 674 kg of CO_2 equivalent per m^3.

The comparison between the two product life stages (forestry operations and plywood production) shows that the plywood production process contributes the main environmental burdens in the five documented impact categories. This is consistent with prior reports on plywood production, and wood products in general. The calculated potential impacts should contribute to the update of the environmental product declaration of softwood plywood produced in the U.S. and should allow a fair comparison with competing products.

In future updates, it is recommended to request the veneer recovery ratio (VRR) as a performance indicator for softwood plywood mills. This factor allows a direct comparison of actual wood input to the production output and eliminates potential over- and underrun caused by scaling methods.

13. Critical Review

13.1 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.

13.2 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).

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.

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15. Appendix I: Economic allocation

15.1 Cradle-to-gate LCI results – Economic allocation

Life-cycle inventory results for plywood are presented by two life cycle stages, 1) forestry operations, 2) Plywood production (Table 23 – Table 27).

Most of the raw material consumption used for energy production occurs during plywood manufacturing, with only a very small portion arising from forestry operations. Table 23 lists the raw material consumption of energy inputs per m^3 of plywood. Highest consumption rates are for wood fuel with all processes consuming a total of 278 kg/m^3. Wood fuel is used for on-site thermal energy during plywood manufacturing for log conditioning, drying veneers, and pressing the plywood panels. Coal and natural gas, primarily consumed offsite and used to generate electricity, were the next highest fuel contributor at 11 and 7 percent, respectively.

Table 23 Cradle to gate raw material energy consumption per 1 m^3 of softwood plywood produced in the PNW region (economic allocation)

Fuel	Percent Distribution of Total	Total	Forestry Operations	Plywood Production
		kg/m^3		
Coal, in ground	11%	3.76E+01	1.92E-01	3.74E+01
Gas, natural, in ground	7%	2.38E+01	1.72E-01	2.36E+01
Oil, crude, in ground	5%	1.79E+01	3.27E+00	1.46E+01
Uranium oxide, in ore	0%	7.93E-04	4.50E-06	7.89E-04
Wood waste[1]	78%	2.78E+02	0.00E+00	2.78E+02

[1]Included in total wood waste burned for energy is wet and dry co-products produced during debarking and trimming.

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 24 provides the environmental impact by category for PNW plywood. 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 25).

For GWP, 95 percent of the CO_2 eq. emissions come from producing PNW plywood. Similar results are presented for acidification, eutrophication, and smog, representing 92, 86, and 85 percent contributed from plywood, respectively.

Overall, the manufacture of PNW plywood is 62 percent energy self-sufficient with its use of renewable biomass for thermal energy. Non-renewable fossil fuels and non-renewable nuclear represented 33 and 3 percent of the total primary energy, respectively. Plywood manufacturing (includes all fuel and resin upstream processes) consumes 98 percent of the total primary energy consumption.

Table 24 Environmental performance of 1 m[3] softwood plywood produced in the PNW region (economic allocation)

Impact Category	Unit	Total	Forestry Operations	Plywood Production
Global warming potential (GWP)	kg CO_2 eq.	1.82E+02	1.10E+01	1.72E+02
Acidification potential	SO_2 eq.	2.02E+00	1.51E-01	1.87E+00
Eutrophication potential	kg N eq.	7.60E-02	1.04E-02	6.56E-02
Ozone depletion potential	kg CFC-11 eq.	1.26E-07	4.94E-10	1.25E-07
Smog potential	kg O3 eq.	3.09E+01	4.73E+00	2.62E+01
Primary Energy Consumption				
Total	MJ	9.41E+03	1.65E+02	9.24E+03
Non-renewable fossil	MJ	3.10E+03	1.63E+02	2.93E+03
Non-renewable nuclear	MJ	3.02E+02	1.72E+00	3.01E+02
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	1.92E+02	2.69E-01	1.92E+02
Renewable, biomass	MJ	5.82E+03	1.62E-03	5.82E+03
Material Resources Consumption (Non-fuel resources)				
Non-renewable materials	kg	7.31E+00	9.09E-03	7.30E+00
Renewable materials	kg	8.77E+02	0.00E+00	8.77E+02
Fresh water	L	1.36E+03	1.05E+01	1.34E+03
Waste generated				
Solid waste	kg	1.51E+01	1.71E-01	1.49E+01

15.2 Carbon – Economic allocation

Using the same method applied for mass allocation, 183 kg CO_2e were released in the production of 1 m^3 of PNW plywood. That same 1 m^3 of plywood stores 223 kg of carbon[6] or 817 kg CO_2 eq.[7], resulting in more carbon storage in the product then released during manufacturing (cradle to gate) (Table 26). There was a 40-kilogram CO_2 eq. difference between mass and economic allocation methods.

Table 25 Carbon balance of one m[3] of softwood plywood produced in the PNW region – Economic allocation

	kg CO_2 equivalent
Released during forestry operations	1.10E+01
Released during manufacture	1.72E+02
Stored in product	8.17E+02

[6] Assuming a 50% carbon content

[7] 446 OD kg of wood in plywood × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO_2/kmole/12 kg carbon/kmole) = 817 kg CO_2 eq.

15.3 Cradle to gate LCI air emissions (economic allocation)

Table 26 Emissions to air per 1 m³ of softwood plywood produced in the PNW region (economic allocation)

Substance	Total	Forestry Operations	Plywood Production
	kg/m³		
2-Chloroacetophenone	4.09E-10	1.81E-12	4.07E-10
2-Methyl-4-chlorophenoxyacetic acid	2.55E-11	0.00E+00	2.55E-11
2,4-D	1.37E-09	0.00E+00	1.37E-09
5-methyl Chrysene	3.57E-10	1.85E-12	3.55E-10
Acenaphthene	8.28E-09	4.28E-11	8.23E-09
Acenaphthylene	4.06E-09	2.10E-11	4.04E-09
Acetaldehyde	1.66E-02	4.36E-05	1.66E-02
Acetochlor	1.90E-08	0.00E+00	1.90E-08
Acetone	1.45E-02	0.00E+00	1.45E-02
Acetophenone	8.76E-10	3.87E-12	8.72E-10
Acrolein	3.39E-03	5.28E-06	3.39E-03
Alachlor	1.87E-09	0.00E+00	1.87E-09
Aldehydes, unspecified	7.14E-04	1.33E-04	5.81E-04
Ammonia	3.76E-03	8.87E-05	3.67E-03
Ammonium chloride	4.20E-05	2.39E-07	4.17E-05
Anthracene	3.41E-09	1.76E-11	3.39E-09
Antimony	2.99E-07	1.51E-09	2.98E-07
Arsenic	6.88E-06	4.79E-08	6.84E-06
Atrazine	3.70E-08	0.00E+00	3.70E-08
Barium	2.14E-07	0.00E+00	2.14E-07
Bentazone	1.51E-10	0.00E+00	1.51E-10
Benzene	1.99E-02	5.32E-05	1.98E-02
Benzene, chloro-	1.29E-09	5.68E-12	1.28E-09
Benzene, ethyl-	8.55E-07	2.42E-11	8.55E-07
Benzo(a)anthracene	1.30E-09	6.72E-12	1.29E-09
Benzo(a)pyrene	6.17E-10	3.19E-12	6.14E-10
Benzo(b,j,k)fluoranthene	1.79E-09	9.24E-12	1.78E-09
Benzo(g,h,i)perylene	4.34E-10	2.24E-12	4.32E-10
Benzo(ghi)perylene	4.44E-12	3.06E-14	4.41E-12
Benzyl chloride	4.09E-08	1.81E-10	4.07E-08
Beryllium	3.67E-07	2.36E-09	3.64E-07
Biphenyl	2.76E-08	1.43E-10	2.74E-08
Bromoform	2.28E-09	1.01E-11	2.27E-09
Bromoxynil	3.31E-10	0.00E+00	3.31E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	8.32E-03	6.07E-05	8.26E-03
Butadiene	4.19E-06	2.22E-06	1.97E-06
Cadmium	1.32E-06	1.17E-08	1.31E-06
Carbofuran	2.83E-10	0.00E+00	2.83E-10
Carbon dioxide	2.21E-01	2.85E-02	1.92E-01
Carbon dioxide, biogenic	4.76E+02	8.28E-03	4.76E+02

