Cradle to Gate Life Cycle Assessment of Composite I-Joists Production from the Southeast

Maureen Puettmann, WoodLife Environmental Consultants, LLC
Elaine Oneil, CORRIM
James Wilson, Professor Emeritus, Oregon State University
Leonard Johnson, Professor Emeritus, University of Idaho

January 2013
Updated June 2013

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 southeast (SE) region. The SE regional data is a representative cross-section of forest growth and manufacturing processes in Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas. 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 SE 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 (2004a) 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 production are included 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 TRACI2 v4.0 method. This report follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011) that will provide the guidance for preparation of North American wood product EPD. This report does not include comparative assertions.

2 Introduction

The goal of this work is to determine energy and material inputs and outputs associated with the production of I-joists from the manufacturing base located in the SE 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 Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Texas. This study includes the cradle-to-gate environmental impacts of laminated veneer lumber (LVL) (Wilson and Dancer 2004b, 2005b) and oriented strand board (OSB) (Kline 2005) as input to the I-joist plant, as well as all impacts associated with its manufacture. It covers the impacts in terms of input materials, fuels, and electricity through to the output of products, co-products, and emissions. The logs used for LVL and OSB production are obtained from the forest resource base located in Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas as representative of the SE region (Johnson et al. 2005).

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" of material, (Figure 1). In most modern I-joists, the flanges are made from LVL that has been ripped into specific dimensions, while the web material is generally made from 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. The LVL and OSB are made from a combination of pine species, primarily loblolly (P. taeda L.) and slash (P. elliottii Engelm.), which are known as southern pine.

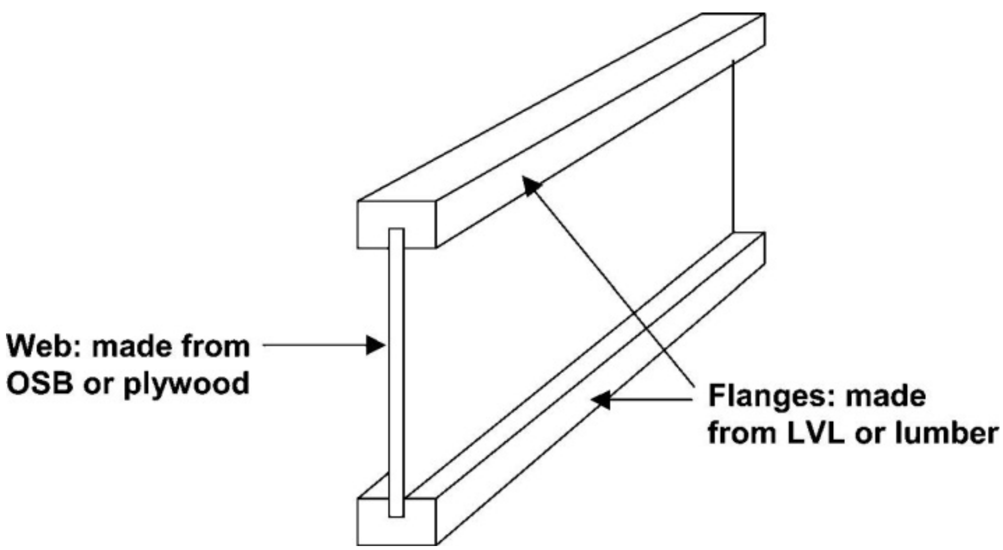

Figure 1 Diagram of the cross-section of a typical composite I-joist

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 SE 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, SE.

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 SE and ends with an I-joists packaged to leave the mill gate (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which includes site preparation, thinning and fertilization and final harvest. Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The transportation of logs from the woods to the mill is accounted for with the plywood manufacturing and then the dry veneer sheets are transported to LVL plants (Figure 2). For OSB production, logs are transported from southeastern forestry operations to a southeastern OSB facility. The system boundary also includes the production and transportation of resins to the LVL plant and OSB. 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 (shavings, trimmings, and sawdust). The co-products are no longer tracked once they leave the system boundary.

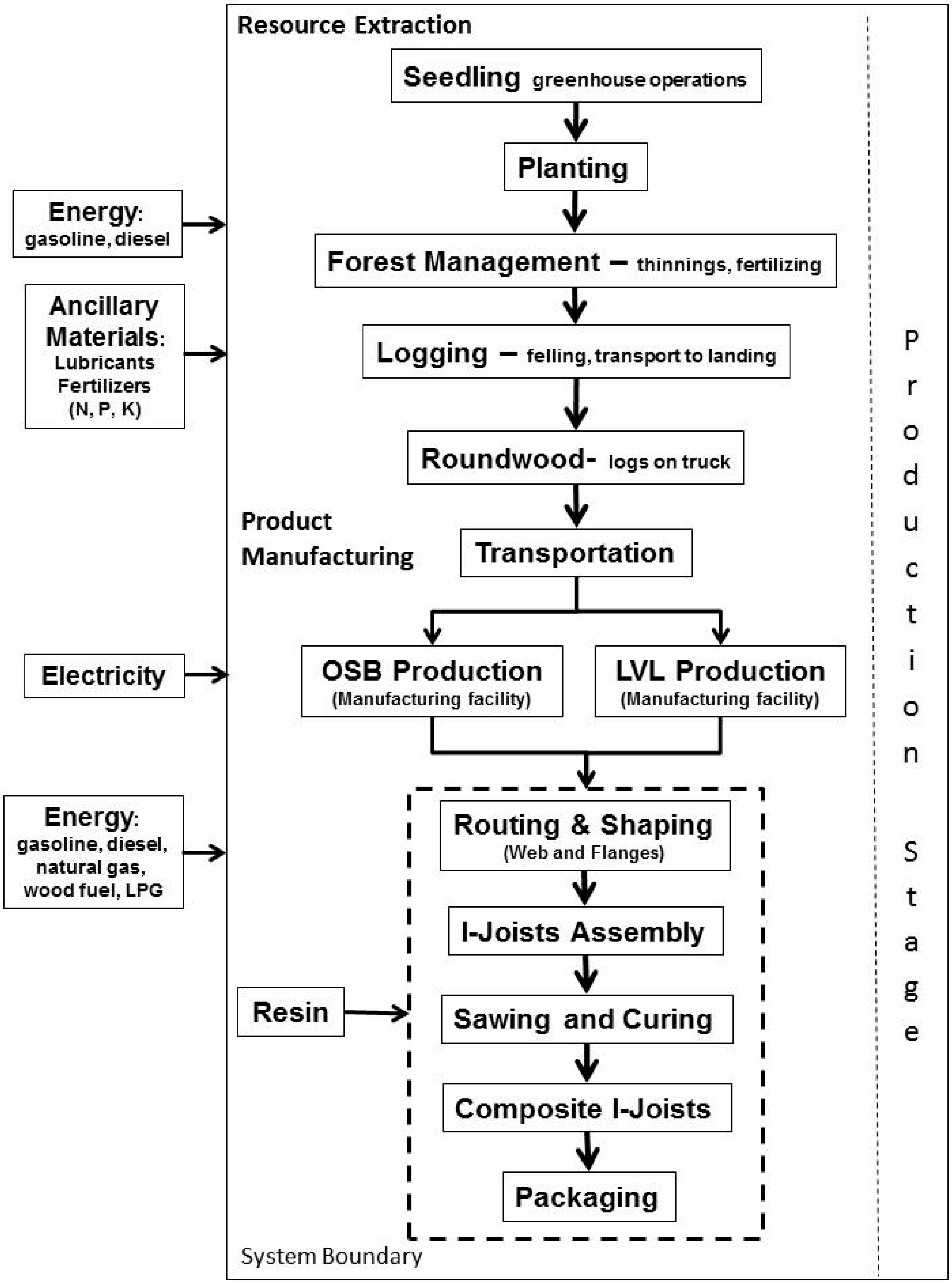

Figure 2 Cradle to gate life cycle stages for Composite I-Joists, SE.

3.3 Description of data/Process Description

3.3.1 Forestry Operations

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

Logs used in the production of LVL and OSB in the SE 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 preparation of the site for planting and planting of seedlings on the prepared site. Intermediate stand treatments enhance growth and productivity while the stand is growing and can involve thinning, fertilization, or both. In the SE, 68% of stands have some level of fertilizer applied, with the area treated determined by management intensity.

In the SE most harvested volume comes from forest operations on private lands where investment in timber is the precursor to harvest. Harvested lands are reforested for the next crop cycle with the sequence of treatments from planting to harvest averaging 27 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 wood product 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. Scenarios developed for the Southeast represent a composite of stands from the extensive database managed by the Forest Nutrition Cooperative at North Carolina State University (Hafley et al 1982; Buford 1991). Management intensities ranged from little intervention on low site productivity lands that are often managed by Non-industrial Private Forest Landowners with a focus on other forest values, to higher management intensities involving combinations of fertilization and thinning on high productivity lands owned by industrial interests. Associated with each combination of management intensity and site productivity is an estimated yield of biomass based on forest growth and yield models. For the SE, growth and yield was based on models by Hafley et al. (1982) and Buford (1991).

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 2). Greenhouse operations data for the SE were based on data from South and Zwolinski 1996. All seedlings in the SE were planted by hand. The only energy factors associated with planting were related to travel to and from the planting site.

Stand treatment options for the Southeast were developed by Lee Allen of the North Carolina Tree Nutrition Cooperative (Allen 2001). Based on that input, fertilization regimes were developed for the mid-intensity and high-intensity scenarios but not for the low-intensity option. Fertilization differences between the mid-and high-intensity options were primarily associated with the frequency of application. The high intensity option involved fertilization every four years over the 25-year life of the stand. The mid-intensity option involved fertilization at years two and sixteen. 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	38.55	132.27	272.21	104.59
Seedlings, at greenhouse	p[1]	1,794	1,794	1,794	1,794
Nitrogen in fertilizer					
In Seedlings	kg	0.14	0.14	0.14	0.14
On Site	kg	-	264.52	712.86	189.06
Phosphorous in fertilizer		-	-	-	-
In Seedlings	kg	0.01	0.01	0.01	0.01
On Site	kg	-	72.86	128.90	48.70
Potassium in fertilizer		-	-	-	-
In Seedlings	kg	0.08	0.08	0.08	0.08
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. Primary transportation is hauling logs from the woods to a manufacturing location and it is included in the LCI for the primary manufacturing facility.

