Cradle to Gate Life Cycle Assessment of Engineered I-Joists Production from the Pacific Northwest

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1 Background

CORRIM, the Consortium for Research on Renewable Industrial Materials, has conducted life cycle inventory (LCI) for major wood products and wood production regions in the United States. The life cycle inventory data cover from forest regeneration through to final product at the mill gate. Research has covered nine major forest products including both structural and nonstructural uses and four major regions: in this report we focus on Composite I-Joists (I-joists) produced in the US Pacific Northwest (PNW) region. The PNW regional data is a representative cross-section of forest growth and manufacturing processes in western Washington and Oregon. This document updates the current wood product LCI's from a gate to gate to a cradle to gate LCI. Updates include the addition of PNW forestry operations, boiler, resin, and electrical grid data that have been developed since the original mill surveys were conducted during 1999 and 2000. The updated LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2 (Simapro version 4) (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare et al. 2011). These updates are necessary for the development of environmental product declarations (EPD) which will be based on this document. This document originates from the CORRIM LCI report by Wilson and Dancer (2004a, 2005a) and Johnson et al. (2005). Updates in this report from the original Wilson and Dancer report include, wood combustion boiler updates, resin (Franklin 2010), and electricity grid updates Goemans 2010), with results expressed per unit of final product (1 km of I-joists), and an LCIA. Updates to Laminated Veneer Lumber and Oriented Strand Board (SE OSB) production are included in the "Cradle to grave life cycle assessment Laminated Veneer Lumber from the Pacific Northwest " and "Cradle to grave life cycle assessment Oriented Strand Board from the Southeast" reports (Puettmann et al. 2012a, 2012b). Updates to the forestry operations include electricity grid updates and an LCIA using the TRACI method consistent with the approach taken for laminated veneer lumber in the PNW. This report follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011) that will provide the guidance for preparation of North American wood product EPD. This report does not include comparative assertions.

2 Introduction

The goal of this work is to determine energy and material inputs and outputs associated with the production of I-joists from the manufacturing base located in the PNW region of North America. These data are needed for the inclusion of the production process in life-cycle analyses of wood. The data were obtained through a scientifically sound and consistent process established by the Consortium for Research on Renewable Industrial Materials (CORRIM), following ISO14040 standards (ISO 2006).

The scope of this study was to develop an LCI and LCIA for the production of I-joists based on current manufacturing practices in Oregon and Washington. This study includes the cradle-to-gate environmental impacts of laminated veneer lumber (LVL) (Wilson and Dancer 2004b, 2005b) and SE oriented strand board (SE OSB) (Kline 2005), and resins as upstream inputs to I-joist production, as well as all impacts associated with its manufacture. It covers the impacts in terms of input materials, fuels, and electricity through the outputs of product, co-products, and emissions. The logs used for LVL production are obtained from the forest resource base located in western Washington and Oregon as representative of the PNW region (Johnson et al. 2005). Since OSB is not produced in the PNW, SE OSB was used as an input into the system boundary with all upstream processes and burdens associated with its production, including forest operations included therein.

3 Description of Product

Composite I-joists, which are most commonly referred to as I-joists, are wood-based building materials that are designed to replace structural lumber in floor and roof joist systems. Composite I-joists are engineered products and are comprised of two different wood components. As the name implies, these products have an “I” shaped cross-section with the top and bottom flanges separated by a narrow “webbing” material, (Figure 1). In most modern I-joists, the flanges are made from laminated veneer lumber (LVL) that has been cut to specific dimensions, while the web material is generally made from oriented strandboard (OSB). In some instances, the flange material is made from solid-sawn lumber and the web material can be made from plywood. There are many different dimensions of composite I-joists but the most common are dimensions that directly replace 50.8 x 254 mm (2 x 10-inch) and 50.8 x 304.8 mm (2 x 12-inch) structural lumber. I-joists are usually made in continuous lengths and then cut to 18.29 meter lengths (60-feet) for shipping. This study focused on large-scale production facilities that would be representative of the industry. Laminated veneer lumber in the PNW region is made with Douglas-fir (Pseudotsuga menziesii (Mirbel) Franco). Oriented strand board are made from a combination of pine species, primarily loblolly (P. taeda L.) and slash (P. elliottii Engelm.), which are known as southern pine.

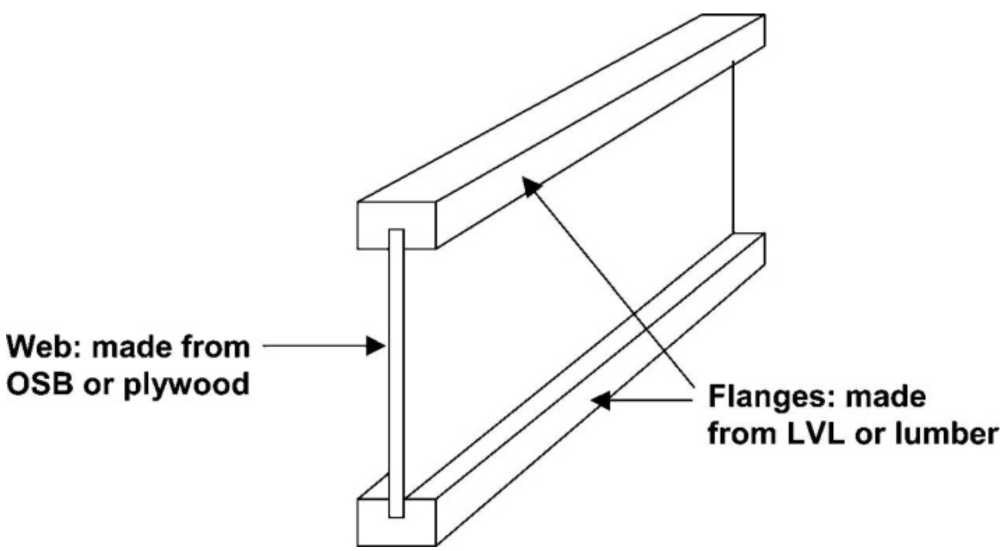

Figure 1 Diagram of the cross-section of a typical composite I-joist

Production of I-joists is measured on a lineal basis (feet, meters) with no measurement for the dimensions of height and width, which is the practice for the I-joist data given in this study. The most common dimensions of I-joist for the PNW can be found in table 1. This LCA uses a weighted average for producing a generic I-joist (Table 1). This I-joist is slightly larger than you would expect to find in that region. The reason for the generic I-joists being larger than typical I-joists is due to the small amount of waste and inefficiencies of producing the I-joists included in the product.

Table 1 Common dimensions for composite I-Joists, PNW.

Common I –Joist Dimensions					
Height	**Flange thickness**	**Width**	**Height**	**Flange thickness**	**Width**
millimeter			**inches**		
241.30	33.34	44.45	9.50	1.31	1.75
301.63	79.38	38.10	11.88	3.13	1.50
Generic I-Joists Dimension					
298.45	33.34	47.75	11.75	1.31	1.88

3.1 Functional and declared Unit

The unit of output is 1.0 thousand linear meters (km) with no regard to flange thickness and width or I-joist height. Based on the data obtained from the surveys, the generic I-joist in the PNW has a height of 298.45 mm, a flange thickness of 33.34mm and a width of 47.75 mm (Table 1). As the analysis does not take the declared unit to the stage of being an installed building product no service life is assigned.

3.2 System Boundaries

The system boundary begins with forestry operations for the PNW and ends with an I-joist (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which included site preparation, thinning, and fertilization on a subset of hectares, and final harvest. The transportation of logs from the woods to the mill is accounted for with the LVL manufacturing as is transportation and resins (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. For SE OSB inputs all upstream processes including forest operations, transportation, and resins are included. Composite I-joist production process was modeled into a single unit process (Figure 2, dashed line). Outputs to the system boundary include 1 km of I-joists ready to be shipped, air and water emissions, solid waste and small volumes of co-products (chips and sawdust). The co-products are no longer tracked once they leave the system boundary.

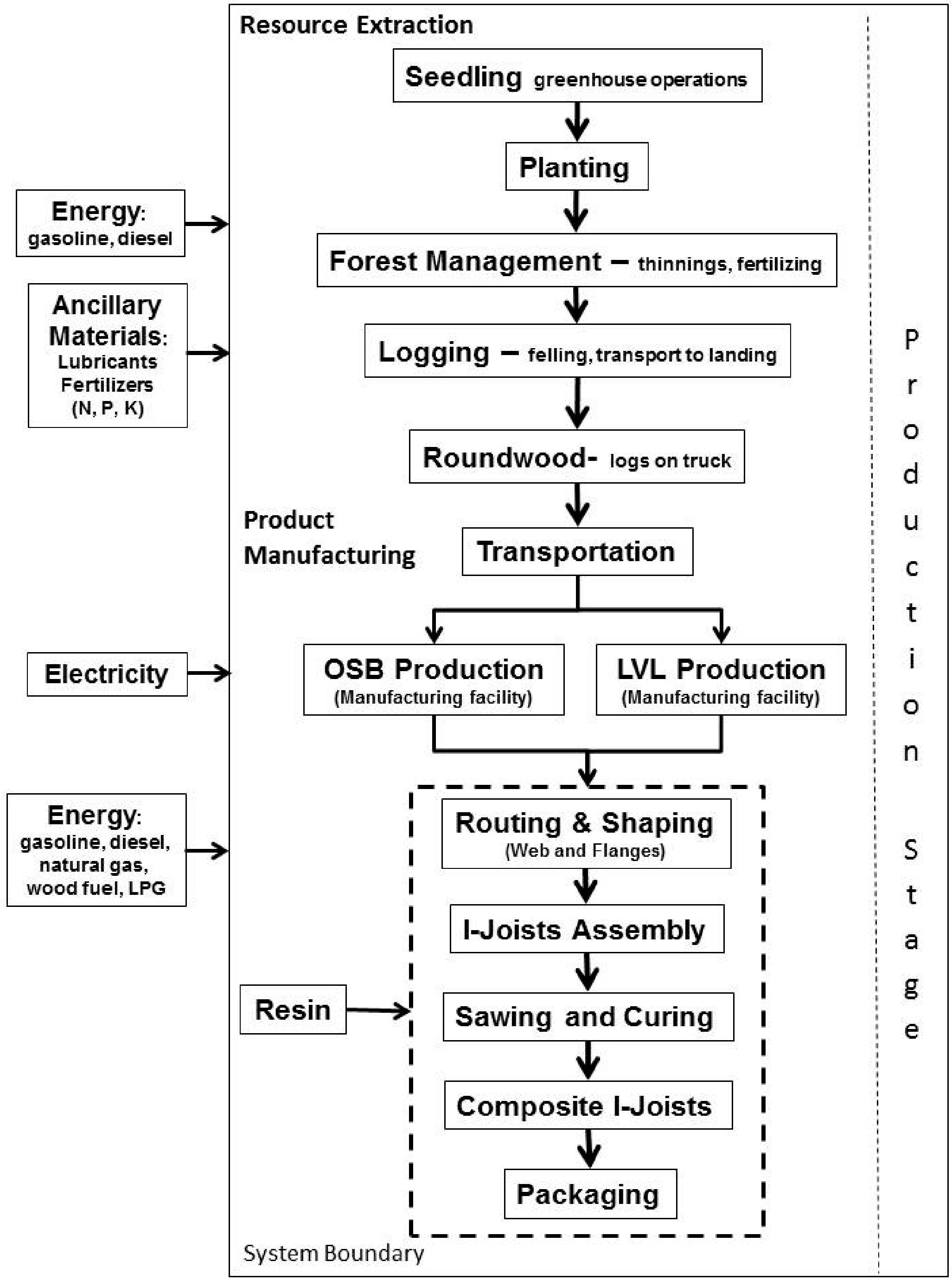

Figure 2 Cradle to gate life cycle stages for Composite I-Joists, PNW.