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Carbon dioxide, fossil	1.68E+02	1.05E+01	1.57E+02
Carbon disulfide	7.59E-09	3.35E-11	7.56E-09
Carbon monoxide	1.47E-02	3.92E-06	1.47E-02
Carbon monoxide, biogenic	1.17E+00	0.00E+00	1.17E+00
Carbon monoxide, fossil	3.97E-01	9.59E-02	3.01E-01
Chloride	9.73E-10	6.34E-12	9.66E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	1.73E-07	0.00E+00	1.73E-07
Chlorine	2.83E-06	0.00E+00	2.83E-06
Chloroform	3.45E-09	1.52E-11	3.43E-09
Chlorpyrifos	2.17E-09	0.00E+00	2.17E-09
Chromium	4.88E-06	3.43E-08	4.84E-06
Chromium VI	1.28E-06	6.63E-09	1.28E-06
Chrysene	1.62E-09	8.40E-12	1.61E-09
Cobalt	2.16E-06	6.56E-08	2.09E-06
Copper	3.65E-08	5.89E-10	3.59E-08
Cumene	1.03E-02	0.00E+00	1.03E-02
Cyanazine	3.26E-10	0.00E+00	3.26E-10
Cyanide	1.46E-07	6.45E-10	1.45E-07
Dicamba	1.92E-09	0.00E+00	1.92E-09
Dimethenamid	4.54E-09	0.00E+00	4.54E-09
Dimethyl ether	7.44E-05	0.00E+00	7.44E-05
Dinitrogen monoxide	2.91E-03	1.78E-04	2.74E-03
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	1.47E-09	2.12E-13	1.47E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	3.56E-19	0.00E+00	3.56E-19
Dipropylthiocarbamic acid S-ethyl ester	3.11E-09	0.00E+00	3.11E-09
Ethane, 1,1,1-trichloro-, HCFC-140	2.78E-09	3.12E-10	2.46E-09
Ethane, 1,2-dibromo-	7.04E-11	3.10E-13	7.01E-11
Ethane, 1,2-dichloro-	2.34E-09	1.03E-11	2.33E-09
Ethane, chloro-	2.45E-09	1.08E-11	2.44E-09
Ethene, tetrachloro-	7.07E-07	4.33E-09	7.03E-07
Ethene, trichloro-	2.52E-13	0.00E+00	2.52E-13
Ethylene oxide	1.83E-08	0.00E+00	1.83E-08
Fluoranthene	1.15E-08	5.96E-11	1.15E-08
Fluorene	1.48E-08	7.64E-11	1.47E-08
Fluoride	3.88E-06	3.41E-07	3.54E-06
Formaldehyde	8.91E-03	6.77E-05	8.85E-03
Furan	7.93E-11	3.84E-13	7.89E-11
Glyphosate	4.08E-09	0.00E+00	4.08E-09
HAPs	1.40E-03	0.00E+00	1.40E-03
HAPS, unspecified	1.15E-07	0.00E+00	1.15E-07
Heat, waste	1.16E+01	0.00E+00	1.16E+01
Hexane	3.91E-09	1.73E-11	3.90E-09
Hydrazine, methyl-	9.93E-09	4.39E-11	9.89E-09

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Hydrocarbons, unspecified	2.42E-04	1.38E-06	2.41E-04
Hydrogen	5.48E-06	0.00E+00	5.48E-06
Hydrogen chloride	1.98E-02	1.08E-04	1.97E-02
Hydrogen fluoride	2.43E-03	1.26E-05	2.42E-03
Hydrogen sulfide	3.14E-11	2.05E-13	3.12E-11
Indeno(1,2,3-cd)pyrene	9.90E-10	5.12E-12	9.85E-10
Iron	2.14E-07	0.00E+00	2.14E-07
Isophorone	3.39E-08	1.50E-10	3.37E-08
Isoprene	3.19E-02	2.08E-04	3.17E-02
Kerosene	2.01E-05	1.14E-07	2.00E-05
Lead	4.64E-05	5.31E-08	4.64E-05
Magnesium	1.79E-04	9.24E-07	1.78E-04
Manganese	1.02E-05	7.12E-08	1.01E-05
Mercaptans, unspecified	1.27E-05	5.55E-08	1.26E-05
Mercury	2.24E-06	9.44E-09	2.23E-06
Metals, unspecified	3.73E-05	0.00E+00	3.73E-05
Methane	4.86E-01	1.44E-02	4.71E-01
Methane, biogenic	4.97E-03	0.00E+00	4.97E-03
Methane, bromo-, Halon 1001	9.35E-09	4.13E-11	9.31E-09
Methane, chlorodifluoro-, HCFC-22	1.52E-13	0.00E+00	1.52E-13
Methane, chlorotrifluoro-, CFC-13	1.45E-12	0.00E+00	1.45E-12
Methane, dichloro-, HCC-30	5.55E-06	7.31E-08	5.48E-06
Methane, dichlorodifluoro-, CFC-12	1.99E-09	3.80E-10	1.61E-09
Methane, fossil	5.09E-02	1.09E-03	4.98E-02
Methane, monochloro-, R-40	3.10E-08	1.37E-10	3.08E-08
Methane, tetrachloro-, CFC-10	1.54E-07	3.80E-11	1.54E-07
Methanol	4.82E-02	0.00E+00	4.82E-02
Methyl ethyl ketone	2.28E-08	1.01E-10	2.27E-08
Methyl methacrylate	1.17E-09	5.16E-12	1.16E-09
Metolachlor	1.50E-08	0.00E+00	1.50E-08
Metribuzin	6.95E-11	0.00E+00	6.95E-11
N-Nitrodimethylamine	5.62E-14	0.00E+00	5.62E-14
Naphthalene	1.37E-05	1.36E-08	1.36E-05
Nickel	1.24E-05	8.29E-07	1.16E-05
Nitrogen oxides	1.16E+00	1.90E-01	9.74E-01
Nitrogen, total	6.45E-06	6.45E-06	1.83E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	5.40E-02	6.45E-03	4.76E-02
Organic acids	1.54E-07	8.78E-10	1.53E-07
Organic substances, unspecified	9.77E-04	5.21E-07	9.77E-04
Other Organic	4.71E-05	0.00E+00	4.71E-05
PAH, polycyclic aromatic hydrocarbons	1.79E-05	9.55E-06	8.39E-06
Paraquat	3.03E-10	0.00E+00	3.03E-10
Parathion, methyl	2.29E-10	0.00E+00	2.29E-10
Particulates	3.63E-05	0.00E+00	3.63E-05
Particulates, < 10 um	3.06E-01	0.00E+00	3.06E-01