This analysis is based on data for the most common mechanized harvesting system in use in the SE region. Mechanized felling utilizes a cutting device mounted on a woods tractor (feller-buncher) that travels through the stand to cut and bunch trees, transportation of those harvested trees to a landing (skidding), and the use of another machine that can delimb and process trees into logs at the landing. Two general systems were used. A smaller feller-buncher and grapple skidder and a larger, more capital-intensive system. The processing operation for this type of system generally takes place at the landing. Thus, whole trees are moved to the landing through the secondary transportation operation and are then processed into logs. Since whole trees are moved to the landing, the removed carbon from the site includes both the stem and the crown.

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 affects machine productivity and therefore emissions per m3 of logs produced. To account for this, equipment usage was allocated between thinning operations and final harvest for those management regimes that use thinning (Table 3).

Table 3 Equipment allocation by treatment and management intensity.

Management Intensity	Thinning	Final Harvest (usage per final volume harvested)
Low intensity site		
Medium Feller Buncher	NA	100%
Small Skidder	NA	100%
Slide Boom De-limber	NA	100%
Large Loader	NA	100%
Medium intensity		
Large Feller Buncher	26%	74%
Medium Crawler	26%	74%
Slide Boom De-limber	26%	74%
Large Loader	26%	74%
High intensity		
Large Feller Buncher	36%	64%
Medium Crawler	36%	64%
Slide Boom De-limber	36%	64%
Large Loader	36%	64%

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 based on the relative percentage of the land base they occupy which is given as percent area in management class in Table 4. Site productivity as measured by site index, the height of dominant trees at a base year, usually 25 or 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 the management intensity classes. The first class reflects non-industrial private forests (NIPF) with low-intensity management that might be implemented by the small private landowner. The second reflects high-intensity management on NIPF lands and/or low intensity management on industrial lands. The third scenario reflects high intensity management on industrial tree farms. Specific assumptions associated with these three scenarios are outlined in Table 4. In the Southeast, 37% of industrial and non-industrial private forestlands were classified in the lowest productivity class, 58% in the middle productivity class, and 5% in the highest class. The allocation of forested area to management intensity/site productivity class produces the expected log volume recovered from the forest resource as shown in Table 4. Allocating per ha values from Table 2 to the total yield of 236 m3/ha is used to carry forward the environmental burdens of the reforestation effort on a per m3 basis.

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

Management intensity class prescription	Low Intensity	Medium Intensity	High Intensity	Weighted Average
	per hectare			
Rotation Age - Years	30	25	25	27
Planting Density-Trees/hectare	1,794	1,794	1,794	1,794
Fertilization	None	Years 2,16	Years 2,5,9,13,17,21	
Commercial Thin 1st - m^3	0	63	59	39
at year		17	13	
Commercial Thin 2nd - m^3	0	0	58	3
at year			19	
Final Harvest - m^3	220	175	205	193
at year	30	25	25	
Total yield/hectare - m^3	220	238	323	236
Percent Thinned	0%	26%	36%	17%
Percent Sawlogs	38%	31%	52%	35%
Percent area in Class	37%	58%	5%	

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 SE region by major process (Table 5).

Table 5 Fuel consumption for SE 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	0.515
Lubricants	L	0.009
Electricity	kWh	0.455
Commercial Thinning and Final Harvest		
Diesel	L	2.930
Lubricants	L	0.050
Total Forest Extraction Process		
Gasoline and Diesel	L	3.440
Lubricants	L	*0.054*
Electricity	kWh	0.455

3.3.2 Product Manufacturing

3.3.2.1 Transportation Process

Hauling is the first process of product manufacturing (Figure 2) with the one-way delivery distances for hauling shown in Table 6. Delivery of all input materials was by truck. The values for LVL shipping distances are zero since the surveyed I-joist plants also produce LVL on-site. Logs are transported from the forest landing to veneer production which is for LVL manufacturing and directly to the OSB facility. Resins are transported to LVL, OSB and I-joist mills. Veneer is transported to the LVL facility. Final transport is for OSB to the I-joist facility. All flow analyses of roundwood in the process were tracked during OSB and LVL production. A density of 649 kg/m3 was used for OSB and 606 kg/m3 for LVL.

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

Material delivered to mill	Delivery Distance (km)	
	km	miles
OSB to I-joist plant	515	320
LVL to I-Joist plant	0	0
MDI and PRF resin to I-Joist plant	1191	740

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, 2,230 kg of LVL (3.68 m3) was incorporated into the final product. Dry veneers and resin are the primary raw materials consumed for the production of SE 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, 1,645 kg of OSB (2.54 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 SE comes from electricity, natural gas, diesel, and liquid petroleum gas (LPG). 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. None of the plants that were surveyed used hogged fuel (wood and bark waste fuel) as a source of energy in the manufacturing process, although wood fuel is used during OSB production and to produce veneer used in making LVL.

3.3.2.5 Methylene diphenyl di-isocyanate (MDI) resin

The LCI for the production of methylene diphenyl diisocyanate resin was based on a cradle-to-gate study of 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 approximately 95% of North American production capacity (Franklin 2010).

The LCI generated by Franklins Associates 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 are 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

Phenol-resorcinol-formaldehyde (PRF) resin is used for both web to web joints and web to flange joints. The PRF data was collected by survey from 8 plants in U.S. that represented 63% of total production for the year 2005 (Wilson 2009). Total annual production of PRF was 15,513,000 kg (34,166,667 lb) of neat[1] resin at 60% non-volatile solids content. PRF resins differ somewhat from the other resins in that hardeners are required to help in curing glue laminated timbers and 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 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) or phenol resorcinol formaldehyde (PRF)) resins are 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, OSB, and resins are the main materials consumed for the production of I-joists (Table 7). The final weight of SE I-joist is 3870 kg/km (1,000 m). This required 2400 kg of LVL, 1770 kg of OSB, and 12.28 kg of resin (MDI and PRF combined) of which 92.98% was allocated to the final product with the rest becoming sawdust (Table 7).

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

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

Products	Value	Unit/km	Allocation (%)
SE Composite I-Joists (1 km for EPD)	1.00	km	92.98
SE Sawdust	292.00	kg	7.02
Resources			
Water, unspecified	711.70	L	
Materials/fuels			
Electricity, at Grid	246.00	kWh	
Diesel	3.60	L	
LPG	4.72	L	
Natural gas	5.95	m^3	
Laminated veneer lumber, at plant, US SE	2,400.00	kg	
Oriented strand board product, US SE	1,770.00	kg	
Methylene diphenyl diisocyanate resin (MDI)	7.74	kg	
Phenol Resorcinol Formaldehyde resin, (PRF)	4.54	kg	
Transport, combination truck, diesel powered, MDI	9.22	tkm	
Transport, combination truck, diesel powered, PRF	5.41	tkm	
Transport, combination truck, diesel powered, OSB	912.00	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	0.0417	kg	

3.3.2.8 Packaging

Materials used for packaging composite I-joist for shipping are shown in Table 8. For this study it was assumed that only wrapping material was used for each I-joist. Packing materials for I-joists represent 1.23 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 based on I-joists and co-products' production, raw material usage, electricity and fuel usage, and emissions. The LVL and OSB used to make I-joists are generated in the region where they are produced.

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 SE was 86,563 km or 284,000 thousand linear feet (MLF) (APA 2001). The SE surveyed mills represented almost 27 percent 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 were in conformance with ISO 14040 and CORRIM research protocol (ISO 2006). Complete details of this study for I-joist production and the overall CORRIM project can be found in Wilson and Dancer (2004) and Lippke et al. (2004), respectively.

6 Life cycle inventory analysis

6.1 Data collection

Primary data for the LCI was collected through mill surveys administered in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production and emissions data provided by I-joist producers from the SE 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 SE region included Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas. 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; Keegan et al. 1995; Kellogg and Bettinger. 1995; Kellogg et al. 1996; Lawson 2002; Reynolds 2002). 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 to I-joist manufacturing. 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. When data was missing for a variable, the weighted average for that variable reflected those facilities reporting the data in the surveys. Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros.

6.3 Allocation rules

Allocation was based on mass. SE I-joist production generates low value co-products (7.02% by mass of input). Co-products are sold as dry wood residues with a price differential approximately 31 times[2] lower than I-joist based on equivalent mass. The differential on a mass versus economic allocation is 3.9 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, SE.

Fuel	Total	Forestry Operations	I-Joist Production	SE OSB Production	LVL Production	Resin Production
	kg/km					
Coal, in ground	403.915	1.545	74.147	156.654	167.557	4.012
Gas, natural, in ground	218.459	5.598	25.471	90.555	87.794	9.041
Oil, crude, in ground	181.201	23.284	33.288	68.692	50.608	5.329
Uranium oxide, in ore	0.011	0.000	0.002	0.004	0.005	0.000
Wood waste	1095.9911	0.0000	9.3661	478.0159	608.6091	0.0000

[2] 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.