3.3 Description of data/Process Description

3.3.1 Forestry Operations

Forestry operations include growing seedlings, planting, thinning, fertilization (where applicable) and final harvest. The specific processes involved are reforestation: which includes seedling production, site preparation, planting, pre-commercial thinning, and fertilization, and harvesting: which includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. Weighted average allocation to different processes takes into account inherent differences in site productivity and energy usage by different kinds of logging equipment. Inputs to the forest resources management LCI include seed, electricity used during greenhouse operations, fertilizer used during seedling production and stand growth, and the fuel and lubricants needed to power and maintain equipment for thinning, and harvest operations. The primary output product for this analysis is a log destined for the plywood mill where the first step of LVL manufacturing occurs. The co-product, non-merchantable slash, is generally left at a landing. Slash disposal was not modeled as it was assumed to decay in-situ.

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

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

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

3.3.1.1 Regeneration (seedling production and planting process)

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

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

Table 2 Inputs to the regeneration phase and mid-rotation fertilization per hectare (ha) of forest.

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

1 p = individual seedling

3.3.1.2 Equipment

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

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

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

Table 3 Equipment allocation by treatment and management intensity.

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

3.3.1.3 Thinning and Final Harvest Process

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

Table 1 to the total yield of 501 m^3/ha is used to carry forward the environmental burdens of the reforestation effort on a per m^3 basis.

Table 4 Input assumptions for three levels of management intensity in the PNW.

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

Fuel consumption and energy use for forest resource management processes were averaged by the percent area in each class to develop weighted average values for the PNW region by major process (Table 5).

Table 5 Fuel consumption for PNW forest resource management processes (regeneration, thinning, and harvest).

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

3.3.2 Product Manufacturing

3.3.2.1 Transportation Process

Hauling is the first process of product manufacturing (Figure 2). Delivery of the input materials was by both truck and train. Large distances were involved with transportation of SE OSB to the PNW region since there are no OSB manufacturing plants in the PNW region. The values for LVL shipping distances are zero since the I-joist plants that were surveyed produce LVL onsite. The one-way delivery distances for the I-joist inputs are shown in Table 7. All upstream transportation of inputs to LVL and OSB production is included in the respective LCI input values.

Table 6 Delivery distance (one-way) of materials for 1,000 m (1 km) composite I-joist production, PNW.

Material delivered to mill	Delivery Distance (km)	
	km	miles
SE OSB to I-joist plant	3,026	1,880
LVL (produced on site)	0	0
MDI resin to I-joist plant	707	439

3.3.2.2 Laminated Veneer Lumber Process

Laminated veneer lumber is used as an input into composite I-joist manufacturing. For every kilometer (km) of I-joists produced, 1510 kg of LVL (2.85 m3) was incorporated into the final product. Dry veneers, parallel laminated lumber, and resins are the primary raw materials consumed for the production of PNW LVL. For detailed information on the production of LVL see Wilson and Dancer (2004b; 2005b).

3.3.2.3 Oriented Strandboard Process

OSB is used as an input into composite I-joist manufacturing. For every kilometer (km) of I-joists produced, 1,473 kg of OSB (2.27 m3) was incorporated into the final product. Chips and resins are the primary raw materials consumed for the production of SE OSB. See Kline et al. (2005) for detailed information about SE OSB manufacturing.

3.3.2.4 Energy generation

Energy for the production of I-joists in the PNW comes from electricity, natural gas, diesel, and liquid petroleum gas (LPG). None of the plants that were surveyed used hogged fuel (wood and bark waste fuel) as a source of energy in the manufacturing process. The electricity in the plant is used to run the various saws and assembly machinery in the I-joist plant. The natural gas is used to generate heat in order to cure the resin used in the I-joist assembly. The diesel fuel and LPG are used to operate the equipment that moves the input material and output product around the manufacturing facility.

3.3.2.5 Methylene diphenyl di-isocyanate (MDI) resin

Methylene diphenyl di-isocyanate (MDI) is the only resin reported in for PNW I-joist manufacturing surveys. The LCI for the production of MDI resin was based on a cradle-to-gate study on plastic resins and polyurethane precursors completed by Franklin Associates in 2010 (Franklin 2010). Franklin Associates collected primary data for MDI production including data on the following MDI precursors: olefins, benzene, chlorine/caustic soda, and nitric acid/nitrobenzene/aniline. For MDI production, data was gathered from four North American producers that represent roughly 95% of North American production capacity (Franklin 2010).

The LCI generated in this study was only published as system-level cradle-to-gate profiles, and have not yet been published in the SimaPro release of the USLCI database. This means that the underlying unit processes that are technosphere inputs to the MDI production process were not published. To address this data limitation, the terminal flows (inputs from nature and emissions to air, land, and water) were manually entered into a SimaPro profile for MDI as published in the online version of the USLCI database from the LCA Commons website (www.lcacommons.gov) under the process name "Methylene diphenyl diisocyanate, resin, at plant, CTR".

3.3.2.6 Phenol resorcinol formaldehyde resin

This resin was not used in the manufacturing of PNW I-joists

3.3.2.7 Composite I-Joist Production

The first step in producing composite I-joists is routing and shaping of web and flanges. This process requires machining of the OSB web pieces so they fit together at the ends as well as tapering them on the top and bottom edges so that they can be fitted into the LVL flanges. The LVL flanges are routed their entire length to accept the inserted tapered SE OSB web material. The co-product created during this process is sawdust. Next is the assembly of I-joist web and flanges after methylene diphenyl diisocyanate resin (MDI) resin is applied in web-to-web and web-to-flange joints. Assembly is done mechanically, pressing web sections end-to-end and into the top and bottom flange which are also pressed end-to-end; the result is a continuous ribbon of I-beam that can be of infinite length. No co-products are created during this process. The final step before packaging is sawing the I-joists to length and allowing the joints to cure. In some cases the I-joist may be heated in an oven to accelerate resin cure time. For more information about composite I-joist manufacturing and the data used in the cradle-to-gate report, see Wilson and Dancer (2004a, 2005a)

Laminated veneer lumber, SE OSB, and resins are the main materials consumed for the production of I-joists (Table 7). The final weight of PNW I-joist is 3010 kg/km (1,000 m). This required 1680 kg of LVL, 1640 kg SE OSB, and 18.20 kg of resin (MDI), of which 89.8% was allocated to the final product with the rest becoming sawdust (Table 7).

Table 7 Unit process inputs/outputs for 1,000 meters (1 km) of composite I-Joists, PNW.

Products	Value	Unit/km	Allocation (%)
Composite I-Joists (1 km)	1.00	km	89.8
Sawdust	342.00	kg	10.2
Resources			
Water, unspecified	211.00	L	
Materials/fuels			
Electricity, at Grid	276.00	kWh	
Diesel	0.99	L	
LPG	2.04	L	
Natural gas	0.46	m^3	
Laminated veneer lumber, at plant, US PNW	1680.00	kg	
Oriented strand board product, US SE	1640.00	kg	
Methylene diphenyl diisocyanate resin (MDI)	18.20	kg	
Transport, rail, diesel powered/US, SE OSB	4960.00	tkm	
Transport, combination truck, diesel powered/US, MDI	6.43	tkm	
Wrapping material - Packaging	47.45	kg	
Strap Protectors - Packaging	-		
Strapping - Packaging	-		
Spacers - Packaging	-		
Emissions to air			
Acetone	0.0002	kg	
Formaldehyde	0.0003	kg	
Methanol	0.0253	kg	
Particulates, unspecified	-	kg	

3.3.2.8 Packaging

Materials used for packaging composite I-joist for shipping are shown in Table 9. For this study it was assumed that only wrapping material was used for each I-joist. Packing materials for represent 1.58 percent of the cumulative mass of the model flow.

Table 8 Materials used in packaging and shipping per km, SE I-joist.

Material	Value	Unit
Wrapping Material – HDPE and LDPE laminated paper	47.45	kg
PET Strapping	-	kg
Cardboard strap protectors	-	kg
Wooden spacers	-	kg

4 Cut-off rules

According to the PCR, if the mass/energy of a flow is less 1% of the cumulative mass/energy of the model flow it may be excluded, provided its environmental relevance is minor. This analysis included all energy and mass flows for primary data and with the exception of packaging noted above, raw materials/energy from upstream processes that were used in small quantities that comprise less than 1% of the product mass/energy were not included in the LCA.

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

5 Data quality requirements

To conduct the survey, mills were identified in each region based on their production capabilities and their representativeness of the industry. Each mill provided data for I-joist and co-product outputs, raw material, electricity and fuel usage, and emissions. All of the inputs used to make I-joists are generated in the region where they are produced with the exception of SE OSB. There are no facilities in the PNW that produce SE OSB; therefore it is usually shipped from either the upper mid-western U.S. or northwestern Canada. We used the SE OSB production representative of the SE production region as our OSB input.

The industry measures their production of I-joist on a linear basis (meters or feet) since a volume measure is unrealistic because of their I-shape. In 2000, the total I-joist production in the PNW was 64,618 km or 212,000 thousand linear feet (MLF) (APA 2001). In the PNW the surveyed mills represented almost 33% of the total production of I-joists for the region.

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

6 Life cycle inventory analysis

6.1 Data collection

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

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

6.2 Calculation rules

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

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

The survey results were converted to a production basis and production-weighted averages were calculated for inputs into producing I-joists. This approach resulted in a mill complex that represents a composite of the mills surveyed, but may not represent any mill in particular. The USLCI database (NREL 2012) was used to assess off-site impacts associated with the materials and energy consumed. SimaPro, version 7.3.3 (Pré Consultants 2012) was used as the accounting program to track all of the materials.

Missing data are defined as data not reported in surveys by the I-joist facilities. Missing data were carefully noted so they were not averaged as zeros. Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros.

6.3 Allocation rules

Allocation was based on mass. PNW I-joist production generates low value co-products (10.2% by mass of input). Co-products are sold as dry wood residues with a price differential approximately 39 times[1] lower than I-joists based on equivalent mass. The differential on a mass versus economic allocation is 7.7 percent.

6.4 LCI results

Life cycle inventory results for I-joists include five life cycle stages: 1) forestry operations, 2) OSB production, 3) LVL Production, 4) resin production, and 5) I-joist production. The majority of the raw material energy consumption occurs during OSB and LVL production with only a small portion arising from forestry operations and resin production. Raw material energy requirements are presented in Table 9 for 1km of composite I-joist by each of the five life cycle stages. Air emissions are reported in Table 10, water emissions are reported in Table 11 and solid waste emissions are reported in Table 12 with separate columns for forestry operations and I-joist production (wrapped up). I-joist production (wrapped up) encompasses OSB, LVL, and resin production.