Substance	**Total**	**Forestry Operations**	**Plywood Production**
	kg/m³		
Particulates, < 2.5 um	1.79E-01	0.00E+00	1.79E-01
Particulates, > 10 um	7.21E-04	0.00E+00	7.21E-04
Particulates, > 2.5 um, and < 10um	2.13E-02	5.82E-03	1.55E-02
Particulates, unspecified	5.89E-02	1.05E-03	5.79E-02
Pendimethalin	1.56E-09	0.00E+00	1.56E-09
Permethrin	1.40E-10	0.00E+00	1.40E-10
Phenanthrene	4.38E-08	2.27E-10	4.36E-08
Phenol	7.69E-04	1.00E-11	7.69E-04
Phenols, unspecified	7.50E-07	3.81E-08	7.11E-07
Phorate	7.18E-11	0.00E+00	7.18E-11
Phosphate	1.48E-07	#VALUE!	x
Phthalate, dioctyl-	4.26E-09	1.88E-11	4.25E-09
Polycyclic organic matter, unspecified	3.68E-12	0.00E+00	3.68E-12
Potassium	3.79E-05	0.00E+00	3.79E-05
Propanal	1.30E-05	9.80E-11	1.30E-05
Propene	4.07E-03	1.47E-04	3.92E-03
Propylene oxide	7.68E-07	0.00E+00	7.68E-07
Pyrene	5.36E-09	2.77E-11	5.33E-09
Radioactive species, unspecified	9.15E+05	4.75E+03	9.10E+05
Radionuclides (Including Radon)	1.12E-03	6.40E-06	1.12E-03
Selenium	2.13E-05	1.17E-07	2.11E-05
Simazine	9.84E-10	0.00E+00	9.84E-10
Sodium	8.74E-07	0.00E+00	8.74E-07
Styrene	1.46E-09	6.45E-12	1.45E-09
Sulfur	4.61E-06	0.00E+00	4.61E-06
Sulfur dioxide	1.11E+00	6.92E-03	1.11E+00
Sulfur monoxide	4.60E-02	1.05E-02	3.54E-02
Sulfur oxides	1.52E-02	1.35E-04	1.50E-02
Sulfur, total reduced	2.70E-06	0.00E+00	2.70E-06
Sulfuric acid, dimethyl ester	2.80E-09	1.24E-11	2.79E-09
t-Butyl methyl ether	2.04E-09	9.03E-12	2.04E-09
Tar	1.09E-09	7.13E-12	1.09E-09
Terbufos	2.45E-09	0.00E+00	2.45E-09
TOC, Total Organic Carbon	3.57E-06	0.00E+00	3.57E-06
Toluene	4.72E-05	2.33E-05	2.40E-05
Toluene, 2,4-dinitro-	1.64E-11	7.22E-14	1.63E-11
Vinyl acetate	4.44E-10	1.96E-12	4.42E-10
VOC, volatile organic compounds	3.81E-01	5.09E-03	3.76E-01
Wood (dust)	2.38E-01	0.00E+00	2.38E-01
Xylene	3.22E-05	1.62E-05	1.60E-05
Zinc	3.57E-07	1.20E-07	2.38E-07

15.4 Cradle to gate LCI water emissions (economic allocation)

Table 27 Emissions to water per 1 m^3 of softwood plywood produced in the PNW region (economic allocation)

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
2-Hexanone	1.10E-06	8.11E-08	1.02E-06
2-Methyl-4-chlorophenoxyacetic acid	1.09E-12	0.00E+00	1.09E-12
2-Propanol	2.54E-09	0.00E+00	2.54E-09
2,4-D	5.86E-11	0.00E+00	5.86E-11
4-Methyl-2-pentanone	7.06E-07	5.22E-08	6.53E-07
Acetaldehyde	1.93E-08	0.00E+00	1.93E-08
Acetochlor	8.13E-10	0.00E+00	8.13E-10
Acetone	1.68E-06	1.24E-07	1.55E-06
Acidity, unspecified	9.09E-15	0.00E+00	9.09E-15
Acids, unspecified	3.63E-06	1.33E-10	3.63E-06
Alachlor	8.00E-11	0.00E+00	8.00E-11
Aluminium	7.78E-03	1.06E-03	6.72E-03
Aluminum	1.03E-05	0.00E+00	1.03E-05
Ammonia	2.56E-03	2.31E-04	2.32E-03
Ammonia, as N	1.03E-08	6.69E-11	1.02E-08
Ammonium, ion	2.64E-04	5.11E-08	2.64E-04
Antimony	4.62E-06	6.61E-07	3.96E-06
Arsenic	3.16E-05	3.62E-06	2.80E-05
Arsenic, ion	9.40E-06	5.26E-08	9.35E-06
Atrazine	1.58E-09	0.00E+00	1.58E-09
Barium	1.05E-01	1.45E-02	9.07E-02
Bentazone	6.46E-12	0.00E+00	6.46E-12
Benzene	1.72E-02	2.08E-05	1.71E-02
Benzene, 1-methyl-4-(1-methylethyl)-	1.68E-08	1.24E-09	1.55E-08
Benzene, ethyl-	1.58E-05	1.17E-06	1.47E-05
Benzene, pentamethyl-	1.26E-08	9.31E-10	1.17E-08
Benzenes, alkylated, unspecified	4.05E-06	5.80E-07	3.47E-06
Benzo(a)pyrene	2.64E-10	0.00E+00	2.64E-10
Benzoic acid	1.70E-04	1.26E-05	1.58E-04
Beryllium	2.02E-06	1.88E-07	1.83E-06
Biphenyl	2.62E-07	3.75E-08	2.24E-07
BOD5, Biological Oxygen Demand	1.90E-01	2.27E-03	1.87E-01
Boron	5.27E-04	3.90E-05	4.88E-04
Bromide	3.60E-02	2.66E-03	3.33E-02
Bromoxynil	8.55E-12	0.00E+00	8.55E-12
Cadmium	4.78E-06	5.86E-07	4.20E-06
Cadmium, ion	1.38E-06	7.77E-09	1.37E-06
Calcium	4.15E-01	3.93E-02	3.76E-01
Calcium, ion	1.24E-01	6.17E-04	1.23E-01
Carbofuran	1.21E-11	0.00E+00	1.21E-11
CFCs, unspecified	2.54E-09	0.00E+00	2.54E-09