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

Air Emission[1/]	Total	Forestry Operations	I-Joists Production (wrapped up)
	kg/km		
Carbon dioxide, biogenic	1787.3885	0.0659	1787.3226
Carbon dioxide, fossil	1651.5383	76.7765	1574.7618
Carbon dioxide	49.1359	3.4072	45.7288
Sulfur dioxide	10.6874	0.1759	10.5115
Nitrogen oxides	8.4384	1.3729	7.0655
Carbon monoxide	5.6998	0.0002	5.6995
Particulates, > 2.5 um, and < 10um	4.6852	0.0421	4.6431
Methane	4.6202	0.1590	4.4612
Carbon monoxide, fossil	3.1939	0.6854	2.5085
VOC, volatile organic compounds	3.0252	0.0404	2.9849
Particulates, unspecified	2.6833	0.0095	2.6738
Particulates, < 2.5 um	2.0581	0.0000	2.0581
Sulfur oxides	0.8249	0.0763	0.7486
Methanol	0.7007	0.0000	0.7007
Methane, fossil	0.6405	0.0162	0.6242
NMVOC, non-methane volatile organic compounds, unspecified origin	0.4517	0.0460	0.4057
Metals, unspecified	0.3878	0.0000	0.3878
Hydrogen chloride	0.3816	0.0008	0.3808
Formaldehyde	0.1847	0.0005	0.1842
Acetaldehyde	0.1693	0.0003	0.1690
Isoprene	0.1658	0.0017	0.1642
Acrolein	0.0940	0.0000	0.0939
Benzene	0.0836	0.0004	0.0832
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0710	0.0020	0.0690
Cumene	0.0617	0.0000	0.0617
Acetone	0.0501	0.0000	0.0501
TOC, Total Organic Carbon	0.0498	0.0000	0.0498
Dinitrogen monoxide	0.0345	0.0200	0.0145
Phenol	0.0309	0.0000	0.0309
Hydrogen fluoride	0.0260	0.0001	0.0259
Propene	0.0239	0.0011	0.0229
Particulates, < 10 um	0.0201	0.0000	0.0201
Radionuclides (Including Radon)	0.0160	0.0001	0.0160

Air Emission[1/]	Total	Forestry Operations	I-Joists Production (wrapped up)
	kg/km		
Manganese	0.0146	0.0000	0.0146
Chlorine	0.0124	0.0000	0.0124
Ammonia	0.0119	0.0031	0.0089
N-Nitrodimethylamine	0.0114	0.0000	0.0114
Aldehydes, unspecified	0.0062	0.0009	0.0053
Barium	0.0059	0.0000	0.0059
Organic substances, unspecified	0.0057	0.0000	0.0057
alpha-Pinene	0.0055	0.0000	0.0055
Potassium	0.0037	0.0000	0.0037
Hydrocarbons, unspecified	0.0035	0.0000	0.0034
Methane, dichloro-, HCC-30	0.0027	0.0000	0.0027
Toluene	0.0024	0.0002	0.0023
Particulates, > 10 um	0.0023	0.0000	0.0023
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	0.0021	0.0000	0.0021
Magnesium	0.0019	0.0000	0.0019
Sulfate	0.0018	0.0000	0.0018
Hydrogen	0.0013	0.0000	0.0013
Xylene	0.0012	0.0001	0.0011
Naphthalene	0.0009	0.0000	0.0009
Nitrogen, total	0.0008	0.0008	0.0000
Hydrocarbons, aliphatic, alkanes, unspecified	0.0008	0.0000	0.0008
Sulfur trioxide	0.0007	0.0000	0.0007
D-limonene	0.0006	0.0000	0.0006
Ammonium chloride	0.0006	0.0000	0.0006
Acetic acid	0.0006	0.0000	0.0006
Lead	0.0005	0.0000	0.0005
Phenols, unspecified	0.0005	0.0000	0.0005
Dimethyl ether	0.0004	0.0000	0.0004
Nickel	0.0004	0.0000	0.0004
Monoethanolamine	0.0004	0.0000	0.0004
Mercaptans, unspecified	0.0003	0.0000	0.0003
Carbon dioxide, land transformation	0.0003	0.0000	0.0003
Chloroform	0.0003	0.0000	0.0003
Kerosene	0.0003	0.0000	0.0003
Arsenic	0.0003	0.0000	0.0003
Sulfur, total reduced	0.0003	0.0000	0.0003

Air Emission[1/]	Total	Forestry Operations	I-Joists Production (wrapped up)
	kg/km		
Selenium	0.0003	0.0000	0.0003
Chromium	0.0002	0.0000	0.0002
Particulates	0.0002	0.0000	0.0002
Ash	0.0002	0.0000	0.0002
Methylene diisocyanate	0.0002	0.0000	0.0002
Aluminium	0.0002	0.0000	0.0002
Water	0.0002	0.0000	0.0002
Ethane	0.0002	0.0000	0.0002
Butene	0.0002	0.0000	0.0002
Methane, biogenic	0.0002	0.0000	0.0002
Ethene	0.0001	0.0000	0.0001
Fluoride	0.0001	0.0000	0.0001
Nitrobenzene	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. Survey mills report no discharge of any process water. Most wood production facilities operate with this restriction. Water emissions reported in Table11 are result of upstream process (eg. 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, SE.

Water Emission[1/]	Total	Forestry Operations	I-Joists Production (Wrapped up)
	kg/km		
Solved solids	64.2657	4.8159	59.4499
Chloride	52.8527	3.9044	48.9482
Sodium, ion	15.1605	1.1010	14.0595
Calcium, ion	4.6974	0.3473	4.3501
Suspended solids, unspecified	2.1501	0.2443	1.9058
COD, Chemical Oxygen Demand	1.5334	0.0363	1.4972
BOD5, Biological Oxygen Demand	1.2775	0.0196	1.2579
Lithium, ion	0.9824	0.0273	0.9551
Magnesium	0.9313	0.0679	0.8634
Barium	0.9099	0.1088	0.8011
Sulfate	0.6410	0.0087	0.6323

Water Emission[1/]	Total	Forestry Operations	I-Joists Production (Wrapped up)
	kg/km		
Dissolved solids	0.6054	0.0000	0.6054
Bromide	0.3500	0.0232	0.3268
TOC, Total Organic Carbon	0.2857	0.0000	0.2857
DOC, Dissolved Organic Carbon	0.2851	0.0000	0.2851
Iron	0.1584	0.0162	0.1422
Cumene	0.1483	0.0000	0.1483
Benzene	0.1081	0.0002	0.1079
Fluoride	0.1026	0.0977	0.0049
Phosphate	0.0827	0.0736	0.0091
Strontium	0.0795	0.0059	0.0736
Propene	0.0551	0.0000	0.0551
Silicon	0.0485	0.0000	0.0485
Aluminium	0.0444	0.0000	0.0444
Oils, unspecified	0.0338	0.0024	0.0314
Aluminum	0.0306	0.0079	0.0227
Ammonia	0.0222	0.0019	0.0203
Potassium, ion	0.0214	0.0000	0.0214
Carbonate	0.0196	0.0000	0.0196
Iodide	0.0162	0.0000	0.0162
Ammonium, ion	0.0120	0.0000	0.0120
Nitrate	0.0109	0.0000	0.0109
Iron, ion	0.0076	0.0000	0.0076
Chloroacetic acid	0.0073	0.0000	0.0073
Manganese	0.0070	0.0001	0.0068
Formate	0.0061	0.0000	0.0061
Solids, inorganic	0.0048	0.0000	0.0048
Boron	0.0048	0.0003	0.0044
Sulfur	0.0047	0.0003	0.0044
Benzene, chloro-	0.0040	0.0000	0.0040
Acetic acid	0.0031	0.0000	0.0031
Silver	0.0030	0.0002	0.0028
Ethanol	0.0026	0.0000	0.0026
Toluene	0.0026	0.0002	0.0024
Zinc	0.0017	0.0002	0.0016
Chlorate	0.0017	0.0000	0.0017

Water Emission[1/]	Total	Forestry Operations	I-Joists Production (Wrapped up)
	kg/km		
Borate	0.0016	0.0000	0.0016
Formaldehyde	0.0015	0.0000	0.0015
Benzoic acid	0.0015	0.0001	0.0014
Detergent, oil	0.0013	0.0001	0.0013
Chromium	0.0013	0.0002	0.0011
Sulfide	0.0013	0.0000	0.0013
Xylene	0.0012	0.0001	0.0011
Phenol	0.0010	0.0000	0.0010
Acetaldehyde	0.0008	0.0000	0.0008
Titanium, ion	0.0008	0.0001	0.0007
Suspended solids, inorganic	0.0007	0.0000	0.0007
Lead	0.0006	0.0001	0.0006
Acid as H+	0.0006	0.0000	0.0006
Nitrogen, total	0.0006	0.0000	0.0006
Chromium, ion	0.0005	0.0000	0.0005
Copper, ion	0.0005	0.0001	0.0004
Nitrobenzene	0.0005	0.0000	0.0005
Phenols, unspecified	0.0004	0.0000	0.0004
Zinc, ion	0.0004	0.0000	0.0004
Arsenic, ion	0.0004	0.0001	0.0003
Methanol	0.0004	0.0000	0.0004
Dissolved organics	0.0004	0.0000	0.0004
Dimethylamine	0.0004	0.0000	0.0004
Nickel	0.0003	0.0000	0.0003
Hexanoic acid	0.0003	0.0000	0.0003
Phosphorus, total	0.0003	0.0000	0.0003
Chloramine	0.0003	0.0000	0.0003
Benzene, 1,2-dichloro-	0.0003	0.0000	0.0003
Phosphorus	0.0002	0.0000	0.0002
Nickel, ion	0.0002	0.0000	0.0002
Bromate	0.0002	0.0000	0.0002
Tin	0.0002	0.0000	0.0002
Barite	0.0002	0.0000	0.0002
Aniline	0.0002	0.0000	0.0002
Ethane, 1,2-dichloro-	0.0001	0.0000	0.0001

Water Emission[1/]	Total	Forestry Operations	I-Joists Production (Wrapped up)
	kg/km		
Benzene, ethyl-	0.0001	0.0000	0.0001
Propionic acid	0.0001	0.0000	0.0001
Ethylene oxide	0.0001	0.0000	0.0001
Acids, unspecified	0.0001	0.0000	0.0001
2-Propanol	0.0001	0.0000	0.0001
Carboxylic acids, unspecified	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 18% of the total waste generated from cradle to grave.

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

Waste to treatment	Total	Forestry Operations	I-joist Production	OSB Production	LVL Production	Resin Production
	kg/km					
Solid Waste	291.81	1.39	25.33	95.12	156.53	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 SE region. It 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, 39 and 38 percent of the CO2 equivalent emissions come from producing LVL and OSB, respectively. I-joist production generated 16 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 143 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, SE.