Table 9 Raw material energy consumption per 1000 m (1km) of Composite I-joists, PNW.

Fuel	Total	Forestry Operations	I-Joist Production	SE OSB Production	LVL Production	Resin Production
	kg/km					
Coal, in ground	291.628	1.343	45.559	139.564	100.926	4.236
Gas, natural, in ground	219.557	4.868	31.969	80.676	87.406	14.637
Oil, crude, in ground	167.391	20.248	34.071	61.198	45.028	6.846
Uranium oxide, in ore	0.007	0.000	0.001	0.004	0.002	0.000
Wood waste	901.518	0.000	9.045	428.669	463.803	0.000

Table 10 Air emissions released per 1,000 m (1 km) of Composite I-Joists, PNW.

Air Emission[1/]	Total	Forestry Operations	I-Joists Production
	kg/km		
Carbon dioxide, biogenic	1500.2337	0.0573	1500.1764
Carbon dioxide, fossil	1333.3503	66.7658	1266.5846
Carbon dioxide	43.9598	2.9629	40.9969
Nitrogen oxides	8.7625	1.1939	7.5686
Sulfur dioxide	8.6704	0.1530	8.5174
Carbon monoxide	4.8584	0.0002	4.8582
Particulates, > 2.5 um, and < 10um	4.3689	0.0366	4.3322
Methane	3.9404	0.1383	3.8021

[1] Based on http://www.expressheader.com/images/inventory.pdf for I-joist prices and Timber-Mart South Market News quarterly 2nd Q 2013 vol 18 no. 2 for wood residues.

Air Emission[1/]	Total	Forestry Operations	I-Joists Production
	kg/km		
VOC, volatile organic compounds	3.7969	0.0351	3.7618
Carbon monoxide, fossil	2.9468	0.5960	2.3508
Particulates, < 2.5 um	1.6196	0.0000	1.6196
Particulates, unspecified	1.0639	0.0082	1.0556
Acrolein	0.9438	0.0000	0.9438
Sulfur oxides	0.7357	0.0663	0.6694
Methanol	0.6930	0.0000	0.6930
Methane, fossil	0.6856	0.0141	0.6715
NMVOC, non-methane volatile organic compounds, unspecified origin	0.5041	0.0400	0.4641
Metals, unspecified	0.3249	0.0000	0.3249
Hydrogen chloride	0.2899	0.0007	0.2892
Hydrocarbons (other than methane)	0.2326	0.0000	0.2326
Formaldehyde	0.2012	0.0004	0.2008
Isoprene	0.1784	0.0014	0.1769
Acetaldehyde	0.1717	0.0003	0.1715
alpha-Pinene	0.1137	0.0000	0.1137
Benzene	0.0774	0.0003	0.0770
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0661	0.0017	0.0644
Cumene	0.0620	0.0000	0.0620
TOC, Total Organic Carbon	0.0498	0.0000	0.0498
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	0.0441	0.0000	0.0441
Dinitrogen monoxide	0.0329	0.0174	0.0155
Phenol	0.0324	0.0000	0.0324
Particulates, < 10 um	0.0315	0.0000	0.0315
Propene	0.0240	0.0009	0.0231
Acetone	0.0186	0.0000	0.0186
Hydrogen fluoride	0.0181	0.0001	0.0180
Ammonia	0.0130	0.0027	0.0103
D-limonene	0.0128	0.0000	0.0128
Manganese	0.0123	0.0000	0.0123
N-Nitrodimethylamine	0.0102	0.0000	0.0102
Radionuclides (Including Radon)	0.0096	0.0000	0.0096
Barium	0.0087	0.0000	0.0087
Chlorine	0.0080	0.0000	0.0080
Organic substances, unspecified	0.0071	0.0000	0.0071

Air Emission[1/]	Total	Forestry Operations	I-Joists Production
	kg/km		
Aldehydes, unspecified	0.0055	0.0008	0.0047
Potassium	0.0037	0.0000	0.0037
Toluene	0.0031	0.0001	0.0029
Methane, dichloro-, HCC-30	0.0023	0.0000	0.0023
Hydrocarbons, unspecified	0.0021	0.0000	0.0021
Methyl ethyl ketone	0.0018	0.0000	0.0018
Xylene	0.0017	0.0001	0.0016
Magnesium	0.0013	0.0000	0.0013
Particulates, > 10 um	0.0009	0.0000	0.0009
2-Butanone, 3,3-dimethyl-	0.0008	0.0000	0.0008
Naphthalene	0.0008	0.0000	0.0008
Nitrogen, total	0.0007	0.0007	0.0000
Sulfate	0.0007	0.0000	0.0007
Hydrogen	0.0005	0.0000	0.0005
Dimethyl ether	0.0005	0.0000	0.0005
Lead	0.0004	0.0000	0.0004
Phenols, unspecified	0.0004	0.0000	0.0004
Ammonium chloride	0.0004	0.0000	0.0004
Nickel	0.0004	0.0000	0.0004
Mercaptans, unspecified	0.0003	0.0000	0.0003
Hydrocarbons, aliphatic, alkanes, unspecified	0.0003	0.0000	0.0003
Sulfur, total reduced	0.0003	0.0000	0.0003
Sulfur trioxide	0.0003	0.0000	0.0003
Particulates, SPM	0.0002	0.0000	0.0002
Acetic acid	0.0002	0.0000	0.0002
Arsenic	0.0002	0.0000	0.0002
Particulates	0.0002	0.0000	0.0002
Chromium	0.0002	0.0000	0.0002
Ash	0.0002	0.0000	0.0002
Selenium	0.0002	0.0000	0.0002
Methylene diisocyanate	0.0002	0.0000	0.0002
Kerosene	0.0002	0.0000	0.0002
Monoethanolamine	0.0001	0.0000	0.0001
PFC (perfluorocarbons)	0.0001	0.0000	0.0001
Carbon dioxide, land transformation	0.0001	0.0000	0.0001
Chloroform	0.0001	0.0000	0.0001
Fluoride	0.0001	0.0000	0.0001

[1/]Due to large amount of air emissions, emissions less than 10^{-4} are not shown. A complete list of all air emissions can be found in Section 13.

Waterborne emissions are all off-site. No mill in the survey discharged any process water. Most wood production facilities operate with this restriction. Water emissions reported in Table11 are result of upstream process (eg. OSB, LVL, fuels, electricity, and resin production). A complete list of all emissions to water is located in the Appendix (Section 13) of this report.

Table 11 Emissions to water released per 1,000 m (1 km) of Composite I-Joists, PNW.

Water Emission[1/]	Total	Forestry Operations	I-Joists Production
	kg/km		
Solved solids	58.7141	4.1879	54.5261
Chloride	47.9044	3.3953	44.5091
Sodium, ion	13.6003	0.9574	12.6428
Calcium, ion	4.2590	0.3020	3.9569
Suspended solids, unspecified	1.9531	0.2124	1.7407
COD, Chemical Oxygen Demand	1.4888	0.0315	1.4573
BOD5, Biological Oxygen Demand	1.2366	0.0170	1.2196
Lithium, ion	0.9154	0.0237	0.8916
Dissolved solids	0.8903	0.0000	0.8903
Magnesium	0.8376	0.0590	0.7785
Barium	0.8191	0.0946	0.7245
Sulfate	0.3575	0.0076	0.3499
Bromide	0.2979	0.0201	0.2778
TOC, Total Organic Carbon	0.2799	0.0000	0.2799
DOC, Dissolved Organic Carbon	0.2792	0.0000	0.2792
Cumene	0.1491	0.0000	0.1491
Iron	0.1403	0.0141	0.1263
Benzene	0.1056	0.0002	0.1055
Fluoride	0.0873	0.0850	0.0023
Strontium	0.0723	0.0051	0.0671
Phosphate	0.0681	0.0640	0.0041
Propene	0.0551	0.0000	0.0551
Aluminium	0.0343	0.0000	0.0343
Oils, unspecified	0.0303	0.0021	0.0282
Aluminum	0.0293	0.0069	0.0224
Ammonia	0.0204	0.0016	0.0188
Silicon	0.0185	0.0000	0.0185
Potassium, ion	0.0081	0.0000	0.0081

Water Emission[1/]	Total	Forestry Operations	I-Joists Production
	kg/km		
Carbonate	0.0075	0.0000	0.0075
Iodide	0.0062	0.0000	0.0062
Ammonium, ion	0.0046	0.0000	0.0046
Manganese	0.0044	0.0001	0.0043
Boron	0.0042	0.0003	0.0039
Nitrate	0.0042	0.0000	0.0042
Sulfur	0.0038	0.0002	0.0036
Iron, ion	0.0029	0.0000	0.0029
Chloroacetic acid	0.0028	0.0000	0.0028
Silver	0.0028	0.0002	0.0026
Formate	0.0023	0.0000	0.0023
Toluene	0.0022	0.0001	0.0020
Solids, inorganic	0.0018	0.0000	0.0018
Benzene, chloro-	0.0015	0.0000	0.0015
Zinc	0.0015	0.0002	0.0014
Benzoic acid	0.0013	0.0001	0.0012
Detergent, oil	0.0012	0.0001	0.0012
Sulfide	0.0012	0.0000	0.0012
Acetic acid	0.0012	0.0000	0.0012
Chromium	0.0012	0.0002	0.0010
Xylene	0.0011	0.0001	0.0010
Ethanol	0.0010	0.0000	0.0010
Propanal	0.0007	0.0000	0.0007
Chlorate	0.0006	0.0000	0.0006
Borate	0.0006	0.0000	0.0006
Titanium, ion	0.0006	0.0001	0.0005
Formaldehyde	0.0006	0.0000	0.0006
Lead	0.0006	0.0001	0.0005
Acid as H+	0.0005	0.0000	0.0005
Phenol	0.0005	0.0000	0.0005
Chromium, ion	0.0005	0.0000	0.0005
Nitrogen, total	0.0004	0.0000	0.0004
Phenols, unspecified	0.0004	0.0000	0.0004
Copper, ion	0.0004	0.0000	0.0003
Arsenic, ion	0.0004	0.0001	0.0003
Dissolved organics	0.0003	0.0000	0.0003
Acetaldehyde	0.0003	0.0000	0.0003

Water Emission[1/]	Total	Forestry Operations	I-Joists Production
	kg/km		
Phosphorus, total	0.0003	0.0000	0.0003
Nickel	0.0003	0.0000	0.0003
Hexanoic acid	0.0003	0.0000	0.0003
Suspended solids, inorganic	0.0003	0.0000	0.0003
Tin	0.0002	0.0000	0.0002
Nitrobenzene	0.0002	0.0000	0.0002
Zinc, ion	0.0002	0.0000	0.0002
Methanol	0.0001	0.0000	0.0001
Dimethylamine	0.0001	0.0000	0.0001
Acids, unspecified	0.0001	0.0000	0.0001
Benzene, ethyl-	0.0001	0.0000	0.0001
Phosphorus	0.0001	0.0000	0.0001
Chloramine	0.0001	0.0000	0.0001
Benzene, 1,2-dichloro-	0.0001	0.0000	0.0001

[1/]Due to large amount of air emissions, emissions less than 10^{-4} are not shown.