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Chloride	6.06E+00	4.49E-01	5.62E+00
Chlorpyrifos	9.32E-11	0.00E+00	9.32E-11
Chromate	5.14E-13	0.00E+00	5.14E-13
Chromium	1.46E-04	2.83E-05	1.18E-04
Chromium III	4.95E-05	2.17E-06	4.73E-05
Chromium VI	6.13E-07	1.17E-07	4.96E-07
Chromium, ion	1.41E-05	3.31E-08	1.41E-05
Cobalt	3.72E-06	2.75E-07	3.44E-06
COD, Chemical Oxygen Demand	2.15E-01	4.30E-03	2.11E-01
Copper	3.33E-05	3.65E-06	2.97E-05
Copper, ion	7.83E-06	5.46E-08	7.78E-06
Cumene	2.47E-02	0.00E+00	2.47E-02
Cyanazine	1.40E-11	0.00E+00	1.40E-11
Cyanide	4.24E-08	8.97E-10	4.15E-08
Decane	4.89E-06	3.62E-07	4.53E-06
Detergent, oil	1.57E-04	1.05E-05	1.47E-04
Dibenzofuran	3.19E-08	2.36E-09	2.96E-08
Dibenzothiophene	2.67E-08	2.03E-09	2.46E-08
Dicamba	8.23E-11	0.00E+00	8.23E-11
Dimethenamid	1.94E-10	0.00E+00	1.94E-10
Dipropylthiocarbamic acid S-ethyl ester	8.03E-11	0.00E+00	8.03E-11
Disulfoton	4.80E-12	0.00E+00	4.80E-12
Diuron	1.35E-12	0.00E+00	1.35E-12
DOC, Dissolved Organic Carbon	4.56E-02	0.00E+00	4.56E-02
Docosane	1.80E-07	1.33E-08	1.66E-07
Dodecane	9.28E-06	6.87E-07	8.60E-06
Eicosane	2.56E-06	1.89E-07	2.37E-06
Fluorene	3.61E-13	0.00E+00	3.61E-13
Fluorene, 1-methyl-	1.91E-08	1.41E-09	1.77E-08
Fluorenes, alkylated, unspecified	2.35E-07	3.36E-08	2.01E-07
Fluoride	9.69E-04	8.24E-04	1.45E-04
Fluorine	1.23E-07	1.66E-08	1.06E-07
Furan	9.32E-11	0.00E+00	9.32E-11
Glyphosate	1.75E-10	0.00E+00	1.75E-10
Hexadecane	1.01E-05	7.50E-07	9.38E-06
Hexanoic acid	3.53E-05	2.61E-06	3.27E-05
Hydrocarbons, unspecified	9.33E-08	5.12E-13	9.33E-08
Iron	1.79E-02	2.12E-03	1.57E-02
Lead	7.11E-05	7.24E-06	6.39E-05
Lead-210/kg	1.74E-14	1.29E-15	1.62E-14
Lithium	9.00E-02	8.40E-04	8.92E-02
Lithium, ion	2.48E-02	1.04E-05	2.48E-02
m-Xylene	5.09E-06	3.76E-07	4.71E-06
Magnesium	1.05E-01	7.80E-03	9.77E-02
Manganese	4.55E-04	1.39E-05	4.41E-04
Mercury	9.74E-08	1.58E-08	8.16E-08

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Metallic ions, unspecified	3.08E-09	6.25E-12	3.07E-09
Methane, monochloro-, R-40	6.76E-09	5.00E-10	6.26E-09
Methyl ethyl ketone	1.35E-08	1.00E-09	1.25E-08
Metolachlor	6.42E-10	0.00E+00	6.42E-10
Metribuzin	2.98E-12	0.00E+00	2.98E-12
Molybdenum	3.86E-06	2.86E-07	3.57E-06
n-Hexacosane	1.12E-07	8.29E-09	1.04E-07
Naphthalene	3.05E-06	2.26E-07	2.82E-06
Naphthalene, 2-methyl-	2.66E-06	1.97E-07	2.46E-06
Naphthalenes, alkylated, unspecified	6.63E-08	9.50E-09	5.68E-08
Nickel	3.56E-05	3.48E-06	3.21E-05
Nickel, ion	2.94E-13	0.00E+00	2.94E-13
Nitrate	3.02E-07	5.00E-14	3.02E-07
Nitrate compounds	2.77E-10	1.81E-12	2.75E-10
Nitric acid	6.21E-07	4.05E-09	6.17E-07
Nitrogen, total	3.29E-05	1.27E-07	3.27E-05
o-Cresol	4.83E-06	3.57E-07	4.47E-06
o-Xylene	7.67E-13	0.00E+00	7.67E-13
Octadecane	2.50E-06	1.85E-07	2.32E-06
Oils, unspecified	3.65E-03	2.86E-04	3.37E-03
Organic substances, unspecified	2.48E-09	0.00E+00	2.48E-09
p-Cresol	5.21E-06	3.85E-07	4.83E-06
p-Xylene	7.67E-13	0.00E+00	7.67E-13
Paraquat	1.30E-11	0.00E+00	1.30E-11
Parathion, methyl	9.82E-12	0.00E+00	9.82E-12
Pendimethalin	6.68E-11	0.00E+00	6.68E-11
Permethrin	6.00E-12	0.00E+00	6.00E-12
Phenanthrene	3.11E-08	3.42E-09	2.77E-08
Phenanthrenes, alkylated, unspecified	2.75E-08	3.94E-09	2.36E-08
Phenol	2.75E-05	5.19E-06	2.23E-05
Phenol, 2,4-dimethyl-	4.70E-06	3.48E-07	4.35E-06
Phenols, unspecified	5.20E-05	1.08E-06	5.09E-05
Phorate	1.86E-12	0.00E+00	1.86E-12
Phosphate	6.42E-04	6.20E-04	2.27E-05
Phosphorus	5.21E-06	0.00E+00	5.21E-06
Phosphorus compounds, unspecified	3.44E-08	0.00E+00	3.44E-08
Phosphorus, total	3.08E-06	0.00E+00	3.08E-06
Process solvents, unspecified	9.32E-09	0.00E+00	9.32E-09
Propene	9.11E-03	0.00E+00	9.11E-03
Radioactive species, Nuclides, unspecified	1.30E+03	7.42E+00	1.30E+03
Radium-226/kg	6.07E-12	4.49E-13	5.62E-12
Radium-228/kg	3.10E-14	2.30E-15	2.87E-14
Selenium	4.04E-06	1.46E-07	3.89E-06
Silver	3.52E-04	2.61E-05	3.26E-04
Simazine	4.22E-11	0.00E+00	4.22E-11