Impact category	Unit	Total	Forestry Operations	I-Joist Production	OSB Production	LVL Production	Resin Production
Global warming potential (GWP)	kg CO_2 equiv	1843.84	90.52	303.51	695.59	725.55	28.66
Acidification Potential	H+ moles equiv	943.57	68.12	136.81	354.06	373.16	11.43
Eutrophication Potential	kg N equiv	0.7437	0.2405	0.0643	0.1958	0.1968	0.0464
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Smog Potential	kg O3 equiv	227.32	34.23	27.69	83.69	80.00	1.72
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**I-Joist Production**	**OSB Production**	**LVL Production**	**Resin Production**
Non-renewable fossil	MJ	30,834	1,404	4,845	12,240	11,474	839
Non-renewable nuclear	MJ	4,313	13	773	1,681	1,812	34
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	46	1	4	11	25	5
Renewable, biomass	MJ	23,056	0	205	10,087	12,763	1
Material resources consumption (non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**I-joist Production**	**OSB Production**	**LVL Production**	**Resin Production**
Non-renewable materials	kg	19.19	0.00	4.96	6.97	2.03	5.23
Renewable materials	kg	4697.07	0.00	0.00	1993.72	2703.35	0.00
Fresh water	L	4,639.65	0.33	661.74	1,180.35	2,232.98	564.24
Waste generated	**Unit**	**Total**	**Forestry Operations**	**I-joist Production**	**OSB Production**	**LVL Production**	**Resin Production**
Solid waste	kg	291.81	1.39	25.33	95.12	156.53	13.43

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, 1844 kg CO_2e were released in the production of 1 km of I-joist. That same 1 km stores 7072 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	90.52
released manufacturing	1752.48
CO_2 eq. stored in product	7072.36

9 Conclusions

The cradle to gate LCA for composite I-joist includes the LCI of forest resources that relies on secondary and tertiary data and the LCI of manufacturing that relies on primary survey data for wood product and resin inputs 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 loblolly and slash pines. The survey data are representative of the I-joists sizes and production volumes consistent with trade association production data.

There was a total 9.36 cubic meters of roundwood used to produce both the OSB and LVL for SE I-joist production. Oriented strandboard required 4.13 m3 or 44% while LVL used in I-joists consumed 5.23 m3 or 56% or of the wood resource. To produce one kilometer of southeast I-joists required 1,646 kg of OSB and 2,231 kg of LVL. The I-joists production process produced very little coproduct (sawdust) representing only 7% by mass or 292 kg/ km. One kilometer of I-joists weighed 3,870 kg. The use of wood fuel was consumed during OSB or LVL production or subsequent upstream processes used in OSB or LVL production.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The scope of this study encompassed the environmental impacts of forestry operations, I-joists, LVL, OSB, and resin production, and transportation of all materials including the logs to LVL and OSB facilities. The LCI data for I-joists are presented on a production unit of 1,000 meters (1 kilometer), an acceptable U.S. industry unit. 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 10 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 53 percent of the total energy from cradle to gate. Resins used to bond the LVL, 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 less than 3 percent.

The TRACI impact method does not count the contribution of wood-derived CO2 emissions from burning wood fuel in the boiler towards the global warming impact estimate. This is consistent with the current US EPA ruling on wood emissions from stationary sources which considers the CO2 taken up by the forest ecosystem when the tree grew as balancing any CO2 emissions when it is burned. Under the TRACI method, combustion of fossil fuels generates CO2 and other air emissions that contribute to the global warming impact. Using this method, 1844 kg CO2e were released in the production of 1 km of I-joist. That same 1 km stores 7072 kg CO2e.

10 Acknowledgments

The original research project would not have been possible without the financial and technical assistance provided by the USDA Forest Service, Forest Products Laboratory (JV1111169-156), by DOE's support for developing the research plan (DE-FC07-961D13437), CORRIM's University membership, and the contributions of many companies. The data updates provided in this document were made possible with the financial assistance of the American Wood Council. Our special thanks are extended to those companies and their employees that participated in the surveys to obtain production data. Any opinions,

findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the contributing entities.

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.

12 References

Aasestad, K. 2008. The Norwegian Emission Inventory 2008. Documentation of methodologies for estimating emissions of greenhouse gases and long-range trans-boundary air pollutants. Statistisk sentralbyrå. Reports 2008/48 252 pp.

Allen, H. L. 2001. Stand treatment options and distribution of acreage by management intensity. Personal Communication. 2001. Silvicultural treatments to enhance productivity. Chap. 6, in J. Evans ed. The forests handbook. Volume II. Blackwell Science Ltd., Oxford, UK. 382 pp.

APA-The Engineered Wood Association (APA). 2001. North America Structural Panel Production by Geography 2000. March, 1p.

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

Biltonen, Tom. 2002. Bennett Lumber, Field Forester, Princeton, Idaho, Personal Interview.

Buford, M. A. 1991. Performance of four yield models for predicting stand dynamics of a 30-year-old loblolly pine (Pinus taeda L.) spacing study. For. Ecol. Mgmt. 46:23–38.

Franklin Associates (2010). Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors. Prepared for the Plastics Division of the American Chemistry Council. Published online: http://www51.honeywell.com/sm/chemicals/enovate/common/documents/FP_Enovate_July_2010_Report_by_the_American_Chemistry_Council_Manual.pdf

Frazier, J. R., H. E. Burkhart, AND J. W. McMinn. 1981. Energy input/output relationships for loblolly pine stands. J. Forestry 79(10):670 –673.

Hafley, W. L., W. D. Smith, and M. A. Buford. 1982. A new yield prediction model of unthinned loblolly pine plantations. School of Forest Resources, North Carolina State University. Raleigh, NC.

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

ISO 2006. Environmental management - Life cycle assessment–Requirements and guidelines. International Organization for Standardization. (ISO 14044:2006[E]). 54pp.

Johnson, L.R. B. Lippke, J.D. Marshall, and J. Comnick. 2005. Life-cycle impacts of forest resource activities in the Pacific Northwest and southeast United States. Wood and Fiber Sci. 37 CORRIM Special Issue. pp. 30-46.

Keegan, Ch., C. Fiedler & F. Stewart, 1995, Cost of timber harvest under traditional and “new forestry” silvicultural prescriptions, Western Journal of Applied Forestry, 10(1):36-41.

Kellogg, L.D. & P. Bettinger. 1995. Thinning productivity and cost for a mechanized cut-to-length system in the Pacific Coast Region of the USA, Journal of Forest Engineering, p 43-54.

Kellogg, L.D., P. Bettinger & R. Edwards. 1996. A comparison of logging planning, felling and skyline yarding costs between clearcutting and five group-selection harvesting methods, Western journal of Applied Forestry, 11(3):90-96.

Kline, D.E. 2004. Southeastern oriented strandboard production. In CORRIM Phase I Final Report Module E. 84pp.

Kline, D.E. 2005. Gate-to-gate life cycle inventory of oriented strandboard production. Wood and Fiber Sci. 37 CORRIM Special Issue. pp. 74-84.

Lawson, Roy. 2002. Lawson Logging, Owner, Deary, Idaho, Personal Interview.

Lippke, B, J. Wilson, J. Perez-Garcia, J. Bowyer, and J. Meil. 2004. CORRIM: Life cycle environmental performance of renewable building materials. Forest Products J. 54(6)8-99.

Mills, John. 2001. Matching of database on management intensity classes by owner and site index with projected acreage allocations for SE and SE from the 2000 Resources Planning Act Assessment of Forest and Rangelands. Personal Communication.

National Renewable Energy Laboratory (NREL). 2012. US LCI database for Simapro. Updated February 2012.

Pré Consultants, B.V. 2012. Simapro7 Life-Cycle Assessment Software Package, Version 36. Plotter 12, 3821 BB Amersfoort, The Netherlands. Http://www.pre.nl/.

Product Category Rules (PCR). 2011. North American Structural and Architectural Wood Products. FP Innovations. November 8, 2011.

Puettmann, M.E., E. Oneil, J.B. Wilson, and L.R. Johnson. 2012. Cradle to Gate Life Cycle Assessment of Laminated Veneer Lumber from the Southeast. CORRIM Report Update. August 2012. 24pp.

Puettmann, M.E., E. Oneil, E. Kline, and L.R. Johnson. 2012. Cradle to Gate Life Cycle Assessment of Oriented Strandboard from the Southeast. CORRIM Report Update. August 2012. 23 pp.

Reynolds, Mike. 2002. Mike Reynolds Logging, Owner, Priest River, Idaho, Personal Interview.

South, D. B., and J.B. Zwolinski. 1996. Chemicals used in southern forest nurseries. South J. Appl. For. 20(3):127– 135.

USDA Forest Service. 2000. Assessment of forest and range lands. USDA Forest Service. FS-687. Washington, DC. 78pp.

Werner, Frank. 2004. Review in conformity with ISO 14044FF. Module F. Composite I-Joists– Pacific Northwest and Southeast region. Wilson and Dancer , 26 July, 2004.

Wilson, J.B. 2009. Resins: A life cycle inventory of manufacturing resins used in the wood composites industry. In CORRIM Phase II Final Report Module H. January 2009. 103pp. http://www.corrim.org/pubs/reports/2010/phase2/Module_H.pdf. August 2012

Wilson, J.B. and E. R. Dancer. 2004a. Composite I-Joists–Pacific Northwest and Southeast. In CORRIM Phase I Final Report Module F. 122 pp. http://www.corrim.org/pubs/reports/2005/Phase1/Module_F_Final.pdf. August 2012

__________________________ . 2004b. Laminated veneer lumber manufacturing. In CORRIM Phase I Final Report Module H. 92 pp. http://www.corrim.org/pubs/reports/2005/Phase1/Module_H_Final.pdf. August 2012

___________________________. 2005a. Gate-to-gate life-cycle inventory of I-joist production. 37 CORRIM Special Issue, pp. 85-98.

___________________________ . 2005b. Gate-to-gate life-cycle inventory of laminated veneer lumber. Wood and Fiber Science, 37 CORRIM Special Issue, pp. 114-127.