Solid emissions are a result of primary log breakdown (LVL) and processes other than the wood production processes (Table 12). Most (85%) were a result from veneer production during log storage a veneer plants. Bark unusable for energy generation was sent to the landfill. Waste generated by the production of LVL represented 21% of the total waste generated from cradle to grave.

Table 12 Waste to treatment per 1,000 m (1 km) of composite I-joists, PNW.

Waste to treatment	Total	Forestry Operations	I-joist Production	OSB Production	LVL Production	Resin Production
	kg/km					
Solid Waste	234.12	1.21	16.44	84.75	131.71	0.00

7 Life cycle impact assessment

The life cycle impact assessment (LCIA) phase establishes links between the life cycle inventory results and potential environmental impacts. The LCIA calculates impact indicators, such as global warming potential and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 13. Environmental impacts are determined using the TRACI method (Bare et. al 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (PCR 2011).

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

Impact Indicator	Characterization Model	Impact Category
Greenhouse gas (GHG) emissions	Calculate total equivalent CO_2 emissions for CO_2, methane, and nitrous oxide per functional unit.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the stratosphere. CFC's HCFC's, chlorine, bromine. Ozone depletion value is in units of CFC's eq. is used as a reference unit.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total hydrogen ion (H+) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of H^+ mole-eq. is used as a reference unit	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photo-chemically oxidized. Smog forming potential of O_3 is used as a reference unit.	Photochemical smog
Releases to air potentially resulting in eutrophication of water bodies	Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit.	Eutrophication

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

Table 14 provides the environmental impact by category for 1 kilometer of composite I-joist produced in the PNW region. In addition, energy and material resource consumption values and the waste generated are also provided. Environmental performance results for global warming potential (GWP), acidification, eutrophication, ozone depletion and smog, energy consumption from non-renewables, renewables, wind, hydro, solar, and nuclear fuels, renewable and nonrenewable resources, and solid waste are shown in Table 14. For GWP, 35 and 40 percent of the CO_2 equivalent emissions come from producing LVL and OSB, respectively. I-joist production generated 17 percent of the emissions with the remainder coming from to forestry operations (5%) and resin production (2%).Values in Table 14 are the cumulative impact of all upstream processes required for I-joist production including those from forestry, LVL, OSB, resin, and packaging production and transportation energy required to move these materials to the I-joists facility. For example, differences between I-joist Production data in table 7 with results in table 14 are a result of the resources and fuels used in the upstream processes, i.e. fresh water use.

Table 14 Environmental performance per 1,000 m (1 km) composite I-joists, PNW.

Impact category	Unit	Total	Forestry Operations	I-Joist Production	SE OSB Production	LVL Production	Resin Production
Global warming potential (GWP)	kg CO_2 equiv	1,557.78	78.72	270.55	619.71	550.85	37.95
Acidification Potential	H+ moles equiv	874.54	59.24	188.85	315.43	302.73	8.28
Eutrophication Potential	kg N equiv	0.73	0.21	0.14	0.17	0.21	0.00
Ozone depletion Potential	kg CFC-11 equiv	0.00	0.00	0.00	0.00	0.00	0.00
Smog Potential	kg O_3 equiv	253.15	29.76	67.36	74.56	79.86	1.61
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**I-Joist Production**	**SE OSB Production**	**LVL Production**	**Resin Production**
Non-renewable fossil	MJ	27,308	1,221	4,484	10,932	9,451	1,219
Non-renewable nuclear	MJ	2,664	12	337	1,498	786	31
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	861	1	243	42	569	3
Renewable, biomass	MJ	18,894	0	194	8,986	9,714	1
Material resources consumption (non fuel resources)	**Unit**	**Total**	**Forestry Operations**	**I-joist Production**	**SE OSB Production**	**LVL Production**	**Resin Production**
Non-renewable materials	kg	21.49	0.00	4.79	6.21	4.19	6.31
Renewable materials	kg	4,233.79	0.00	0.00	2,142.40	2,091.39	0.00
Fresh water	L	1,783.04	0.00	189.48	656.02	937.40	0.15
Waste generated	**Unit**	**Total**	**Forestry Operations**	**I-joist Production**	**SE OSB Production**	**LVL Production**	**Resin Production**
Solid waste	kg	234.12	1.21	16.44	84.75	131.71	0.00

8 Treatment of biogenic carbon

Treatment of biogenic carbon is consistent with the Intergovernmental Panel for Climate Change (IPCC 2006) inventory reporting framework in that there is no assumption that biomass combustion is carbon neutral, but that net carbon emissions from biomass combustion are accounted for under the Land-Use Change and Forestry (LUCF) Sector and are therefore ignored in energy emissions reporting for the product LCA to prevent double counting. Standards such as ASTM D7612, which are used in North America to define legal, responsible and/or certified sources of wood materials, are in place to provide assurances regarding forest regeneration and sustainable harvest rates that serve as proxies to ensure stable carbon balances in the forest sector. They are outside the accounting framework for this LCA.

This approach to the treatment of biogenic carbon was taken for the Norwegian Solid Wood Product PCR (Aasestad 2008), and the North American PCR has adopted an identical approach to ensure comparability and consistency. The North American PCR approach is followed here for GWP reporting therefore the default TRACI impact assessment method was used. This default method does not count the CO_2 emissions released during the combustion of woody biomass during production. Other emissions associated from wood combustion, e.g., methane or nitrogen oxides, do contribute to and are included in the GWP impact category. For a complete list of emissions factors for the GWP method used, see Bare et al. (2011). Using this method, 1,558 kg CO_2e were released in the production of 1 km of I-joist. That same 1 km stores 5,485 kg CO_2e (Table 15).

Table 15 Carbon per 1,000 m (1 km) composite I-Joists, SE.

	kg CO_2 equivalent
released forestry operations	78.72
released manufacturing	1,479.06
CO_2 eq. stored in product	5,484.87

9 Conclusions

The cradle to gate LCA for softwood lumber includes the LCI of forest resources that relies on secondary and tertiary data and the LCI of manufacturing that relies on primary survey data and secondary data on process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest operations in the region that produce Douglas –fir and Hemlock. The survey data are representative of the I-joists sizes and production volumes consistent with trade association production data.

There was a total 8.37 cubic meters of roundwood used to produce both the OSB and LVL for PNW I-joist production. Oriented strandboard required 3.68 m^3 or 44% while LVL used in I-joists consumed 4.69 m^3 or 56% or of the wood resource. To produce one kilometer of PNW I-joists required 1,473 kg of OSB and 1,509 kg of LVL. The I-joists production process produced very little co-product (sawdust) representing only 10.2% by mass or 342 kg/ km. One kilometer of I-joists weighed 3,010 kg. The use of wood fuel was consumed during OSB or LVL production or upstream processes used in OSB or LVL production.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The LVL, SE OSB, and resin manufacturing processes are contained in the composite I-joists results. The scope of this study encompassed the environmental impacts of forestry operations, LVL and SE OSB production, and transportation of all materials including the logs from the forest to primary manufacturing facilities. The LCI data for I-joists are presented on a production unit of 1,000 meters (1 kilometer). The LCA considered those impacts including the production and delivery of electricity and fuel, and the production of resin. Transportation distances of materials to the plants are given.

Energy use for manufacturing I-joists is dominated by electricity use for the manufacture of its component parts: LVL, OSB, and resins. The energy allocated to the I-joist production facility is approximately 8 percent of the cradle to gate energy consumed. Consistent with where the highest energy use occurs, the environmental impact is also distributed to the production of component parts. Energy generated by renewable fuels, such as woody biomass, represents about 40 percent of the total energy from cradle to gate. Of the renewable biomass fuels, 99 percent were used for the production of OSB and LVL. Total non-renewable fossil fuel use was 55 percent of the total energy from cradle to gate. Resins used to bond the LVL, SE OSB, and I-joists were also almost exclusively dependent upon fossil fuels for both energy and feedstock, but there contribution to the total non-renewable fossil fuel use was 4.5 percent.

The TRACI impact method does not count the contribution of wood-derived CO_2 emissions from burning wood fuel in the boiler towards the global warming impact estimate. This is consistent with the current US EPA ruling on wood emissions from stationary sources which considers the CO_2 taken up by the forest ecosystem when the tree grew as balancing any CO_2 emissions when it is burned. Under the TRACI method, combustion of fossil fuels generates CO_2 and other air emissions that contribute to the global warming impact. Using this method, 1,558 kg CO_2e were released in the production of 1 km of I-joist. That same 1 km stores 5485 kg CO_2e.

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11 Critical Review

11.1 Internal Review

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

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

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

11.2 External Review

The external review process is intended to ensure consistency between the completed LCA and the principals and requirements of the International Standards on LCA (ISO 2006) and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011). Following CORRIM's internal review evaluation, documents were submitted to UL Environment (ULE) for independent external review. The independent external review performed by ULE was conducted by:

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

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13 Appendix

13.1 Air Emissions

Table A.1 Air emissions released per 1,000 m (1 km) composite I-joists, PNW.

Substance	Unit	Total	Forestry Operations	I-Joists Production
1,4-Butanediol	kg	2.12E-05		2.12E-05
1-Butanol	kg	4.61E-06		4.61E-06
1-Pentanol	kg	5.25E-14		5.25E-14
1-Pentene	kg	3.96E-14		3.96E-14
1-Propanol	kg	2.54E-11		2.54E-11
2,4-D	kg	6.83E-09		6.83E-09
2-Aminopropanol	kg	2.69E-06		2.69E-06
2-Butanone, 3,3-dimethyl-	kg	7.87E-04		7.87E-04
2-Butene, 2-methyl-	kg	8.79E-18		8.79E-18
2-Chloroacetophenone	kg	1.13E-08	1.60E-10	1.11E-08
2-Methyl-1-propanol	kg	4.11E-06		4.11E-06
2-Nitrobenzoic acid	kg	1.10E-05		1.10E-05
2-Propanol	kg	9.22E-06		9.22E-06
5-methyl Chrysene	kg	2.67E-09	1.29E-11	2.65E-09
Acenaphthene	kg	6.18E-08	3.00E-10	6.15E-08
Acenaphthylene	kg	3.03E-08	1.47E-10	3.01E-08
Acetaldehyde	kg	1.72E-01	2.73E-04	1.71E-01
Acetic acid	kg	2.25E-04		2.25E-04
Acetochlor	kg	9.47E-08		9.47E-08
Acetone	kg	1.86E-02		1.86E-02
Acetonitrile	kg	3.81E-09		3.81E-09
Acetophenone	kg	2.42E-08	3.43E-10	2.38E-08
Acrolein	kg	9.44E-01	3.31E-05	9.44E-01
Acrylic acid	kg	1.00E-09		1.00E-09
Actinides, radioactive, unspecified	Bq	2.52E-04		2.52E-04
Aerosols, radioactive, unspecified	Bq	5.60E-03		5.60E-03
Alachlor	kg	9.32E-09		9.32E-09
Aldehydes, unspecified	kg	5.47E-03	8.23E-04	4.65E-03
alpha-Pinene	kg	1.14E-01		1.14E-01
Aluminium	kg	6.72E-05		6.72E-05
Ammonia	kg	1.30E-02	2.67E-03	1.03E-02