Substance	**Total**	**Forestry Operations**	**Plywood Production**
	kg/m^3		
Sodium	1.32E+00	1.25E-01	1.19E+00
Sodium, ion	3.93E-01	1.95E-03	3.91E-01
Solids, inorganic	1.58E-09	1.03E-11	1.57E-09
Solved solids	1.72E+00	8.55E-03	1.71E+00
Strontium	9.15E-03	6.77E-04	8.47E-03
Styrene	3.20E-10	0.00E+00	3.20E-10
Sulfate	3.05E-02	1.01E-03	2.95E-02
Sulfide	3.60E-05	6.02E-07	3.54E-05
Sulfur	4.45E-04	3.29E-05	4.12E-04
Sulfuric acid	2.18E-10	0.00E+00	2.18E-10
Surfactants	3.55E-11	0.00E+00	3.55E-11
Suspended solids, unspecified	6.04E+00	5.77E-01	5.46E+00
Tar	1.56E-11	1.02E-13	1.55E-11
Terbufos	6.34E-11	0.00E+00	6.34E-11
Tetradecane	4.07E-06	3.01E-07	3.77E-06
Thallium	9.74E-07	1.39E-07	8.34E-07
Tin	2.55E-05	2.70E-06	2.28E-05
Titanium	5.36E-05	9.99E-06	4.36E-05
Titanium, ion	1.73E-05	1.59E-07	1.72E-05
TOC, Total Organic Carbon	4.56E-02	0.00E+00	4.56E-02
Toluene	2.66E-04	1.97E-05	2.47E-04
Vanadium	4.56E-06	3.37E-07	4.22E-06
Waste water	7.68E-04	0.00E+00	7.68E-04
Xylene	1.40E-04	1.06E-05	1.29E-04
Yttrium	1.13E-06	8.37E-08	1.05E-06
Zinc	1.93E-04	2.45E-05	1.68E-04
Zinc, ion	4.11E-07	0.00E+00	4.11E-07

16. Appendix II: Emissions (mass allocation)

16.1 Cradle to gate LCI air emissions (mass allocation)

Table 28 Emissions to air per 1 m^3 of softwood plywood produced in the PNW region (mass allocation

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
2-Chloroacetophenone	3.73E-10	1.81E-12	3.71E-10
2-Methyl-4-chlorophenoxyacetic acid	2.55E-11	0.00E+00	2.55E-11
2,4-D	1.37E-09	0.00E+00	1.37E-09
5-methyl Chrysene	2.78E-10	1.85E-12	2.76E-10
Acenaphthene	6.43E-09	4.28E-11	6.39E-09
Acenaphthylene	3.15E-09	2.10E-11	3.13E-09
Acetaldehyde	1.33E-02	4.36E-05	1.32E-02
Acetochlor	1.90E-08	0.00E+00	1.90E-08
Acetone	1.15E-02	0.00E+00	1.15E-02
Acetophenone	7.99E-10	3.87E-12	7.95E-10
Acrolein	2.70E-03	5.28E-06	2.70E-03
Alachlor	1.87E-09	0.00E+00	1.87E-09
Aldehydes, unspecified	5.76E-04	1.33E-04	4.43E-04
Ammonia	2.99E-03	8.87E-05	2.90E-03
Ammonium chloride	3.26E-05	2.39E-07	3.24E-05
Anthracene	2.65E-09	1.76E-11	2.63E-09
Antimony	2.34E-07	1.51E-09	2.32E-07
Arsenic	5.36E-06	4.79E-08	5.31E-06
Atrazine	3.70E-08	0.00E+00	3.70E-08
Barium	2.14E-07	0.00E+00	2.14E-07
Bentazone	1.51E-10	0.00E+00	1.51E-10
Benzene	1.58E-02	5.32E-05	1.58E-02
Benzene, chloro-	1.17E-09	5.68E-12	1.17E-09
Benzene, ethyl-	6.81E-07	2.42E-11	6.81E-07
Benzo(a)anthracene	1.01E-09	6.72E-12	1.00E-09
Benzo(a)pyrene	4.79E-10	3.19E-12	4.76E-10
Benzo(b,j,k)fluoranthen e	1.39E-09	9.24E-12	1.38E-09
Benzo(g,h,i)perylene	3.37E-10	2.24E-12	3.35E-10
Benzo(ghi)perylene	3.70E-12	3.06E-14	3.67E-12
Benzyl chloride	3.73E-08	1.81E-10	3.71E-08
Beryllium	2.85E-07	2.36E-09	2.83E-07
Biphenyl	2.14E-08	1.43E-10	2.13E-08
Bromoform	2.08E-09	1.01E-11	2.07E-09
Bromoxynil	3.31E-10	0.00E+00	3.31E-10
BTEX (Benzene, Toluene, Ethylbenzene,	6.52E-03	6.07E-05	6.45E-03

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
and Xylene), unspecified ratio			
Butadiene	3.66E-06	2.22E-06	1.44E-06
Cadmium	1.03E-06	1.17E-08	1.02E-06
Carbofuran	2.83E-10	0.00E+00	2.83E-10
Carbon dioxide	1.81E-01	2.85E-02	1.53E-01
Carbon dioxide, biogenic	3.77E+02	8.27E-03	3.77E+02
Carbon dioxide, fossil	1.32E+02	1.05E+01	1.21E+02
Carbon disulfide	6.92E-09	3.35E-11	6.89E-09
Carbon monoxide	1.21E-02	3.92E-06	1.21E-02
Carbon monoxide, biogenic	9.27E-01	0.00E+00	9.27E-01
Carbon monoxide, fossil	3.25E-01	9.59E-02	2.29E-01
Chloride	7.54E-10	6.34E-12	7.48E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	1.43E-07	0.00E+00	1.43E-07
Chlorine	2.48E-06	0.00E+00	2.48E-06
Chloroform	3.14E-09	1.52E-11	3.13E-09
Chlorpyrifos	2.17E-09	0.00E+00	2.17E-09
Chromium	3.80E-06	3.43E-08	3.76E-06
Chromium VI	9.97E-07	6.63E-09	9.90E-07
Chrysene	1.26E-09	8.40E-12	1.25E-09
Cobalt	1.69E-06	6.56E-08	1.62E-06
Copper	2.85E-08	5.89E-10	2.79E-08
Cumene	8.19E-03	0.00E+00	8.19E-03
Cyanazine	3.26E-10	0.00E+00	3.26E-10
Cyanide	1.33E-07	6.45E-10	1.33E-07
Dicamba	1.92E-09	0.00E+00	1.92E-09
Dimethenamid	4.54E-09	0.00E+00	4.54E-09
Dimethyl ether	5.92E-05	0.00E+00	5.92E-05
Dinitrogen monoxide	2.43E-03	1.78E-04	2.25E-03
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	1.47E-09	2.12E-13	1.47E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	3.56E-19	0.00E+00	3.56E-19
Dipropylthiocarbamic acid S-ethyl ester	3.11E-09	0.00E+00	3.11E-09
Ethane, 1,1,1-trichloro-, HCFC-140	2.36E-09	3.12E-10	2.05E-09
Ethane, 1,2-dibromo-	6.41E-11	3.10E-13	6.38E-11
Ethane, 1,2-dichloro-	2.13E-09	1.03E-11	2.12E-09