13 Appendix

13.1 Air Emissions

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

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
1,4-Butanediol	kg	5.58E-05		5.58E-05
1-Butanol	kg	1.21E-05		1.21E-05
1-Pentanol	kg	1.38E-13		1.38E-13
1-Pentene	kg	1.04E-13		1.04E-13
1-Propanol	kg	6.66E-11		6.66E-11
2,4-D	kg	3.27E-09		3.27E-09
2-Aminopropanol	kg	7.07E-06		7.07E-06
2-Butene, 2-methyl-	kg	2.31E-17		2.31E-17
2-Chloroacetophenone	kg	1.07E-08	1.84E-10	1.05E-08
2-Methyl-1-propanol	kg	1.08E-05		1.08E-05
2-Nitrobenzoic acid	kg	2.89E-05		2.89E-05
2-Propanol	kg	2.42E-05		2.42E-05
5-methyl Chrysene	kg	3.82E-09	1.49E-11	3.80E-09
Acenaphthene	kg	8.85E-08	3.45E-10	8.82E-08
Acenaphthylene	kg	4.34E-08	1.69E-10	4.32E-08
Acetaldehyde	kg	1.69E-01	3.14E-04	1.69E-01
Acetic acid	kg	5.91E-04		5.91E-04
Acetochlor	kg	4.53E-08		4.53E-08
Acetone	kg	5.01E-02		5.01E-02
Acetonitrile	kg	1.00E-08		1.00E-08
Acetophenone	kg	2.29E-08	3.95E-10	2.25E-08
Acrolein	kg	9.40E-02	3.80E-05	9.39E-02
Acrylic acid	kg	2.63E-09		2.63E-09
Actinides, radioactive, unspecified	Bq	6.61E-04		6.61E-04
Aerosols, radioactive, unspecified	Bq	1.47E-02		1.47E-02
Alachlor	kg	4.46E-09		4.46E-09
Aldehydes, unspecified	kg	6.22E-03	9.46E-04	5.28E-03
alpha-Pinene	kg	5.50E-03		5.50E-03
Aluminium	kg	1.76E-04		1.76E-04
Ammonia	kg	1.19E-02	3.07E-03	8.86E-03

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Ammonium carbonate	kg	1.72E-08		1.72E-08
Ammonium chloride	kg	5.98E-04	1.87E-06	5.96E-04
Aniline	kg	4.41E-05		4.41E-05
Anthracene	kg	3.64E-08	1.42E-10	3.63E-08
Anthranilic acid	kg	1.34E-05		1.34E-05
Antimony	kg	7.49E-05	1.22E-08	7.49E-05
Antimony-124	Bq	1.29E-07		1.29E-07
Antimony-125	Bq	1.35E-06		1.35E-06
Argon-41	Bq	7.74E+0 0		7.74E+00
Arsenic	kg	2.75E-04	3.74E-07	2.75E-04
Arsine	kg	3.06E-14		3.06E-14
Ash	kg	2.19E-04		2.19E-04
Atrazine	kg	8.84E-08		8.84E-08
Barium	kg	5.92E-03		5.92E-03
Barium-140	Bq	8.76E-05		8.76E-05
Bentazone	kg	3.61E-10		3.61E-10
Benzal chloride	kg	1.48E-16		1.48E-16
Benzaldehyde	kg	1.19E-10		1.19E-10
Benzene	kg	8.36E-02	3.85E-04	8.32E-02
Benzene, 1,2-dichloro-	kg	3.25E-05		3.25E-05
Benzene, 1-methyl-2-nitro-	kg	2.50E-05		2.50E-05
Benzene, chloro-	kg	3.35E-08	5.79E-10	3.30E-08
Benzene, ethyl-	kg	4.79E-06	2.47E-09	4.79E-06
Benzene, hexachloro-	kg	2.94E-10		2.94E-10
Benzene, pentachloro-	kg	3.46E-11		3.46E-11
Benzo(a)anthracene	kg	1.39E-08	5.41E-11	1.38E-08
Benzo(a)pyrene	kg	5.51E-08	2.57E-11	5.51E-08
Benzo(b,j,k)fluoranthene	kg	1.91E-08	7.44E-11	1.90E-08
Benzo(ghi)perylene	kg	4.69E-09	1.83E-11	4.67E-09
Benzyl chloride	kg	1.07E-06	1.84E-08	1.05E-06
Beryllium	kg	1.43E-05	1.88E-08	1.43E-05
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	kg	2.13E-03		2.13E-03
Biphenyl	kg	2.95E-07	1.15E-09	2.94E-07
Boron	kg	2.32E-05		2.32E-05
Boron trifluoride	kg	4.19E-16		4.19E-16
Bromine	kg	2.41E-06		2.41E-06
Bromoform	kg	5.95E-08	1.03E-09	5.84E-08

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Bromoxynil	kg	7.90E-10		7.90E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	7.10E-02	1.97E-03	6.90E-02
Butadiene	kg	1.65E-05	1.60E-05	4.78E-07
Butane	kg	5.41E-05		5.41E-05
Butene	kg	1.65E-04		1.65E-04
Butyrolactone	kg	1.57E-11		1.57E-11
Cadmium	kg	5.16E-05	9.54E-08	5.15E-05
Calcium	kg	1.71E-05		1.71E-05
Carbofuran	kg	6.76E-10		6.76E-10
Carbon dioxide	kg	4.91E+01	3.41E+00	4.57E+01
Carbon dioxide, biogenic	kg	1.79E+03	6.59E-02	1.79E+03
Carbon dioxide, fossil	kg	1.65E+03	7.68E+01	1.57E+03
Carbon dioxide, land transformation	kg	3.11E-04		3.11E-04
Carbon disulfide	kg	1.62E-05	3.42E-09	1.62E-05
Carbon monoxide	kg	5.70E+00	2.40E-04	5.70E+00
Carbon monoxide, biogenic	kg	2.01E-05		2.01E-05
Carbon monoxide, fossil	kg	3.19E+00	6.85E-01	2.51E+00
Carbon-14	Bq	6.19E+01		6.19E+01
Cerium-141	Bq	2.12E-05		2.12E-05
Cesium-134	Bq	1.02E-06		1.02E-06
Cesium-137	Bq	1.80E-05		1.80E-05
Chloramine	kg	1.81E-05		1.81E-05
Chloride	kg	5.06E-09	5.05E-11	5.01E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	3.35E-06		3.35E-06
Chlorine	kg	1.24E-02		1.24E-02
Chloroacetic acid	kg	9.12E-05		9.12E-05
Chloroform	kg	3.10E-04	1.55E-09	3.10E-04
Chlorosilane, trimethyl-	kg	3.55E-10		3.55E-10
Chlorosulfonic acid	kg	1.38E-05		1.38E-05
Chlorpyrifos	kg	5.20E-09		5.20E-09
Chromium	kg	2.49E-04	2.73E-07	2.49E-04
Chromium VI	kg	1.39E-05	5.34E-08	1.38E-05
Chromium-51	Bq	1.36E-06		1.36E-06
Chrysene	kg	1.74E-08	6.76E-11	1.73E-08

Substance	**Unit**	**Total**	**Forestry Operations**	**I-Joists Production (Wrapped up)**
Cobalt	kg	8.18E-05	4.82E-07	8.13E-05
Cobalt-58	Bq	1.90E-06		1.90E-06
Cobalt-60	Bq	1.67E-05		1.67E-05
Copper	kg	8.72E-06	4.96E-09	8.72E-06
Cumene	kg	6.17E-02	1.39E-10	6.17E-02
Cyanazine	kg	7.79E-10		7.79E-10
Cyanide	kg	2.14E-05	6.58E-08	2.13E-05
Cyanoacetic acid	kg	1.13E-05		1.13E-05
Dicamba	kg	4.59E-09		4.59E-09
Diethylamine	kg	3.55E-05		3.55E-05
Dimethenamid	kg	1.08E-08		1.08E-08
Dimethyl ether	kg	4.40E-04		4.40E-04
Dimethyl malonate	kg	1.41E-05		1.41E-05
Dinitrogen monoxide	kg	3.45E-02	2.00E-02	1.45E-02
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.51E-05		1.51E-05
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.22E-10	1.57E-12	1.21E-10
Dipropylamine	kg	1.59E-05		1.59E-05
Dipropylthiocarbamic acid S-ethyl ester	kg	7.43E-09		7.43E-09
D-limonene	kg	6.17E-04		6.17E-04
Ethane	kg	1.70E-04		1.70E-04
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	7.57E-07		7.57E-07
Ethane, 1,1,1-trichloro-, HCFC-140	kg	4.43E-08	2.71E-09	4.16E-08
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	1.25E-10		1.25E-10
Ethane, 1,1-difluoro-, HFC-152a	kg	1.85E-09		1.85E-09
Ethane, 1,2-dibromo-	kg	1.83E-09	3.16E-11	1.80E-09
Ethane, 1,2-dichloro-	kg	6.20E-05	1.05E-09	6.20E-05
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	2.58E-08		2.58E-08
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	kg	6.40E-07		6.40E-07
Ethane, chloro-	kg	6.40E-08	1.11E-09	6.29E-08
Ethane, hexafluoro-, HFC-116	kg	9.56E-08		9.56E-08
Ethanol	kg	7.20E-05		7.20E-05
Ethene	kg	1.31E-04		1.31E-04
Ethene, chloro-	kg	7.94E-08		7.94E-08
Ethene, tetrachloro-	kg	7.64E-06	3.44E-08	7.61E-06
Ethene, trichloro-	kg	6.04E-12		6.04E-12
Ethyl acetate	kg	5.01E-06		5.01E-06
Ethyl cellulose	kg	9.54E-09		9.54E-09