Substance	Unit	Total	Forestry Operations	I-Joists Production
Ammonium carbonate	kg	6.54E-09		6.54E-09
Ammonium chloride	kg	3.60E-04	1.63E-06	3.58E-04
Aniline	kg	1.68E-05		1.68E-05
Anthracene	kg	2.54E-08	1.24E-10	2.53E-08
Anthranilic acid	kg	5.08E-06		5.08E-06
Antimony	kg	6.22E-05	1.06E-08	6.22E-05
Antimony-124	Bq	4.92E-08		4.92E-08
Antimony-125	Bq	5.13E-07		5.13E-07
Argon-41	Bq	2.95E+00		2.95E+00
Arsenic	kg	2.20E-04	3.25E-07	2.20E-04
Arsine	kg	1.17E-14		1.17E-14
Ash	kg	1.96E-04		1.96E-04
Atrazine	kg	1.85E-07		1.85E-07
Barium	kg	8.70E-03		8.70E-03
Barium-140	Bq	3.34E-05		3.34E-05
Bentazone	kg	7.53E-10		7.53E-10
Benzal chloride	kg	5.64E-17		5.64E-17
Benzaldehyde	kg	4.53E-11		4.53E-11
Benzene	kg	7.74E-02	3.35E-04	7.70E-02
Benzene, 1,2-dichloro-	kg	1.24E-05		1.24E-05
Benzene, 1-methyl-2-nitro-	kg	9.51E-06		9.51E-06
Benzene, chloro-	kg	3.54E-08	5.03E-10	3.49E-08
Benzene, ethyl-	kg	1.79E-06	2.15E-09	1.78E-06
Benzene, hexachloro-	kg	1.12E-10		1.12E-10
Benzene, pentachloro-	kg	1.32E-11		1.32E-11
Benzo(a)anthracene	kg	9.69E-09	4.71E-11	9.65E-09
Benzo(a)pyrene	kg	2.31E-08	2.24E-11	2.31E-08
Benzo(b,j,k)fluoranthene	kg	1.33E-08	6.47E-11	1.33E-08
Benzo(ghi)perylene	kg	3.27E-09	1.59E-11	3.26E-09
Benzyl chloride	kg	1.13E-06	1.60E-08	1.11E-06
Beryllium	kg	1.13E-05	1.63E-08	1.12E-05
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	kg	4.41E-02		4.41E-02
Biphenyl	kg	2.06E-07	1.00E-09	2.05E-07
Boron	kg	8.83E-06		8.83E-06
Boron trifluoride	kg	1.60E-16		1.60E-16
Bromine	kg	9.20E-07		9.20E-07
Bromoform	kg	6.28E-08	8.92E-10	6.19E-08
Bromoxynil	kg	1.65E-09		1.65E-09

Substance	Unit	Total	Forestry Operations	I-Joists Production
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	6.61E-02	1.71E-03	6.44E-02
Butadiene	kg	1.72E-05	1.39E-05	3.26E-06
Butane	kg	2.06E-05		2.06E-05
Butene	kg	6.30E-05		6.30E-05
Butyrolactone	kg	5.99E-12		5.99E-12
Cadmium	kg	4.21E-05	8.29E-08	4.20E-05
Calcium	kg	6.53E-06		6.53E-06
Carbofuran	kg	1.41E-09		1.41E-09
Carbon dioxide	kg	4.40E+01	2.96E+00	4.10E+01
Carbon dioxide, biogenic	kg	1.50E+03	5.73E-02	1.50E+03
Carbon dioxide, fossil	kg	1.33E+03	6.68E+01	1.27E+03
Carbon dioxide, land transformation	kg	1.19E-04		1.19E-04
Carbon disulfide	kg	6.30E-06	2.97E-09	6.29E-06
Carbon monoxide	kg	4.86E+00	2.08E-04	4.86E+00
Carbon monoxide, biogenic	kg	7.66E-06		7.66E-06
Carbon monoxide, fossil	kg	2.95E+00	5.96E-01	2.35E+00
Carbon-14	Bq	2.36E+01		2.36E+01
Cerium-141	Bq	8.09E-06		8.09E-06
Cesium-134	Bq	3.88E-07		3.88E-07
Cesium-137	Bq	6.87E-06		6.87E-06
Chloramine	kg	6.88E-06		6.88E-06
Chloride	kg	5.44E-09	4.39E-11	5.40E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	3.36E-06		3.36E-06
Chlorine	kg	8.04E-03		8.04E-03
Chloroacetic acid	kg	3.47E-05		3.47E-05
Chloroform	kg	1.18E-04	1.35E-09	1.18E-04
Chlorosilane, trimethyl-	kg	1.35E-10		1.35E-10
Chlorosulfonic acid	kg	5.24E-06		5.24E-06
Chlorpyrifos	kg	1.09E-08		1.09E-08
Chromium	kg	2.00E-04	2.37E-07	1.99E-04
Chromium VI	kg	9.64E-06	4.65E-08	9.59E-06
Chromium-51	Bq	5.18E-07		5.18E-07
Chrysene	kg	1.21E-08	5.88E-11	1.21E-08
Cobalt	kg	6.62E-05	4.19E-07	6.57E-05
Cobalt-58	Bq	7.22E-07		7.22E-07
Cobalt-60	Bq	6.38E-06		6.38E-06

Substance	Unit	Total	Forestry Operations	I-Joists Production
Copper	kg	4.33E-06	4.31E-09	4.33E-06
Cumene	kg	6.20E-02	1.21E-10	6.20E-02
Cyanazine	kg	1.63E-09		1.63E-09
Cyanide	kg	1.07E-05	5.72E-08	1.07E-05
Cyanoacetic acid	kg	4.29E-06		4.29E-06
Dicamba	kg	9.59E-09		9.59E-09
Diethylamine	kg	1.35E-05		1.35E-05
Dimethenamid	kg	2.26E-08		2.26E-08
Dimethyl ether	kg	4.65E-04		4.65E-04
Dimethyl malonate	kg	5.38E-06		5.38E-06
Dinitrogen monoxide	kg	3.29E-02	1.74E-02	1.55E-02
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.26E-05		1.26E-05
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	8.37E-11	1.37E-12	8.23E-11
Dipropylamine	kg	6.05E-06		6.05E-06
Dipropylthiocarbamic acid S-ethyl ester	kg	1.55E-08		1.55E-08
D-limonene	kg	1.28E-02		1.28E-02
Ethane	kg	6.47E-05		6.47E-05
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	9.86E-07		9.86E-07
Ethane, 1,1,1-trichloro-, HCFC-140	kg	4.44E-08	2.36E-09	4.21E-08
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	4.75E-11		4.75E-11
Ethane, 1,1-difluoro-, HFC-152a	kg	7.05E-10		7.05E-10
Ethane, 1,2-dibromo-	kg	1.93E-09	2.75E-11	1.90E-09
Ethane, 1,2-dichloro-	kg	2.36E-05	9.15E-10	2.36E-05
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	9.83E-09		9.83E-09
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	kg	9.41E-07		9.41E-07
Ethane, chloro-	kg	6.76E-08	9.61E-10	6.67E-08
Ethane, hexafluoro-, HFC-116	kg	3.64E-08		3.64E-08
Ethanol	kg	2.74E-05		2.74E-05
Ethene	kg	5.00E-05		5.00E-05
Ethene, chloro-	kg	3.02E-08		3.02E-08
Ethene, tetrachloro-	kg	5.32E-06	2.99E-08	5.29E-06
Ethene, trichloro-	kg	6.00E-12		6.00E-12
Ethyl acetate	kg	1.91E-06		1.91E-06
Ethyl cellulose	kg	3.63E-09		3.63E-09
Ethylamine	kg	1.25E-05		1.25E-05
Ethylene diamine	kg	1.31E-12		1.31E-12

Substance	Unit	Total	Forestry Operations	I-Joists Production
Ethylene dibromide	kg	4.33E-08		4.33E-08
Ethylene oxide	kg	2.44E-07		2.44E-07
Ethyne	kg	2.32E-05		2.32E-05
Fluoranthene	kg	8.60E-08	4.18E-10	8.56E-08
Fluorene	kg	1.10E-07	5.35E-10	1.10E-07
Fluoride	kg	1.13E-04	3.45E-05	7.89E-05
Fluorine	kg	7.12E-07		7.12E-07
Fluosilicic acid	kg	3.87E-08		3.87E-08
Formaldehyde	kg	2.01E-01	4.24E-04	2.01E-01
Formamide	kg	9.59E-14		9.59E-14
Formic acid	kg	2.78E-08		2.78E-08
Furan	kg	7.83E-09	2.57E-12	7.83E-09
Glyphosate	kg	2.04E-08		2.04E-08
Heat, waste	MJ	1.04E+02		1.04E+02
Helium	kg	3.96E-07		3.96E-07
Heptane	kg	1.90E-06		1.90E-06
Hexane	kg	6.71E-06	1.53E-09	6.70E-06
Hydrazine, methyl-	kg	2.74E-07	3.89E-09	2.70E-07
Hydrocarbons (other than methane)	kg	2.33E-01		2.33E-01
Hydrocarbons, aliphatic, alkanes, cyclic	kg	6.89E-07		6.89E-07
Hydrocarbons, aliphatic, alkanes, unspecified	kg	2.86E-04		2.86E-04
Hydrocarbons, aliphatic, unsaturated	kg	7.60E-06		7.60E-06
Hydrocarbons, aromatic	kg	7.80E-06		7.80E-06
Hydrocarbons, chlorinated	kg	1.12E-05		1.12E-05
Hydrocarbons, unspecified	kg	2.08E-03	9.41E-06	2.07E-03
Hydrogen	kg	5.29E-04		5.29E-04
Hydrogen chloride	kg	2.90E-01	7.38E-04	2.89E-01
Hydrogen fluoride	kg	1.81E-02	8.72E-05	1.80E-02
Hydrogen peroxide	kg	2.69E-09		2.69E-09
Hydrogen sulfide	kg	1.27E-05	1.42E-12	1.27E-05
Hydrogen-3, Tritium	Bq	1.33E+02		1.33E+02
Indeno(1,2,3-cd)pyrene	kg	7.39E-09	3.59E-11	7.35E-09
Iodine	kg	4.95E-07		4.95E-07
Iodine-129	Bq	2.34E-02		2.34E-02
Iodine-131	Bq	1.16E+00		1.16E+00
Iodine-133	Bq	7.00E-05		7.00E-05
Iodine-135	Bq	6.53E-05		6.53E-05
Iron	kg	3.87E-05		3.87E-05