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Ethane, chloro-	2.24E-09	1.08E-11	2.23E-09
Ethene, tetrachloro-	5.50E-07	4.33E-09	5.46E-07
Ethene, trichloro-	2.52E-13	0.00E+00	2.52E-13
Ethylene oxide	1.46E-08	0.00E+00	1.46E-08
Fluoranthene	8.96E-09	5.96E-11	8.90E-09
Fluorene	1.15E-08	7.64E-11	1.14E-08
Fluoride	3.44E-06	3.41E-07	3.10E-06
Formaldehyde	7.09E-03	6.77E-05	7.02E-03
Furan	6.16E-11	3.84E-13	6.12E-11
Glyphosate	4.08E-09	0.00E+00	4.08E-09
HAPs	1.11E-03	0.00E+00	1.11E-03
HAPS, unspecified	1.15E-07	0.00E+00	1.15E-07
Heat, waste	9.22E+00	0.00E+00	9.22E+00
Hexane	3.57E-09	1.73E-11	3.55E-09
Hydrazine, methyl-	9.05E-09	4.39E-11	9.01E-09
Hydrocarbons, unspecified	1.89E-04	1.38E-06	1.87E-04
Hydrogen	4.39E-06	0.00E+00	4.39E-06
Hydrogen chloride	1.54E-02	1.08E-04	1.53E-02
Hydrogen fluoride	1.89E-03	1.26E-05	1.88E-03
Hydrogen sulfide	2.44E-11	2.05E-13	2.42E-11
Indeno(1,2,3-cd)pyrene	7.70E-10	5.12E-12	7.65E-10
Iron	2.14E-07	0.00E+00	2.14E-07
Isophorone	3.09E-08	1.50E-10	3.07E-08
Isoprene	2.47E-02	2.08E-04	2.45E-02
Kerosene	1.56E-05	1.14E-07	1.55E-05
Lead	3.67E-05	5.31E-08	3.67E-05
Magnesium	1.39E-04	9.24E-07	1.38E-04
Manganese	8.35E-06	7.12E-08	8.28E-06
Mercaptans, unspecified	1.15E-05	5.55E-08	1.15E-05
Mercury	1.77E-06	9.44E-09	1.76E-06
Metals, unspecified	3.73E-05	0.00E+00	3.73E-05
Methane	3.81E-01	1.44E-02	3.67E-01
Methane, biogenic	3.94E-03	0.00E+00	3.94E-03
Methane, bromo-, Halon 1001	8.52E-09	4.13E-11	8.48E-09
Methane, chlorodifluoro-, HCFC-22	1.21E-13	0.00E+00	1.21E-13
Methane, chlorotrifluoro-, CFC-13	1.15E-12	0.00E+00	1.15E-12
Methane, dichloro-, HCC-30	4.38E-06	7.31E-08	4.31E-06
Methane, dichlorodifluoro-, CFC-12	1.61E-09	3.80E-10	1.23E-09

Substance	Total	Forestry Operations	Plywood Production
	kg/m³		
Methane, fossil	4.00E-02	1.09E-03	3.89E-02
Methane, monochloro-, R-40	2.82E-08	1.37E-10	2.81E-08
Methane, tetrachloro-, CFC-10	1.23E-07	3.80E-11	1.23E-07
Methanol	3.84E-02	0.00E+00	3.84E-02
Methyl ethyl ketone	2.08E-08	1.01E-10	2.07E-08
Methyl methacrylate	1.07E-09	5.16E-12	1.06E-09
Metolachlor	1.50E-08	0.00E+00	1.50E-08
Metribuzin	6.95E-11	0.00E+00	6.95E-11
N-Nitrodimethylamine	5.62E-14	0.00E+00	5.62E-14
Naphthalene	1.09E-05	1.36E-08	1.08E-05
Nickel	9.82E-06	8.29E-07	8.99E-06
Nitrogen oxides	9.43E-01	1.90E-01	7.53E-01
Nitrogen, total	6.45E-06	6.45E-06	1.83E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	4.33E-02	6.45E-03	3.69E-02
Organic acids	1.20E-07	8.78E-10	1.19E-07
Organic substances, unspecified	7.75E-04	5.21E-07	7.74E-04
Other Organic	3.73E-05	0.00E+00	3.73E-05
PAH, polycyclic aromatic hydrocarbons	1.57E-05	9.55E-06	6.14E-06
Paraquat	3.03E-10	0.00E+00	3.03E-10
Parathion, methyl	2.29E-10	0.00E+00	2.29E-10
Particulates	2.89E-05	0.00E+00	2.89E-05
Particulates, < 10 um	2.43E-01	0.00E+00	2.43E-01
Particulates, < 2.5 um	1.42E-01	0.00E+00	1.42E-01
Particulates, > 10 um	6.03E-04	0.00E+00	6.03E-04
Particulates, > 2.5 um, and < 10um	1.77E-02	5.82E-03	1.19E-02
Particulates, unspecified	4.60E-02	1.05E-03	4.50E-02
Pendimethalin	1.56E-09	0.00E+00	1.56E-09
Permethrin	1.40E-10	0.00E+00	1.40E-10
Phenanthrene	3.41E-08	2.27E-10	3.38E-08
Phenol	6.11E-04	1.00E-11	6.11E-04
Phenols, unspecified	6.00E-07	3.81E-08	5.62E-07
Phorate	7.18E-11	0.00E+00	7.18E-11
Phosphate	1.48E-07	1.48E-07	0.00E+00
Phthalate, dioctyl-	3.89E-09	1.88E-11	3.87E-09
Polycyclic organic matter, unspecified	2.93E-12	0.00E+00	2.93E-12
Potassium	3.79E-05	0.00E+00	3.79E-05
Propanal	1.07E-05	9.80E-11	1.07E-05
Propene	3.26E-03	1.47E-04	3.11E-03