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Ethylamine	kg	3.28E-05		3.28E-05
Ethylene diamine	kg	3.45E-12		3.45E-12
Ethylene dibromide	kg	2.94E-08		2.94E-08
Ethylene oxide	kg	6.41E-07		6.41E-07
Ethyne	kg	6.10E-05		6.10E-05
Fluoranthene	kg	1.23E-07	4.80E-10	1.23E-07
Fluorene	kg	1.58E-07	6.15E-10	1.57E-07
Fluoride	kg	1.20E-04	3.96E-05	8.02E-05
Fluorine	kg	1.87E-06		1.87E-06
Fluosilicic acid	kg	1.02E-07		1.02E-07
Formaldehyde	kg	1.85E-01	4.88E-04	1.84E-01
Formamide	kg	2.52E-13		2.52E-13
Formic acid	kg	7.29E-08		7.29E-08
Furan	kg	1.99E-08	2.96E-12	1.99E-08
Glyphosate	kg	9.75E-09		9.75E-09
Heat, waste	MJ	1.66E+02		1.66E+02
Helium	kg	1.04E-06		1.04E-06
Heptane	kg	4.98E-06		4.98E-06
Hexane	kg	1.74E-05	1.76E-09	1.74E-05
Hydrazine, methyl-	kg	2.59E-07	4.47E-09	2.55E-07
Hydrocarbons, aliphatic, alkanes, cyclic	kg	1.81E-06		1.81E-06
Hydrocarbons, aliphatic, alkanes, unspecified	kg	7.52E-04		7.52E-04
Hydrocarbons, aliphatic, unsaturated	kg	2.00E-05		2.00E-05
Hydrocarbons, aromatic	kg	2.05E-05		2.05E-05
Hydrocarbons, chlorinated	kg	2.95E-05		2.95E-05
Hydrocarbons, unspecified	kg	3.45E-03	1.08E-05	3.44E-03
Hydrogen	kg	1.28E-03		1.28E-03
Hydrogen chloride	kg	3.82E-01	8.48E-04	3.81E-01
Hydrogen fluoride	kg	2.60E-02	1.00E-04	2.59E-02
Hydrogen peroxide	kg	7.07E-09		7.07E-09
Hydrogen sulfide	kg	3.33E-05	1.63E-12	3.33E-05
Hydrogen-3, Tritium	Bq	3.50E+02		3.50E+02
Indeno(1,2,3-cd)pyrene	kg	1.06E-08	4.13E-11	1.05E-08
Iodine	kg	1.30E-06		1.30E-06
Iodine-129	Bq	6.15E-02		6.15E-02
Iodine-131	Bq	3.06E+00		3.06E+00

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Iodine-133	Bq	1.84E-04		1.84E-04
Iodine-135	Bq	1.71E-04		1.71E-04
Iron	kg	6.78E-05		6.78E-05
Isocyanic acid	kg	2.96E-08		2.96E-08
Isophorone	kg	8.84E-07	1.53E-08	8.69E-07
Isoprene	kg	1.66E-01	1.66E-03	1.64E-01
Isopropylamine	kg	2.05E-05		2.05E-05
Kerosene	kg	2.87E-04	8.98E-07	2.86E-04
Krypton-85	Bq	2.43E+01		2.43E+01
Krypton-85m	Bq	1.65E+00		1.65E+00
Krypton-87	Bq	5.74E-01		5.74E-01
Krypton-88	Bq	6.01E-01		6.01E-01
Krypton-89	Bq	1.77E-01		1.77E-01
Lactic acid	kg	1.25E-05		1.25E-05
Lanthanum-140	Bq	7.49E-06		7.49E-06
Lead	kg	5.29E-04	4.94E-07	5.29E-04
Lead-210	Bq	5.57E-01		5.57E-01
Magnesium	kg	1.92E-03	7.44E-06	1.92E-03
Manganese	kg	1.46E-02	5.49E-07	1.46E-02
Manganese-54	Bq	6.97E-07		6.97E-07
MCPA	kg	6.10E-11		6.10E-11
Mercaptans, unspecified	kg	3.31E-04	5.71E-06	3.25E-04
Mercury	kg	5.40E-05	1.06E-07	5.39E-05
Metals, unspecified	kg	3.88E-01	1.87E-13	3.88E-01
Methacrylic acid	kg	2.68E-09		2.68E-09
Methacrylic acid, methyl ester	kg	2.75E-08	5.26E-10	2.70E-08
Methane	kg	4.62E+00	1.59E-01	4.46E+00
Methane, biogenic	kg	1.62E-04		1.62E-04
Methane, bromo-, Halon 1001	kg	2.44E-07	4.21E-09	2.40E-07
Methane, bromochlorodifluoro-, Halon 1211	kg	4.15E-08		4.15E-08
Methane, bromotrifluoro-, Halon 1301	kg	1.33E-08		1.33E-08
Methane, chlorodifluoro-, HCFC-22	kg	8.42E-06		8.42E-06
Methane, chlorotrifluoro-, CFC-13	kg	1.51E-07		1.51E-07
Methane, dichloro-, HCC-30	kg	2.72E-03	5.53E-07	2.72E-03
Methane, dichlorodifluoro-, CFC-12	kg	5.97E-07	2.70E-09	5.94E-07
Methane, dichlorofluoro-, HCFC-21	kg	8.38E-13		8.38E-13

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Methane, fossil	kg	6.40E-01	1.62E-02	6.24E-01
Methane, monochloro-, R-40	kg	8.08E-07	1.39E-08	7.94E-07
Methane, tetrachloro-, CFC-10	kg	3.40E-05	2.70E-10	3.40E-05
Methane, tetrafluoro-, CFC-14	kg	7.83E-07		7.83E-07
Methane, trichlorofluoro-, CFC-11	kg	1.36E-12		1.36E-12
Methane, trifluoro-, HFC-23	kg	2.67E-10		2.67E-10
Methanesulfonic acid	kg	1.14E-05		1.14E-05
Methanol	kg	7.01E-01	x	7.01E-01
Methyl acetate	kg	6.70E-06		6.70E-06
Methyl acrylate	kg	2.98E-09		2.98E-09
Methyl amine	kg	3.49E-06		3.49E-06
Methyl borate	kg	1.16E-06		1.16E-06
Methyl ethyl ketone	kg	4.51E-05	1.03E-08	4.51E-05
Methyl formate	kg	1.16E-11		1.16E-11
Methyl lactate	kg	1.37E-05		1.37E-05
Methyl methacrylate	kg	3.24E-10		3.24E-10
Methylene diisocyanate	kg	1.96E-04		1.96E-04
Metolachlor	kg	3.58E-08		3.58E-08
Metribuzin	kg	1.66E-10		1.66E-10
Molybdenum	kg	1.47E-07		1.47E-07
Monoethanolamine	kg	3.87E-04		3.87E-04
m-Xylene	kg	6.59E-08		6.59E-08
Naphthalene	kg	8.96E-04	1.03E-07	8.96E-04
Nickel	kg	4.33E-04	6.04E-06	4.27E-04
Nickel compounds	kg	8.26E-06		8.26E-06
Niobium-95	Bq	8.28E-08		8.28E-08
Nitrate	kg	3.35E-07		3.35E-07
Nitrobenzene	kg	1.18E-04		1.18E-04
Nitrogen oxides	kg	8.44E+00	1.37E+00	7.07E+00
Nitrogen, total	kg	7.70E-04	7.70E-04	4.38E-09
Nitrous oxide	kg	8.13E-06		8.13E-06
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	4.52E-01	4.60E-02	4.06E-01
N-Nitrodimethylamine	kg	1.14E-02		1.14E-02
Noble gases, radioactive, unspecified	Bq	5.91E+05		5.91E+05
Organic acids	kg	2.20E-06	6.89E-09	2.19E-06
Organic substances, unspecified	kg	5.73E-03	4.20E-06	5.73E-03

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Ozone	kg	2.14E-05		2.14E-05
PAH, polycyclic aromatic hydrocarbons	kg	7.07E-05	6.87E-05	1.93E-06
Paraquat	kg	7.25E-10		7.25E-10
Parathion, methyl	kg	5.48E-10		5.48E-10
Particulates	kg	2.19E-04		2.19E-04
Particulates, < 10 um	kg	2.01E-02		2.01E-02
Particulates, < 2.5 um	kg	2.06E+00	x	2.06E+00
Particulates, > 10 um	kg	2.28E-03		2.28E-03
Particulates, > 2.5 um, and < 10um	kg	4.69E+00	4.21E-02	4.64E+00
Particulates, unspecified	kg	2.68E+00	9.46E-03	2.67E+00
Pendimethalin	kg	3.73E-09		3.73E-09
Pentane	kg	6.19E-05		6.19E-05
Permethrin	kg	3.35E-10		3.35E-10
PFC (perfluorocarbons)	kg	8.26E-05		8.26E-05
Phenanthrene	kg	4.69E-07	1.83E-09	4.67E-07
Phenol	kg	3.09E-02	4.21E-10	3.09E-02
Phenol, 2,4-dichloro-	kg	1.81E-05		1.81E-05
Phenol, pentachloro-	kg	1.65E-08		1.65E-08
Phenols, unspecified	kg	4.73E-04	2.80E-07	4.73E-04
Phorate	kg	1.72E-10		1.72E-10
Phosphate	kg	1.76E-05	1.76E-05	
Phosphine	kg	2.27E-12		2.27E-12
Phosphorus	kg	7.99E-06		7.99E-06
Phthalate, diisooctyl-	kg	9.79E-09		9.79E-09
Phthalate, dioctyl-	kg	1.02E-07	1.92E-09	9.96E-08
Platinum	kg	8.89E-13		8.89E-13
Plutonium-238	Bq	8.39E-09		8.39E-09
Plutonium-alpha	Bq	1.92E-08		1.92E-08
Polonium-210	Bq	9.32E-01		9.32E-01
Polychlorinated biphenyls	kg	4.76E-10		4.76E-10
Polycyclic organic matter, unspecified	kg	3.84E-07		3.84E-07
Potassium	kg	3.74E-03		3.74E-03
Potassium-40	Bq	1.17E-01		1.17E-01
Propanal	kg	1.98E-05	1.00E-08	1.98E-05
Propane	kg	8.79E-05		8.79E-05
Propene	kg	2.39E-02	1.06E-03	2.29E-02