Substance	Unit	Total	Forestry Operations	I-Joists Production
Isocyanic acid	kg	1.13E-08		1.13E-08
Isophorone	kg	9.34E-07	1.33E-08	9.21E-07
Isoprene	kg	1.78E-01	1.44E-03	1.77E-01
Isopropylamine	kg	7.81E-06		7.81E-06
Kerosene	kg	1.72E-04	7.81E-07	1.71E-04
Krypton-85	Bq	9.24E+00		9.24E+00
Krypton-85m	Bq	6.28E-01		6.28E-01
Krypton-87	Bq	2.19E-01		2.19E-01
Krypton-88	Bq	2.29E-01		2.29E-01
Krypton-89	Bq	6.74E-02		6.74E-02
Lactic acid	kg	4.74E-06		4.74E-06
Lanthanum-140	Bq	2.85E-06		2.85E-06
Lead	kg	4.34E-04	4.30E-07	4.33E-04
Lead-210	Bq	2.12E-01		2.12E-01
Magnesium	kg	1.34E-03	6.47E-06	1.33E-03
Manganese	kg	1.23E-02	4.77E-07	1.23E-02
Manganese-54	Bq	2.66E-07		2.66E-07
MCPA	kg	1.27E-10		1.27E-10
Mercaptans, unspecified	kg	3.49E-04	4.96E-06	3.44E-04
Mercury	kg	4.42E-05	9.19E-08	4.41E-05
Metals, unspecified	kg	3.25E-01	1.63E-13	3.25E-01
Methacrylic acid	kg	3.95E-09		3.95E-09
Methacrylic acid, methyl ester	kg	2.81E-08	4.58E-10	2.76E-08
Methane	kg	3.94E+00	1.38E-01	3.80E+00
Methane, biogenic	kg	6.16E-05		6.16E-05
Methane, bromo-, Halon 1001	kg	2.58E-07	3.66E-09	2.54E-07
Methane, bromochlorodifluoro-, Halon 1211	kg	1.58E-08		1.58E-08
Methane, bromotrifluoro-, Halon 1301	kg	5.05E-09		5.05E-09
Methane, chlorodifluoro-, HCFC-22	kg	1.22E-05		1.22E-05
Methane, chlorotrifluoro-, CFC-13	kg	2.22E-07		2.22E-07
Methane, dichloro-, HCC-30	kg	2.25E-03	4.81E-07	2.25E-03
Methane, dichlorodifluoro-, CFC-12	kg	2.36E-07	2.35E-09	2.34E-07
Methane, dichlorofluoro-, HCFC-21	kg	3.19E-13		3.19E-13
Methane, fossil	kg	6.86E-01	1.41E-02	6.71E-01
Methane, monochloro-, R-40	kg	8.53E-07	1.21E-08	8.41E-07
Methane, tetrachloro-, CFC-10	kg	1.52E-05	2.35E-10	1.52E-05
Methane, tetrafluoro-, CFC-14	kg	2.98E-07		2.98E-07
Methane, trichlorofluoro-, CFC-11	kg	5.18E-13		5.18E-13

Substance	Unit	Total	Forestry Operations	I-Joists Production
Methane, trifluoro-, HFC-23	kg	1.02E-10		1.02E-10
Methanesulfonic acid	kg	4.34E-06		4.34E-06
Methanol	kg	6.93E-01		6.93E-01
Methyl acetate	kg	2.55E-06		2.55E-06
Methyl acrylate	kg	1.13E-09		1.13E-09
Methyl amine	kg	1.33E-06		1.33E-06
Methyl borate	kg	4.41E-07		4.41E-07
Methyl ethyl ketone	kg	1.84E-03	8.92E-09	1.84E-03
Methyl formate	kg	4.43E-12		4.43E-12
Methyl lactate	kg	5.21E-06		5.21E-06
Methyl methacrylate	kg	1.89E-10		1.89E-10
Methylene diisocyanate	kg	1.75E-04		1.75E-04
Metolachlor	kg	7.48E-08		7.48E-08
Metribuzin	kg	3.47E-10		3.47E-10
Molybdenum	kg	5.60E-08		5.60E-08
Monoethanolamine	kg	1.48E-04		1.48E-04
m-Xylene	kg	2.51E-08		2.51E-08
Naphthalene	kg	7.53E-04	8.95E-08	7.53E-04
Nickel	kg	3.57E-04	5.25E-06	3.52E-04
Nickel compounds	kg	1.21E-05		1.21E-05
Niobium-95	Bq	3.15E-08		3.15E-08
Nitrate	kg	1.28E-07		1.28E-07
Nitrobenzene	kg	4.51E-05		4.51E-05
Nitrogen oxides	kg	8.76E+00	1.19E+00	7.57E+00
Nitrogen, total	kg	6.70E-04	6.70E-04	9.15E-09
Nitrous oxide	kg	1.20E-05		1.20E-05
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	5.04E-01	4.00E-02	4.64E-01
N-Nitrodimethylamine	kg	1.02E-02		1.02E-02
Noble gases, radioactive, unspecified	Bq	2.25E+05		2.25E+05
Organic acids	kg	1.32E-06	5.99E-09	1.32E-06
Organic substances, unspecified	kg	7.12E-03	3.65E-06	7.12E-03
Ozone	kg	8.15E-06		8.15E-06
PAH, polycyclic aromatic hydrocarbons	kg	7.35E-05	5.98E-05	1.37E-05
Paraquat	kg	1.51E-09		1.51E-09
Parathion, methyl	kg	1.14E-09		1.14E-09
Particulates	kg	2.19E-04		2.19E-04
Particulates, < 10 um	kg	3.15E-02		3.15E-02
Particulates, < 2.5 um	kg	1.62E+00		1.62E+00

Substance	Unit	Total	Forestry Operations	I-Joists Production
Particulates, > 10 um	kg	8.69E-04		8.69E-04
Particulates, > 2.5 um, and < 10um	kg	4.37E+00	3.66E-02	4.33E+00
Particulates, SPM	kg	2.30E-04		2.30E-04
Particulates, unspecified	kg	1.06E+00	8.23E-03	1.06E+00
Pendimethalin	kg	7.78E-09		7.78E-09
Pentane	kg	2.36E-05		2.36E-05
Permethrin	kg	6.99E-10		6.99E-10
PFC (perfluorocarbons)	kg	1.21E-04		1.21E-04
Phenanthrene	kg	3.27E-07	1.59E-09	3.26E-07
Phenol	kg	3.24E-02	3.66E-10	3.24E-02
Phenol, 2,4-dichloro-	kg	6.90E-06		6.90E-06
Phenol, pentachloro-	kg	6.30E-09		6.30E-09
Phenols, unspecified	kg	3.94E-04	2.43E-07	3.94E-04
Phorate	kg	3.58E-10		3.58E-10
Phosphate	kg	1.53E-05	1.53E-05	x
Phosphine	kg	8.65E-13		8.65E-13
Phosphorus	kg	3.04E-06		3.04E-06
Phthalate, diisooctyl-	kg	1.44E-08		1.44E-08
Phthalate, dioctyl-	kg	1.03E-07	1.67E-09	1.01E-07
Platinum	kg	3.39E-13		3.39E-13
Plutonium-238	Bq	3.19E-09		3.19E-09
Plutonium-alpha	Bq	7.32E-09		7.32E-09
Polonium-210	Bq	3.55E-01		3.55E-01
Polychlorinated biphenyls	kg	1.81E-10		1.81E-10
Polycyclic organic matter, unspecified	kg	5.64E-07		5.64E-07
Potassium	kg	3.70E-03		3.70E-03
Potassium-40	Bq	4.45E-02		4.45E-02
Propanal	kg	7.93E-06	8.69E-09	7.92E-06
Propane	kg	3.35E-05		3.35E-05
Propene	kg	2.40E-02	9.18E-04	2.31E-02
Propionic acid	kg	2.18E-05		2.18E-05
Propylamine	kg	3.04E-14		3.04E-14
Propylene oxide	kg	4.53E-06		4.53E-06
Protactinium-234	Bq	3.23E-03		3.23E-03
Pyrene	kg	4.00E-08	1.94E-10	3.98E-08
Radioactive species, other beta emitters	Bq	7.15E-02		7.15E-02
Radioactive species, unspecified	Bq	6.77E+06	3.20E+04	6.73E+06
Radionuclides (Including Radon)	kg	9.63E-03	4.37E-05	9.59E-03

Substance	Unit	Total	Forestry Operations	I-Joists Production
Radium-226	Bq	2.13E-01		2.13E-01
Radium-228	Bq	9.23E-02		9.23E-02
Radon-220	Bq	1.26E+00		1.26E+00
Radon-222	Bq	4.27E+05		4.27E+05
Ruthenium-103	Bq	6.93E-09		6.93E-09
Scandium	kg	4.07E-08		4.07E-08
Selenium	kg	1.81E-04	8.17E-07	1.80E-04
Silicon	kg	2.29E-05		2.29E-05
Silicon tetrafluoride	kg	1.09E-10		1.09E-10
Silver	kg	1.75E-09		1.75E-09
Silver-110	Bq	6.86E-08		6.86E-08
Simazine	kg	4.91E-09		4.91E-09
Sodium	kg	8.80E-05		8.80E-05
Sodium chlorate	kg	1.19E-09		1.19E-09
Sodium dichromate	kg	4.17E-09		4.17E-09
Sodium formate	kg	1.18E-10		1.18E-10
Sodium hydroxide	kg	1.00E-08		1.00E-08
Strontium	kg	3.94E-07		3.94E-07
Styrene	kg	5.66E-08	5.72E-10	5.60E-08
Sulfate	kg	6.68E-04		6.68E-04
Sulfur	kg	2.30E-05		2.30E-05
Sulfur dioxide	kg	8.67E+00	1.53E-01	8.52E+00
Sulfur hexafluoride	kg	1.21E-07		1.21E-07
Sulfur oxides	kg	7.36E-01	6.63E-02	6.69E-01
Sulfur trioxide	kg	2.57E-04		2.57E-04
Sulfur, total reduced	kg	2.64E-04		2.64E-04
Sulfuric acid	kg	1.24E-07		1.24E-07
Sulfuric acid, dimethyl ester	kg	7.73E-08	1.10E-09	7.62E-08
Tar	kg	6.12E-09	4.94E-11	6.07E-09
t-Butyl methyl ether	kg	5.70E-08	8.01E-10	5.62E-08
t-Butylamine	kg	7.52E-06		7.52E-06
Terbufos	kg	1.22E-08		1.22E-08
Terpenes	kg	3.18E-09		3.18E-09
Thallium	kg	2.16E-09		2.16E-09
Thorium	kg	2.43E-09		2.43E-09
Thorium-228	Bq	1.26E-02		1.26E-02
Thorium-230	Bq	7.30E-02		7.30E-02
Thorium-232	Bq	1.41E-02		1.41E-02

Substance	Unit	Total	Forestry Operations	I-Joists Production
Thorium-234	Bq	3.23E-03		3.23E-03
Tin	kg	5.33E-08		5.33E-08
Titanium	kg	1.20E-06		1.20E-06
TOC, Total Organic Carbon	kg	4.98E-02		4.98E-02
Toluene	kg	3.08E-03	1.46E-04	2.94E-03
Toluene, 2,4-dinitro-	kg	4.51E-10	6.41E-12	4.44E-10
Toluene, 2-chloro-	kg	2.06E-05		2.06E-05
Trimethylamine	kg	4.92E-15		4.92E-15
Tungsten	kg	4.42E-09		4.42E-09
Uranium	kg	3.21E-09		3.21E-09
Uranium alpha	Bq	1.76E-01		1.76E-01
Uranium-234	Bq	9.86E-02		9.86E-02
Uranium-235	Bq	1.82E-03		1.82E-03
Uranium-238	Bq	1.33E-01		1.33E-01
Vanadium	kg	3.37E-06		3.37E-06
Vinyl acetate	kg	1.22E-08	1.74E-10	1.21E-08
VOC, volatile organic compounds	kg	3.80E+00	3.51E-02	3.76E+00
Water	kg	6.62E-05		6.62E-05
Xenon-131m	Bq	1.03E+00		1.03E+00
Xenon-133	Bq	3.39E+01		3.39E+01
Xenon-133m	Bq	1.19E-01		1.19E-01
Xenon-135	Bq	1.38E+01		1.38E+01
Xenon-135m	Bq	8.28E+00		8.28E+00
Xenon-137	Bq	1.85E-01		1.85E-01
Xenon-138	Bq	1.54E+00		1.54E+00
Xylene	kg	1.74E-03	1.01E-04	1.64E-03
Zinc	kg	3.83E-05	1.23E-05	2.59E-05
Zinc-65	Bq	1.33E-06		1.33E-06
Zirconium	kg	4.87E-10		4.87E-10
Zirconium-95	Bq	1.30E-06		1.30E-06

13.2 Water Emissions

Table 16 Emissions to water released per 1,000 m (1 km) composite I-joists, PNW.