Substance	Total	Forestry Operations	Plywood Production
	kg/m³		
Propylene oxide	6.11E-07	0.00E+00	6.11E-07
Pyrene	4.16E-09	2.77E-11	4.14E-09
Radioactive species, unspecified	7.11E+05	4.75E+03	7.06E+05
Radionuclides (Including Radon)	8.74E-04	6.40E-06	8.68E-04
Selenium	1.65E-05	1.17E-07	1.64E-05
Simazine	9.84E-10	0.00E+00	9.84E-10
Sodium	8.74E-07	0.00E+00	8.74E-07
Styrene	1.33E-09	6.45E-12	1.33E-09
Sulfur	4.61E-06	0.00E+00	4.61E-06
Sulfur dioxide	8.69E-01	6.92E-03	8.62E-01
Sulfur monoxide	3.72E-02	1.05E-02	2.66E-02
Sulfur oxides	1.24E-02	1.35E-04	1.23E-02
Sulfur, total reduced	2.70E-06	0.00E+00	2.70E-06
Sulfuric acid, dimethyl ester	2.56E-09	1.24E-11	2.54E-09
t-Butyl methyl ether	1.86E-09	9.03E-12	1.86E-09
Tar	8.48E-10	7.13E-12	8.41E-10
Terbufos	2.45E-09	0.00E+00	2.45E-09
TOC, Total Organic Carbon	3.57E-06	0.00E+00	3.57E-06
Toluene	4.10E-05	2.33E-05	1.78E-05
Toluene, 2,4-dinitro-	1.49E-11	7.22E-14	1.48E-11
Vinyl acetate	4.05E-10	1.96E-12	4.03E-10
VOC, volatile organic compounds	3.03E-01	5.09E-03	2.98E-01
Wood (dust)	1.89E-01	0.00E+00	1.89E-01
Xylene	2.80E-05	1.62E-05	1.18E-05
Zinc	3.52E-07	1.20E-07	2.32E-07

16.2 Cradle to gate LCI water emissions (mass allocation)

Table 29 Emissions to water per 1 m³ of softwood plywood produced in the PNW region (mass allocation)

Substance	Total	Forestry Operations	Plywood Production
	kg/m³		
2-Hexanone	8.68E-07	8.11E-08	7.87E-07
2-Methyl-4-chlorophenoxyacetic acid	1.09E-12	0.00E+00	1.09E-12
2-Propanol	2.54E-09	0.00E+00	2.54E-09
2,4-D	5.86E-11	0.00E+00	5.86E-11
4-Methyl-2-pentanone	5.59E-07	5.22E-08	5.07E-07
Acetaldehyde	1.54E-08	0.00E+00	1.54E-08
Acetochlor	8.13E-10	0.00E+00	8.13E-10

Substance	Total	Forestry Operations	Plywood Production
	kg/m³		
Acetone	1.33E-06	1.24E-07	1.21E-06
Acidity, unspecified	9.09E-15	0.00E+00	9.09E-15
Acids, unspecified	3.62E-06	1.33E-10	3.62E-06
Alachlor	8.00E-11	0.00E+00	8.00E-11
Aluminium	6.23E-03	1.06E-03	5.17E-03
Aluminum	1.03E-05	0.00E+00	1.03E-05
Ammonia	2.03E-03	2.31E-04	1.80E-03
Ammonia, as N	7.95E-09	6.69E-11	7.89E-09
Ammonium, ion	2.09E-04	5.11E-08	2.09E-04
Antimony	3.70E-06	6.61E-07	3.04E-06
Arsenic	2.51E-05	3.62E-06	2.15E-05
Arsenic, ion	7.50E-06	5.26E-08	7.44E-06
Atrazine	1.58E-09	0.00E+00	1.58E-09
Barium	8.43E-02	1.45E-02	6.98E-02
Bentazone	6.46E-12	0.00E+00	6.46E-12
Benzene	1.36E-02	2.08E-05	1.36E-02
Benzene, 1-methyl-4-(1-methylethyl)-	1.33E-08	1.24E-09	1.20E-08
Benzene, ethyl-	1.26E-05	1.17E-06	1.14E-05
Benzene, pentamethyl-	9.97E-09	9.31E-10	9.04E-09
Benzenes, alkylated, unspecified	3.24E-06	5.80E-07	2.66E-06
Benzo(a)pyrene	2.64E-10	0.00E+00	2.64E-10
Benzoic acid	1.35E-04	1.26E-05	1.22E-04
Beryllium	1.60E-06	1.88E-07	1.41E-06
Biphenyl	2.10E-07	3.75E-08	1.72E-07
BOD5, Biological Oxygen Demand	1.51E-01	2.27E-03	1.49E-01
Boron	4.17E-04	3.90E-05	3.78E-04
Bromide	2.85E-02	2.66E-03	2.58E-02
Bromoxynil	8.55E-12	0.00E+00	8.55E-12
Cadmium	3.81E-06	5.86E-07	3.22E-06
Cadmium, ion	1.10E-06	7.77E-09	1.09E-06
Calcium	3.28E-01	3.93E-02	2.89E-01
Calcium, ion	9.89E-02	6.17E-04	9.83E-02
Carbofuran	1.21E-11	0.00E+00	1.21E-11
CFCs, unspecified	2.54E-09	0.00E+00	2.54E-09
Chloride	4.80E+00	4.49E-01	4.36E+00
Chlorpyrifos	9.32E-11	0.00E+00	9.32E-11
Chromate	5.14E-13	0.00E+00	5.14E-13
Chromium	1.18E-04	2.83E-05	8.99E-05
Chromium III	3.88E-05	2.17E-06	3.67E-05
Chromium VI	4.95E-07	1.17E-07	3.78E-07
Chromium, ion	1.12E-05	3.31E-08	1.12E-05
Cobalt	2.95E-06	2.75E-07	2.67E-06
COD, Chemical Oxygen Demand	1.72E-01	4.30E-03	1.67E-01
Copper	2.64E-05	3.65E-06	2.28E-05
Copper, ion	6.25E-06	5.46E-08	6.20E-06
Cumene	1.97E-02	0.00E+00	1.97E-02