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Propionic acid	kg	5.73E-05		5.73E-05
Propylamine	kg	7.98E-14		7.98E-14
Propylene oxide	kg	1.30E-05		1.30E-05
Protactinium-234	Bq	8.49E-03		8.49E-03
Pyrene	kg	5.73E-08	2.23E-10	5.70E-08
Radioactive species, other beta emitters	Bq	1.88E-01		1.88E-01
Radioactive species, unspecified	Bq	9.74E+06	3.68E+04	9.70E+06
Radionuclides (Including Radon)	kg	1.60E-02	5.02E-05	1.60E-02
Radium-226	Bq	5.60E-01		5.60E-01
Radium-228	Bq	2.42E-01		2.42E-01
Radon-220	Bq	3.31E+00		3.31E+00
Radon-222	Bq	1.12E+06		1.12E+06
Ruthenium-103	Bq	1.82E-08		1.82E-08
Scandium	kg	1.07E-07		1.07E-07
Selenium	kg	2.55E-04	9.39E-07	2.54E-04
Silicon	kg	6.02E-05		6.02E-05
Silicon tetrafluoride	kg	2.86E-10		2.86E-10
Silver	kg	4.60E-09		4.60E-09
Silver-110	Bq	1.80E-07		1.80E-07
Simazine	kg	2.35E-09		2.35E-09
Sodium	kg	9.30E-05		9.30E-05
Sodium chlorate	kg	3.13E-09		3.13E-09
Sodium dichromate	kg	1.10E-08		1.10E-08
Sodium formate	kg	3.10E-10		3.10E-10
Sodium hydroxide	kg	2.63E-08		2.63E-08
Strontium	kg	1.04E-06		1.04E-06
Styrene	kg	8.09E-08	6.58E-10	8.03E-08
Sulfate	kg	1.75E-03		1.75E-03
Sulfur	kg	1.10E-05		1.10E-05
Sulfur dioxide	kg	1.07E+01	1.76E-01	1.05E+01
Sulfur hexafluoride	kg	3.17E-07		3.17E-07
Sulfur oxides	kg	8.25E-01	7.63E-02	7.49E-01
Sulfur trioxide	kg	6.75E-04		6.75E-04
Sulfur, total reduced	kg	2.65E-04		2.65E-04
Sulfuric acid	kg	8.81E-08		8.81E-08
Sulfuric acid, dimethyl ester	kg	7.32E-08	1.26E-09	7.19E-08

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Tar	kg	5.69E-09	5.68E-11	5.63E-09
t-Butyl methyl ether	kg	5.50E-08	9.21E-10	5.41E-08
t-Butylamine	kg	1.98E-05		1.98E-05
Terbufos	kg	5.86E-09		5.86E-09
Terpenes	kg	8.35E-09		8.35E-09
Thallium	kg	5.67E-09		5.67E-09
Thorium	kg	6.39E-09		6.39E-09
Thorium-228	Bq	3.30E-02		3.30E-02
Thorium-230	Bq	1.92E-01		1.92E-01
Thorium-232	Bq	3.71E-02		3.71E-02
Thorium-234	Bq	8.49E-03		8.49E-03
Tin	kg	1.40E-07		1.40E-07
Titanium	kg	3.14E-06		3.14E-06
TOC, Total Organic Carbon	kg	4.98E-02		4.98E-02
Toluene	kg	2.43E-03	1.67E-04	2.27E-03
Toluene, 2,4-dinitro-	kg	4.27E-10	7.37E-12	4.20E-10
Toluene, 2-chloro-	kg	5.42E-05		5.42E-05
Trimethylamine	kg	1.29E-14		1.29E-14
Tungsten	kg	1.16E-08		1.16E-08
Uranium	kg	8.42E-09		8.42E-09
Uranium alpha	Bq	4.61E-01		4.61E-01
Uranium-234	Bq	2.59E-01		2.59E-01
Uranium-235	Bq	4.79E-03		4.79E-03
Uranium-238	Bq	3.49E-01		3.49E-01
Vanadium	kg	8.86E-06		8.86E-06
Vinyl acetate	kg	1.16E-08	2.00E-10	1.14E-08
VOC, volatile organic compounds	kg	3.03E+00	4.04E-02	2.98E+00
Water	kg	1.74E-04		1.74E-04
Xenon-131m	Bq	2.71E+00		2.71E+00
Xenon-133	Bq	8.90E+01		8.90E+01
Xenon-133m	Bq	3.12E-01		3.12E-01
Xenon-135	Bq	3.63E+01		3.63E+01
Xenon-135m	Bq	2.17E+01		2.17E+01
Xenon-137	Bq	4.85E-01		4.85E-01
Xenon-138	Bq	4.05E+00		4.05E+00

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Xylene	kg	1.23E-03	1.17E-04	1.12E-03
Zinc	kg	4.59E-05	1.42E-05	3.17E-05
Zinc-65	Bq	3.48E-06		3.48E-06
Zirconium	kg	1.28E-09		1.28E-09
Zirconium-95	Bq	3.40E-06		3.40E-06

13.2 Water Emissions

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

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
1,4-Butanediol	kg	2.23E-05		2.23E-05
1-Butanol	kg	5.05E-05		5.05E-05
1-Pentanol	kg	3.31E-13		3.31E-13
1-Pentene	kg	2.50E-13		2.50E-13
1-Propanol	kg	6.32E-13		6.32E-13
2,4-D	kg	1.40E-10		1.40E-10
2-Aminopropanol	kg	2.86E-05		2.86E-05
2-Hexanone	kg	9.42E-06	7.06E-07	8.71E-06
2-Methyl-1-propanol	kg	2.59E-05		2.59E-05
2-Methyl-2-butene	kg	5.54E-17		5.54E-17
2-Propanol	kg	1.14E-04		1.14E-04
4-Methyl-2-pentanone	kg	6.05E-06	4.54E-07	5.60E-06
Acenaphthene	kg	1.47E-10		1.47E-10
Acenaphthylene	kg	9.17E-12		9.17E-12
Acetaldehyde	kg	8.15E-04		8.15E-04
Acetic acid	kg	3.07E-03		3.07E-03
Acetochlor	kg	1.94E-09		1.94E-09
Acetone	kg	7.59E-05	1.08E-06	7.48E-05
Acetonitrile	kg	9.43E-06		9.43E-06
Acetyl chloride	kg	2.60E-13		2.60E-13
Acid as H+	kg	5.91E-04		5.91E-04
Acidity, unspecified	kg	5.65E-06		5.65E-06
Acids, unspecified	kg	1.24E-04	1.06E-09	1.24E-04
Acrylate, ion	kg	6.22E-09		6.22E-09
Actinides, radioactive, unspecified	Bq	9.99E-02		9.99E-02
Alachlor	kg	1.91E-10		1.91E-10
Aluminium	kg	4.44E-02		4.44E-02
Aluminum	kg	3.06E-02	7.90E-03	2.27E-02
Ammonia	kg	2.22E-02	1.89E-03	2.03E-02
Ammonia, as N	kg	5.34E-08	5.33E-10	5.28E-08
Ammonium, ion	kg	1.20E-02	4.01E-07	1.20E-02
Aniline	kg	1.79E-04		1.79E-04
Antimony	kg	4.97E-05	4.92E-06	4.47E-05
Antimony-122	Bq	5.20E-05		5.20E-05

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Antimony-124	Bq	1.71E-02		1.71E-02
Antimony-125	Bq	1.57E-02		1.57E-02
AOX, Adsorbable Organic Halogen as Cl	kg	2.39E-06		2.39E-06
Arsenic, ion	kg	4.02E-04	6.15E-05	3.40E-04
Atrazine	kg	3.79E-09		3.79E-09
Barite	kg	2.01E-04		2.01E-04
Barium	kg	9.10E-01	1.09E-01	8.01E-01
Barium-140	Bq	2.28E-04		2.28E-04
Bentazone	kg	1.55E-11		1.55E-11
Benzene	kg	1.08E-01	1.81E-04	1.08E-01
Benzene, 1,2-dichloro-	kg	2.70E-04		2.70E-04
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.44E-07	1.08E-08	1.33E-07
Benzene, chloro-	kg	4.01E-03		4.01E-03
Benzene, ethyl-	kg	1.37E-04	1.02E-05	1.26E-04
Benzene, pentamethyl-	kg	1.08E-07	8.10E-09	9.98E-08
Benzenes, alkylated, unspecified	kg	3.57E-05	4.32E-06	3.13E-05
Benzoic acid	kg	1.46E-03	1.10E-04	1.35E-03
Beryllium	kg	2.12E-05	1.54E-06	1.96E-05
Biphenyl	kg	2.31E-06	2.80E-07	2.03E-06
BOD5, Biological Oxygen Demand	kg	1.28E+00	1.96E-02	1.26E+00
Borate	kg	1.63E-03		1.63E-03
Boron	kg	4.75E-03	3.39E-04	4.41E-03
Bromate	kg	2.21E-04		2.21E-04
Bromide	kg	3.50E-01	2.32E-02	3.27E-01
Bromine	kg	2.50E-05		2.50E-05
Bromoxynil	kg	2.04E-11		2.04E-11
Butene	kg	8.16E-05		8.16E-05
Butyl acetate	kg	2.74E-06		2.74E-06
Butyrolactone	kg	3.78E-11		3.78E-11
Cadmium, ion	kg	6.89E-05	1.52E-05	5.37E-05
Calcium, ion	kg	4.70E+00	3.47E-01	4.35E+00
Carbofuran	kg	2.90E-11		2.90E-11
Carbon disulfide	kg	1.54E-11		1.54E-11
Carbonate	kg	1.96E-02		1.96E-02
Carboxylic acids, unspecified	kg	1.03E-04		1.03E-04
Cerium-141	Bq	9.12E-05		9.12E-05
Cerium-144	Bq	2.77E-05		2.77E-05
Cesium	kg	2.36E-08		2.36E-08