Substance	Unit	Total	Forestry Operations	I-Joists Production
1,4-Butanediol	kg	8.49E-06		8.49E-06
1-Butanol	kg	1.92E-05		1.92E-05
1-Pentanol	kg	1.26E-13		1.26E-13
1-Pentene	kg	9.51E-14		9.51E-14
1-Propanol	kg	2.41E-13		2.41E-13
2,4-D	kg	2.93E-10		2.93E-10
2-Aminopropanol	kg	1.09E-05		1.09E-05
2-Hexanone	kg	8.62E-06	6.14E-07	8.00E-06
2-Methyl-1-propanol	kg	9.87E-06		9.87E-06
2-Methyl-2-butene	kg	2.11E-17		2.11E-17
2-Propanol	kg	4.35E-05		4.35E-05
4-Methyl-2-pentanone	kg	5.53E-06	3.95E-07	5.14E-06
Acenaphthene	kg	5.58E-11		5.58E-11
Acenaphthylene	kg	3.49E-12		3.49E-12
Acetaldehyde	kg	3.10E-04		3.10E-04
Acetic acid	kg	1.17E-03		1.17E-03
Acetochlor	kg	4.06E-09		4.06E-09
Acetone	kg	3.66E-05	9.40E-07	3.56E-05
Acetonitrile	kg	3.59E-06		3.59E-06
Acetyl chloride	kg	9.89E-14		9.89E-14
Acid as H+	kg	5.29E-04		5.29E-04
Acidity, unspecified	kg	2.15E-06		2.15E-06
Acids, unspecified	kg	1.29E-04	9.22E-10	1.29E-04
Acrylate, ion	kg	2.37E-09		2.37E-09
Actinides, radioactive, unspecified	Bq	3.80E-02		3.80E-02
Alachlor	kg	3.99E-10		3.99E-10
Aluminium	kg	3.43E-02		3.43E-02
Aluminum	kg	2.93E-02	6.87E-03	2.24E-02
Ammonia	kg	2.04E-02	1.64E-03	1.88E-02
Ammonia, as N	kg	5.74E-08	4.63E-10	5.69E-08
Ammonium, ion	kg	4.59E-03	3.48E-07	4.59E-03
Aniline	kg	6.81E-05		6.81E-05
Antimony	kg	3.96E-05	4.28E-06	3.53E-05
Antimony-122	Bq	1.98E-05		1.98E-05
Antimony-124	Bq	6.50E-03		6.50E-03

Substance	Unit	Total	Forestry Operations	I-Joists Production
Antimony-125	Bq	5.98E-03		5.98E-03
AOX, Adsorbable Organic Halogen as Cl	kg	9.10E-07		9.10E-07
Arsenic, ion	kg	3.55E-04	5.34E-05	3.01E-04
Atrazine	kg	7.91E-09		7.91E-09
Barite	kg	7.65E-05		7.65E-05
Barium	kg	8.19E-01	9.46E-02	7.24E-01
Barium-140	Bq	8.68E-05		8.68E-05
Bentazone	kg	3.23E-11		3.23E-11
Benzene	kg	1.06E-01	1.58E-04	1.05E-01
Benzene, 1,2-dichloro-	kg	1.03E-04		1.03E-04
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.32E-07	9.39E-09	1.22E-07
Benzene, chloro-	kg	1.53E-03		1.53E-03
Benzene, ethyl-	kg	1.25E-04	8.87E-06	1.16E-04
Benzene, pentamethyl-	kg	9.87E-08	7.05E-09	9.16E-08
Benzenes, alkylated, unspecified	kg	3.24E-05	3.75E-06	2.87E-05
Benzoic acid	kg	1.34E-03	9.54E-05	1.24E-03
Beryllium	kg	1.72E-05	1.34E-06	1.59E-05
Biphenyl	kg	2.10E-06	2.43E-07	1.86E-06
BOD5, Biological Oxygen Demand	kg	1.24E+00	1.70E-02	1.22E+00
Borate	kg	6.19E-04		6.19E-04
Boron	kg	4.23E-03	2.95E-04	3.93E-03
Bromate	kg	8.44E-05		8.44E-05
Bromide	kg	2.98E-01	2.01E-02	2.78E-01
Bromine	kg	9.52E-06		9.52E-06
Bromoxynil	kg	4.27E-11		4.27E-11
Butene	kg	3.11E-05		3.11E-05
Butyl acetate	kg	1.04E-06		1.04E-06
Butyrolactone	kg	1.44E-11		1.44E-11
Cadmium, ion	kg	5.91E-05	1.32E-05	4.59E-05
Calcium, ion	kg	4.26E+00	3.02E-01	3.96E+00
Carbofuran	kg	6.04E-11		6.04E-11
Carbon disulfide	kg	5.88E-12		5.88E-12
Carbonate	kg	7.48E-03		7.48E-03
Carboxylic acids, unspecified	kg	3.93E-05		3.93E-05
Cerium-141	Bq	3.47E-05		3.47E-05
Cerium-144	Bq	1.06E-05		1.06E-05
Cesium	kg	8.98E-09		8.98E-09
Cesium-134	Bq	5.24E-03		5.24E-03

Substance	Unit	Total	Forestry Operations	I-Joists Production
Cesium-136	Bq	6.16E-06		6.16E-06
Cesium-137	Bq	4.38E+00		4.38E+00
CFCs, unspecified	kg	2.48E-07		2.48E-07
Chloramine	kg	1.04E-04		1.04E-04
Chlorate	kg	6.44E-04		6.44E-04
Chloride	kg	4.79E+01	3.40E+00	4.45E+01
Chlorinated solvents, unspecified	kg	4.40E-07		4.40E-07
Chlorine	kg	3.59E-08		3.59E-08
Chloroacetic acid	kg	2.79E-03		2.79E-03
Chloroacetyl chloride	kg	1.46E-05		1.46E-05
Chloroform	kg	1.28E-05		1.28E-05
Chlorosulfonic acid	kg	1.31E-05		1.31E-05
Chlorpyrifos	kg	4.65E-10		4.65E-10
Chromate	kg	3.30E-11		3.30E-11
Chromium	kg	1.17E-03	2.15E-04	9.53E-04
Chromium VI	kg	1.49E-05	7.25E-07	1.42E-05
Chromium, ion	kg	5.03E-04	2.23E-05	4.80E-04
Chromium-51	Bq	9.12E-03		9.12E-03
Cobalt	kg	5.28E-05	2.08E-06	5.07E-05
Cobalt-57	Bq	1.96E-04		1.96E-04
Cobalt-58	Bq	5.95E-02		5.95E-02
Cobalt-60	Bq	4.79E-02		4.79E-02
COD, Chemical Oxygen Demand	kg	1.49E+00	3.15E-02	1.46E+00
Copper	kg	1.27E-06		1.27E-06
Copper, ion	kg	3.72E-04	4.42E-05	3.27E-04
Cumene	kg	1.49E-01		1.49E-01
Cyanazine	kg	6.97E-11		6.97E-11
Cyanide	kg	1.50E-05	6.79E-09	1.50E-05
Decane	kg	3.85E-05	2.74E-06	3.57E-05
Detergent, oil	kg	1.23E-03	8.19E-05	1.15E-03
Dibenzofuran	kg	2.50E-07	1.79E-08	2.32E-07
Dibenzothiophene	kg	2.09E-07	1.52E-08	1.94E-07
Dicamba	kg	4.11E-10		4.11E-10
Dichromate	kg	9.17E-09		9.17E-09
Diethylamine	kg	3.25E-05		3.25E-05
Dimethenamid	kg	9.70E-10		9.70E-10
Dimethylamine	kg	1.43E-04		1.43E-04
Dipropylamine	kg	1.45E-05		1.45E-05

Substance	Unit	Total	Forestry Operations	I-Joists Production
Dipropylthiocarbamic acid S-ethyl ester	kg	4.01E-10		4.01E-10
Dissolved organics	kg	3.39E-04		3.39E-04
Dissolved solids	kg	8.90E-01		8.90E-01
Disulfoton	kg	2.39E-11		2.39E-11
Diuron	kg	6.72E-12		6.72E-12
DOC, Dissolved Organic Carbon	kg	2.79E-01	2.83E-12	2.79E-01
Docosane	kg	1.41E-06	1.01E-07	1.31E-06
Dodecane	kg	7.30E-05	5.20E-06	6.78E-05
Eicosane	kg	2.01E-05	1.43E-06	1.87E-05
Ethane, 1,2-dichloro-	kg	5.64E-05		5.64E-05
Ethanol	kg	9.87E-04		9.87E-04
Ethene	kg	8.96E-06		8.96E-06
Ethene, chloro-	kg	1.87E-09		1.87E-09
Ethyl acetate	kg	4.44E-08		4.44E-08
Ethylamine	kg	3.00E-05		3.00E-05
Ethylene diamine	kg	3.16E-12		3.16E-12
Ethylene oxide	kg	4.86E-05		4.86E-05
Fluorene	kg	3.57E-08		3.57E-08
Fluorene, 1-methyl-	kg	1.50E-07	1.07E-08	1.39E-07
Fluorenes, alkylated, unspecified	kg	1.88E-06	2.18E-07	1.66E-06
Fluoride	kg	8.73E-02	8.50E-02	2.30E-03
Fluorine	kg	9.46E-07	1.09E-07	8.38E-07
Fluosilicic acid	kg	6.97E-08		6.97E-08
Formaldehyde	kg	5.81E-04		5.81E-04
Formamide	kg	2.30E-13		2.30E-13
Formate	kg	2.32E-03		2.32E-03
Formic acid	kg	6.68E-14		6.68E-14
Furan	kg	9.09E-09		9.09E-09
Glutaraldehyde	kg	9.44E-09		9.44E-09
Glyphosate	kg	8.72E-10		8.72E-10
Heat, waste	MJ	1.31E+00		1.31E+00
Hexadecane	kg	7.97E-05	5.67E-06	7.40E-05
Hexanoic acid	kg	2.77E-04	1.97E-05	2.57E-04
Hydrocarbons, aliphatic, alkanes, unspecified	kg	1.17E-06		1.17E-06
Hydrocarbons, aliphatic, unsaturated	kg	1.22E-05		1.22E-05
Hydrocarbons, aromatic	kg	4.88E-06		4.88E-06
Hydrocarbons, unspecified	kg	1.87E-05	3.54E-12	1.87E-05
Hydrogen peroxide	kg	4.44E-07		4.44E-07