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Cyanazine	1.40E-11	0.00E+00	1.40E-11
Cyanide	3.98E-08	8.97E-10	3.89E-08
Decane	3.88E-06	3.62E-07	3.51E-06
Detergent, oil	1.24E-04	1.05E-05	1.14E-04
Dibenzofuran	2.53E-08	2.36E-09	2.29E-08
Dibenzothiophene	2.11E-08	2.03E-09	1.91E-08
Dicamba	8.23E-11	0.00E+00	8.23E-11
Dimethenamid	1.94E-10	0.00E+00	1.94E-10
Dipropylthiocarbamic acid S-ethyl ester	8.03E-11	0.00E+00	8.03E-11
Disulfoton	4.80E-12	0.00E+00	4.80E-12
Diuron	1.35E-12	0.00E+00	1.35E-12
DOC, Dissolved Organic Carbon	3.63E-02	0.00E+00	3.63E-02
Docosane	1.42E-07	1.33E-08	1.29E-07
Dodecane	7.36E-06	6.87E-07	6.67E-06
Eicosane	2.03E-06	1.89E-07	1.84E-06
Fluorene	2.87E-13	0.00E+00	2.87E-13
Fluorene, 1-methyl-	1.51E-08	1.41E-09	1.37E-08
Fluorenes, alkylated, unspecified	1.88E-07	3.36E-08	1.54E-07
Fluoride	9.37E-04	8.24E-04	1.13E-04
Fluorine	9.83E-08	1.66E-08	8.17E-08
Furan	9.32E-11	0.00E+00	9.32E-11
Glyphosate	1.75E-10	0.00E+00	1.75E-10
Hexadecane	8.03E-06	7.50E-07	7.28E-06
Hexanoic acid	2.79E-05	2.61E-06	2.53E-05
Hydrocarbons, unspecified	9.33E-08	5.12E-13	9.33E-08
Iron	1.43E-02	2.12E-03	1.21E-02
Lead	5.66E-05	7.24E-06	4.94E-05
Lead-210/kg	1.38E-14	1.29E-15	1.25E-14
Lithium	7.03E-02	8.40E-04	6.94E-02
Lithium, ion	1.97E-02	1.04E-05	1.97E-02
m-Xylene	4.03E-06	3.76E-07	3.65E-06
Magnesium	8.36E-02	7.80E-03	7.58E-02
Manganese	3.56E-04	1.39E-05	3.42E-04
Mercury	7.86E-08	1.58E-08	6.28E-08
Metallic ions, unspecified	2.86E-09	6.25E-12	2.86E-09
Methane, monochloro-, R-40	5.35E-09	5.00E-10	4.85E-09
Methyl ethyl ketone	1.07E-08	1.00E-09	9.71E-09
Metolachlor	6.42E-10	0.00E+00	6.42E-10
Metribuzin	2.98E-12	0.00E+00	2.98E-12
Molybdenum	3.06E-06	2.86E-07	2.77E-06
n-Hexacosane	8.88E-08	8.29E-09	8.05E-08
Naphthalene	2.42E-06	2.26E-07	2.19E-06
Naphthalene, 2-methyl-	2.11E-06	1.97E-07	1.91E-06
Naphthalenes, alkylated, unspecified	5.31E-08	9.50E-09	4.36E-08
Nickel	2.83E-05	3.48E-06	2.49E-05
Nickel, ion	2.94E-13	0.00E+00	2.94E-13

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Nitrate	3.02E-07	4.00E-14	3.02E-07
Nitrate compounds	2.15E-10	1.81E-12	2.13E-10
Nitric acid	4.81E-07	4.05E-09	4.77E-07
Nitrogen, total	2.79E-05	1.27E-07	2.78E-05
o-Cresol	3.83E-06	3.57E-07	3.47E-06
o-Xylene	6.10E-13	0.00E+00	6.10E-13
Octadecane	1.98E-06	1.85E-07	1.80E-06
Oils, unspecified	2.90E-03	2.86E-04	2.62E-03
Organic substances, unspecified	2.48E-09	0.00E+00	2.48E-09
p-Cresol	4.13E-06	3.85E-07	3.74E-06
p-Xylene	6.10E-13	0.00E+00	6.10E-13
Paraquat	1.30E-11	0.00E+00	1.30E-11
Parathion, methyl	9.82E-12	0.00E+00	9.82E-12
Pendimethalin	6.68E-11	0.00E+00	6.68E-11
Permethrin	6.00E-12	0.00E+00	6.00E-12
Phenanthrene	2.48E-08	3.42E-09	2.14E-08
Phenanthrenes, alkylated, unspecified	2.20E-08	3.94E-09	1.81E-08
Phenol	2.23E-05	5.19E-06	1.71E-05
Phenol, 2,4-dimethyl-	3.73E-06	3.48E-07	3.38E-06
Phenols, unspecified	4.08E-05	1.08E-06	3.97E-05
Phorate	1.86E-12	0.00E+00	1.86E-12
Phosphate	6.42E-04	6.20E-04	2.27E-05
Phosphorus	5.21E-06	0.00E+00	5.21E-06
Phosphorus compounds, unspecified	3.44E-08	0.00E+00	3.44E-08
Phosphorus, total	3.08E-06	0.00E+00	3.08E-06
Process solvents, unspecified	9.32E-09	0.00E+00	9.32E-09
Propene	7.24E-03	0.00E+00	7.24E-03
Radioactive species, Nuclides, unspecified	1.01E+03	7.42E+00	1.01E+03
Radium-226/kg	4.81E-12	4.49E-13	4.36E-12
Radium-228/kg	2.46E-14	2.30E-15	2.23E-14
Selenium	3.16E-06	1.46E-07	3.02E-06
Silver	2.79E-04	2.61E-05	2.53E-04
Simazine	4.22E-11	0.00E+00	4.22E-11
Sodium	1.04E+00	1.25E-01	9.17E-01
Sodium, ion	3.13E-01	1.95E-03	3.12E-01
Solids, inorganic	1.22E-09	1.03E-11	1.21E-09
Solved solids	1.37E+00	8.55E-03	1.36E+00
Strontium	7.25E-03	6.77E-04	6.57E-03
Styrene	2.57E-10	0.00E+00	2.57E-10
Sulfate	2.39E-02	1.01E-03	2.29E-02
Sulfide	3.46E-05	6.02E-07	3.40E-05
Sulfur	3.52E-04	3.29E-05	3.19E-04
Sulfuric acid	2.18E-10	0.00E+00	2.18E-10
Surfactants	2.83E-11	0.00E+00	2.83E-11
Suspended solids, unspecified	4.78E+00	5.77E-01	4.20E+00

Substance	Total	Forestry Operations	Plywood Production
	kg/m^3		
Tar	1.21E-11	1.02E-13	1.20E-11
Terbufos	6.34E-11	0.00E+00	6.34E-11
Tetradecane	3.22E-06	3.01E-07	2.92E-06
Thallium	7.80E-07	1.39E-07	6.41E-07
Tin	2.03E-05	2.70E-06	1.76E-05
Titanium	4.30E-05	9.99E-06	3.30E-05
Titanium, ion	1.38E-05	1.59E-07	1.37E-05
TOC, Total Organic Carbon	3.63E-02	0.00E+00	3.63E-02
Toluene	2.11E-04	1.97E-05	1.91E-04
Vanadium	3.61E-06	3.37E-07	3.27E-06
Waste water/m3	7.68E-04	0.00E+00	7.68E-04
Xylene	1.11E-04	1.06E-05	1.00E-04
Yttrium	8.96E-07	8.37E-08	8.13E-07
Zinc	1.54E-04	2.45E-05	1.29E-04
Zinc, ion	4.11E-07	0.00E+00	4.11E-07

17. Appendix III: Survey (clickable .pdf)

The Consortium for Research on Renewable Industrial Materials (CORRIM II)

Softwood Plywood Mills 2013

The information from this survey will be used in a project by CORRIM, a consortium of universities, industry, and government groups. CORRIM is updating life-cycle assessment data that describes environmental impacts of building materials. This survey is designed specifically for softwood plywood mills. Questions concentrate on annual production, electricity production and usage, fuel use, material flows, and environmental emissions.

Your data will be confidential; only average values for the industry will be reported.

Company: ______ You can also insert your business card.

Facility Site (city, state): ______

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

Name:		**Title:**	
E-mail:		**Telephone:**	

If you have questions about the survey, please contact:
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