Substance	Unit	Total	Forestry Operations	I-Joists Production
Hydrogen sulfide	kg	6.90E-07		6.90E-07
Hydrogen-3, Tritium	Bq	1.00E+04		1.00E+04
Hydroxide	kg	5.84E-06		5.84E-06
Hypochlorite	kg	5.35E-07		5.35E-07
Iodide	kg	6.16E-03		6.16E-03
Iodine-131	Bq	1.22E-03		1.22E-03
Iodine-133	Bq	5.45E-05		5.45E-05
Iron	kg	1.40E-01	1.41E-02	1.26E-01
Iron, ion	kg	2.88E-03		2.88E-03
Iron-59	Bq	1.50E-05		1.50E-05
Isopropylamine	kg	1.88E-05		1.88E-05
Lactic acid	kg	1.14E-05		1.14E-05
Lanthanum-140	Bq	9.25E-05		9.25E-05
Lead	kg	5.74E-04	6.37E-05	5.10E-04
Lead-210	Bq	9.61E-02		9.61E-02
Lead-210/kg	kg	1.37E-13	9.77E-15	1.27E-13
Lithium, ion	kg	9.15E-01	2.37E-02	8.92E-01
Magnesium	kg	8.38E-01	5.90E-02	7.79E-01
Manganese	kg	4.37E-03	1.05E-04	4.27E-03
Manganese-54	Bq	3.65E-03		3.65E-03
MCPA	kg	5.46E-12		5.46E-12
Mercury	kg	1.48E-06	5.05E-07	9.76E-07
Metallic ions, unspecified	kg	8.29E-08	4.33E-11	8.28E-08
Methane, dichloro-, HCC-30	kg	1.60E-05		1.60E-05
Methane, monochloro-, R-40	kg	5.30E-08	3.78E-09	4.92E-08
Methanol	kg	1.46E-04		1.46E-04
Methyl acetate	kg	6.12E-06		6.12E-06
Methyl acrylate	kg	2.22E-08		2.22E-08
Methyl amine	kg	3.19E-06		3.19E-06
Methyl ethyl ketone	kg	1.06E-07	7.57E-09	9.84E-08
Methyl formate	kg	1.77E-12		1.77E-12
Metolachlor	kg	3.21E-09		3.21E-09
Metribuzin	kg	1.49E-11		1.49E-11
Molybdenum	kg	3.61E-05	2.16E-06	3.40E-05
Molybdenum-99	Bq	3.19E-05		3.19E-05
m-Xylene	kg	4.00E-05	2.85E-06	3.71E-05
Naphthalene	kg	2.40E-05	1.71E-06	2.23E-05
Naphthalene, 2-methyl-	kg	2.09E-05	1.49E-06	1.94E-05

Substance	Unit	Total	Forestry Operations	I-Joists Production
Naphthalenes, alkylated, unspecified	kg	5.31E-07	6.15E-08	4.70E-07
n-Hexacosane	kg	8.79E-07	6.28E-08	8.16E-07
Nickel	kg	2.92E-04	3.80E-05	2.54E-04
Nickel, ion	kg	8.59E-05		8.59E-05
Niobium-95	Bq	5.17E-04		5.17E-04
Nitrate	kg	4.18E-03	3.10E-13	4.18E-03
Nitrate compounds	kg	1.80E-09	1.25E-11	1.79E-09
Nitric acid	kg	3.47E-06	2.80E-08	3.45E-06
Nitrite	kg	1.53E-06		1.53E-06
Nitrobenzene	kg	1.81E-04		1.81E-04
Nitrogen	kg	2.40E-05		2.40E-05
Nitrogen, organic bound	kg	3.58E-06		3.58E-06
Nitrogen, total	kg	4.47E-04	8.68E-07	4.46E-04
o-Cresol	kg	3.80E-05	2.70E-06	3.53E-05
Octadecane	kg	1.97E-05	1.40E-06	1.83E-05
Oils, unspecified	kg	3.03E-02	2.10E-03	2.82E-02
Organic substances, unspecified	kg	1.81E-07		1.81E-07
o-Xylene	kg	7.51E-08		7.51E-08
PAH, polycyclic aromatic hydrocarbons	kg	5.60E-08		5.60E-08
Paraquat	kg	6.49E-11		6.49E-11
Parathion, methyl	kg	4.90E-11		4.90E-11
p-Cresol	kg	4.10E-05	2.92E-06	3.80E-05
Pendimethalin	kg	3.33E-10		3.33E-10
Permethrin	kg	3.00E-11		3.00E-11
Phenanthrene	kg	2.47E-07	2.34E-08	2.23E-07
Phenanthrenes, alkylated, unspecified	kg	2.20E-07	2.55E-08	1.95E-07
Phenol	kg	5.15E-04	3.21E-05	4.83E-04
Phenol, 2,4-dimethyl-	kg	3.70E-05	2.63E-06	3.43E-05
Phenols, unspecified	kg	4.16E-04	1.44E-05	4.02E-04
Phorate	kg	9.27E-12		9.27E-12
Phosphate	kg	6.81E-02	6.40E-02	4.12E-03
Phosphorus	kg	1.08E-04		1.08E-04
Phosphorus compounds, unspecified	kg	1.72E-07		1.72E-07
Phosphorus, total	kg	3.00E-04		3.00E-04
Polonium-210	Bq	1.18E-01		1.18E-01
Potassium, ion	kg	8.14E-03		8.14E-03
Potassium-40	Bq	7.32E-02		7.32E-02
Process solvents, unspecified	kg	9.09E-07		9.09E-07

Substance	Unit	Total	Forestry Operations	I-Joists Production
Propanal	kg	6.65E-04		6.65E-04
Propene	kg	5.51E-02		5.51E-02
Propionic acid	kg	5.20E-05		5.20E-05
Propylamine	kg	7.29E-14		7.29E-14
Propylene oxide	kg	8.91E-06		8.91E-06
Protactinium-234	Bq	5.96E-02		5.96E-02
p-Xylene	kg	7.51E-08		7.51E-08
Radioactive species, alpha emitters	Bq	3.45E-02		3.45E-02
Radioactive species, Nuclides, unspecified	Bq	1.12E+04	5.06E+01	1.11E+04
Radium-224	Bq	4.49E-01		4.49E-01
Radium-226	Bq	3.79E+01		3.79E+01
Radium-226/kg	kg	4.77E-11	3.40E-12	4.43E-11
Radium-228	Bq	8.98E-01		8.98E-01
Radium-228/kg	kg	2.44E-13	1.74E-14	2.27E-13
Rubidium	kg	8.98E-08		8.98E-08
Ruthenium-103	Bq	6.73E-06		6.73E-06
Scandium	kg	2.49E-06		2.49E-06
Selenium	kg	3.76E-05	9.53E-07	3.67E-05
Silicon	kg	1.85E-02		1.85E-02
Silver	kg	2.76E-03	1.97E-04	2.56E-03
Silver, ion	kg	1.16E-07		1.16E-07
Silver-110	Bq	4.50E-02		4.50E-02
Simazine	kg	2.11E-10		2.11E-10
Sodium formate	kg	2.84E-10		2.84E-10
Sodium, ion	kg	1.36E+01	9.57E-01	1.26E+01
Sodium-24	Bq	2.41E-04		2.41E-04
Solids, inorganic	kg	1.84E-03	7.13E-11	1.84E-03
Solved solids	kg	5.87E+01	4.19E+00	5.45E+01
Strontium	kg	7.23E-02	5.12E-03	6.71E-02
Strontium-89	Bq	8.58E-04		8.58E-04
Strontium-90	Bq	3.22E+01		3.22E+01
Styrene	kg	6.47E-09		6.47E-09
Sulfate	kg	3.57E-01	7.56E-03	3.50E-01
Sulfide	kg	1.18E-03	3.72E-06	1.17E-03
Sulfite	kg	1.45E-06		1.45E-06
Sulfur	kg	3.83E-03	2.49E-04	3.58E-03
Sulfuric acid	kg	7.96E-09		7.96E-09
Surfactants	kg	3.54E-06		3.54E-06

Substance	Unit	Total	Forestry Operations	I-Joists Production
Suspended solids, inorganic	kg	2.68E-04		2.68E-04
Suspended solids, unspecified	kg	1.95E+00	2.12E-01	1.74E+00
Tar	kg	8.76E-11	7.07E-13	8.68E-11
t-Butyl methyl ether	kg	2.60E-08		2.60E-08
t-Butylamine	kg	1.81E-05		1.81E-05
Technetium-99m	Bq	7.36E-04		7.36E-04
Tellurium-123m	Bq	6.80E-04		6.80E-04
Tellurium-132	Bq	1.85E-06		1.85E-06
Terbufos	kg	3.16E-10		3.16E-10
Tetradecane	kg	3.20E-05	2.28E-06	2.97E-05
Thallium	kg	7.78E-06	9.02E-07	6.88E-06
Thorium-228	Bq	1.80E+00		1.80E+00
Thorium-230	Bq	8.13E+00		8.13E+00
Thorium-232	Bq	1.27E-02		1.27E-02
Thorium-234	Bq	5.96E-02		5.96E-02
Tin	kg	1.99E-04	1.86E-05	1.81E-04
Tin, ion	kg	1.78E-06		1.78E-06
Titanium, ion	kg	6.15E-04	6.57E-05	5.50E-04
TOC, Total Organic Carbon	kg	2.80E-01		2.80E-01
Toluene	kg	2.19E-03	1.49E-04	2.04E-03
Toluene, 2-chloro-	kg	3.63E-05		3.63E-05
Tributyltin compounds	kg	1.78E-08		1.78E-08
Triethylene glycol	kg	1.79E-07		1.79E-07
Trimethylamine	kg	1.18E-14		1.18E-14
Tungsten	kg	2.20E-06		2.20E-06
Uranium alpha	Bq	3.43E+00		3.43E+00
Uranium-234	Bq	7.15E-02		7.15E-02
Uranium-235	Bq	1.18E-01		1.18E-01
Uranium-238	Bq	2.28E-01		2.28E-01
Urea	kg	2.16E-13		2.16E-13
Vanadium	kg	3.64E-05	2.55E-06	3.38E-05
Vanadium, ion	kg	8.38E-06		8.38E-06
VOC, volatile organic compounds, unspecified origin	kg	3.29E-06		3.29E-06
Waste water/m3	m3	3.83E-03		3.83E-03
Xylene	kg	1.10E-03	7.95E-05	1.02E-03
Yttrium	kg	8.89E-06	6.34E-07	8.26E-06
Zinc	kg	1.51E-03	1.60E-04	1.35E-03
Zinc, ion	kg	1.74E-04		1.74E-04

Substance	Unit	Total	Forestry Operations	I-Joists Production
Zinc-65	Bq	3.27E-03		3.27E-03
Zirconium-95	Bq	3.79E-05		3.79E-05