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Cesium-134	Bq	1.38E-02		1.38E-02
Cesium-136	Bq	1.62E-05		1.62E-05
Cesium-137	Bq	1.15E+01		1.15E+01
CFCs, unspecified	kg	2.50E-07		2.50E-07
Chloramine	kg	2.72E-04		2.72E-04
Chlorate	kg	1.69E-03		1.69E-03
Chloride	kg	5.29E+01	3.90E+00	4.89E+01
Chlorinated solvents, unspecified	kg	1.16E-06		1.16E-06
Chlorine	kg	9.42E-08		9.42E-08
Chloroacetic acid	kg	7.32E-03		7.32E-03
Chloroacetyl chloride	kg	3.82E-05		3.82E-05
Chloroform	kg	3.35E-05		3.35E-05
Chlorosulfonic acid	kg	3.43E-05		3.43E-05
Chlorpyrifos	kg	2.23E-10		2.23E-10
Chromate	kg	3.32E-11		3.32E-11
Chromium	kg	1.32E-03	2.47E-04	1.07E-03
Chromium VI	kg	3.22E-05	8.33E-07	3.14E-05
Chromium, ion	kg	5.45E-04	2.57E-05	5.19E-04
Chromium-51	Bq	2.39E-02		2.39E-02
Cobalt	kg	9.37E-05	2.40E-06	9.13E-05
Cobalt-57	Bq	5.14E-04		5.14E-04
Cobalt-58	Bq	1.56E-01		1.56E-01
Cobalt-60	Bq	1.26E-01		1.26E-01
COD, Chemical Oxygen Demand	kg	1.53E+00	3.63E-02	1.50E+00
Copper	kg	8.65E-07		8.65E-07
Copper, ion	kg	4.91E-04		4.40E-04
Cumene	kg	1.48E-01		1.48E-01
Cyanazine	kg	3.34E-11		3.34E-11
Cyanide	kg	3.93E-05	7.81E-09	3.93E-05
Decane	kg	4.20E-05	3.15E-06	3.89E-05
Detergent, oil	kg	1.35E-03	9.42E-05	1.25E-03
Dibenzofuran	kg	2.74E-07	2.06E-08	2.53E-07
Dibenzothiophene	kg	2.29E-07	1.75E-08	2.11E-07
Dicamba	kg	1.97E-10		1.97E-10
Dichromate	kg	2.41E-08		2.41E-08
Diethylamine	kg	8.52E-05		8.52E-05
Dimethenamid	kg	4.65E-10		4.65E-10
Dimethylamine	kg	3.75E-04		3.75E-04

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Dipropylamine	kg	3.81E-05		3.81E-05
Dipropylthiocarbamic acid S-ethyl ester	kg	1.92E-10		1.92E-10
Dissolved organics	kg	3.78E-04		3.78E-04
Dissolved solids	kg	6.05E-01		6.05E-01
Disulfoton	kg	1.15E-11		1.15E-11
Diuron	kg	3.22E-12		3.22E-12
DOC, Dissolved Organic Carbon	kg	2.85E-01	3.26E-12	2.85E-01
Docosane	kg	1.54E-06	1.16E-07	1.43E-06
Dodecane	kg	7.98E-05	5.98E-06	7.38E-05
Eicosane	kg	2.20E-05	1.65E-06	2.03E-05
Ethane, 1,2-dichloro-	kg	1.48E-04		1.48E-04
Ethanol	kg	2.59E-03		2.59E-03
Ethene	kg	2.35E-05		2.35E-05
Ethene, chloro-	kg	4.90E-09		4.90E-09
Ethyl acetate	kg	1.17E-07		1.17E-07
Ethylamine	kg	7.88E-05		7.88E-05
Ethylene diamine	kg	8.29E-12		8.29E-12
Ethylene oxide	kg	1.28E-04		1.28E-04
Fluorene	kg	2.42E-08		2.42E-08
Fluorene, 1-methyl-	kg	1.64E-07	1.23E-08	1.52E-07
Fluorenes, alkylated, unspecified	kg	2.07E-06	2.50E-07	1.82E-06
Fluoride	kg	1.03E-01	9.77E-02	4.86E-03
Fluorine	kg	1.05E-06	1.25E-07	9.30E-07
Fluosilicic acid	kg	1.83E-07		1.83E-07
Formaldehyde	kg	1.52E-03		1.52E-03
Formamide	kg	6.05E-13		6.05E-13
Formate	kg	6.09E-03		6.09E-03
Formic acid	kg	1.75E-13		1.75E-13
Furan	kg	9.16E-09		9.16E-09
Glutaraldehyde	kg	2.48E-08		2.48E-08
Glyphosate	kg	4.18E-10		4.18E-10
Heat, waste	MJ	3.44E+00		3.44E+00
Hexadecane	kg	8.71E-05	6.53E-06	8.05E-05
Hexanoic acid	kg	3.03E-04	2.27E-05	2.80E-04
Hydrocarbons, aliphatic, alkanes, unspecified	kg	3.06E-06		3.06E-06
Hydrocarbons, aliphatic, unsaturated	kg	3.21E-05		3.21E-05
Hydrocarbons, aromatic	kg	1.28E-05		1.28E-05
Hydrocarbons, unspecified	kg	3.44E-05	4.08E-12	3.44E-05

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Hydrogen peroxide	kg	1.17E-06		1.17E-06
Hydrogen sulfide	kg	1.81E-06		1.81E-06
Hydrogen-3, Tritium	Bq	2.63E+04		2.63E+04
Hydroxide	kg	1.53E-05		1.53E-05
Hypochlorite	kg	1.40E-06		1.40E-06
Iodide	kg	1.62E-02		1.62E-02
Iodine-131	Bq	3.20E-03		3.20E-03
Iodine-133	Bq	1.43E-04		1.43E-04
Iron	kg	1.58E-01	1.62E-02	1.42E-01
Iron, ion	kg	7.56E-03		7.56E-03
Iron-59	Bq	3.93E-05		3.93E-05
Isopropylamine	kg	4.92E-05		4.92E-05
Lactic acid	kg	2.99E-05		2.99E-05
Lanthanum-140	Bq	2.43E-04		2.43E-04
Lead	kg	6.44E-04	7.33E-05	5.71E-04
Lead-210	Bq	2.52E-01		2.52E-01
Lead-210/kg	kg	1.50E-13	1.12E-14	1.39E-13
Lithium, ion	kg	9.82E-01	2.73E-02	9.55E-01
Magnesium	kg	9.31E-01	6.79E-02	8.63E-01
Manganese	kg	6.96E-03	1.20E-04	6.84E-03
Manganese-54	Bq	9.59E-03		9.59E-03
MCPA	kg	2.62E-12		2.62E-12
Mercury	kg	2.19E-06	5.81E-07	1.61E-06
Metallic ions, unspecified	kg	7.96E-08	4.98E-11	7.95E-08
Methane, dichloro-, HCC-30	kg	4.20E-05		4.20E-05
Methane, monochloro-, R-40	kg	5.80E-08	4.35E-09	5.36E-08
Methanol	kg	3.83E-04		3.83E-04
Methyl acetate	kg	1.61E-05		1.61E-05
Methyl acrylate	kg	5.82E-08		5.82E-08
Methyl amine	kg	8.38E-06		8.38E-06
Methyl ethyl ketone	kg	1.16E-07	8.70E-09	1.07E-07
Methyl formate	kg	4.64E-12		4.64E-12
Metolachlor	kg	1.54E-09		1.54E-09
Metribuzin	kg	7.12E-12		7.12E-12
Molybdenum	kg	4.83E-05	2.49E-06	4.59E-05
Molybdenum-99	Bq	8.37E-05		8.37E-05
m-Xylene	kg	4.37E-05	3.28E-06	4.04E-05
Naphthalene	kg	2.62E-05	1.97E-06	2.43E-05

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Naphthalene, 2-methyl-	kg	2.28E-05	1.71E-06	2.11E-05
Naphthalenes, alkylated, unspecified	kg	5.84E-07	7.07E-08	5.14E-07
n-Hexacosane	kg	9.61E-07	7.22E-08	8.89E-07
Nickel	kg	3.22E-04	4.37E-05	2.78E-04
Nickel, ion	kg	2.26E-04		2.26E-04
Niobium-95	Bq	1.36E-03		1.36E-03
Nitrate	kg	1.09E-02	3.57E-13	1.09E-02
Nitrate compounds	kg	1.61E-09	1.44E-11	1.60E-09
Nitric acid	kg	3.23E-06	3.22E-08	3.20E-06
Nitrite	kg	4.00E-06		4.00E-06
Nitrobenzene	kg	4.75E-04		4.75E-04
Nitrogen	kg	6.29E-05		6.29E-05
Nitrogen, organic bound	kg	9.39E-06		9.39E-06
Nitrogen, total	kg	5.54E-04	9.98E-07	5.53E-04
o-Cresol	kg	4.15E-05	3.11E-06	3.84E-05
Octadecane	kg	2.15E-05	1.61E-06	1.99E-05
Oils, unspecified	kg	3.38E-02	2.41E-03	3.14E-02
Organic substances, unspecified	kg	1.82E-07		1.82E-07
o-Xylene	kg	5.11E-08		5.11E-08
PAH, polycyclic aromatic hydrocarbons	kg	1.47E-07		1.47E-07
Paraquat	kg	3.11E-11		3.11E-11
Parathion, methyl	kg	2.35E-11		2.35E-11
p-Cresol	kg	4.48E-05	3.36E-06	4.14E-05
Pendimethalin	kg	1.60E-10		1.60E-10
Permethrin	kg	1.44E-11		1.44E-11
Phenanthrene	kg	2.70E-07	2.69E-08	2.44E-07
Phenanthrenes, alkylated, unspecified	kg	2.42E-07	2.93E-08	2.13E-07
Phenol	kg	1.01E-03	3.69E-05	9.75E-04
Phenol, 2,4-dimethyl-	kg	4.04E-05	3.03E-06	3.74E-05
Phenols, unspecified	kg	4.47E-04	1.65E-05	4.30E-04
Phorate	kg	4.44E-12		4.44E-12
Phosphate	kg	8.27E-02	7.36E-02	9.10E-03
Phosphorus	kg	2.29E-04		2.29E-04
Phosphorus compounds, unspecified	kg	8.23E-08		8.23E-08
Phosphorus, total	kg	3.02E-04		3.02E-04
Polonium-210	Bq	3.10E-01		3.10E-01
Potassium, ion	kg	2.14E-02		2.14E-02
Potassium-40	Bq	1.92E-01		1.92E-01

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Process solvents, unspecified	kg	9.16E-07		9.16E-07
Propanal	kg	4.79E-13		4.79E-13
Propene	kg	5.51E-02		5.51E-02
Propionic acid	kg	1.36E-04		1.36E-04
Propylamine	kg	1.91E-13		1.91E-13
Propylene oxide	kg	2.34E-05		2.34E-05
Protactinium-234	Bq	1.57E-01		1.57E-01
p-Xylene	kg	5.11E-08		5.11E-08
Radioactive species, alpha emitters	Bq	9.06E-02		9.06E-02
Radioactive species, Nuclides, unspecified	Bq	1.86E+04	5.82E+01	1.86E+04
Radium-224	Bq	1.18E+00		1.18E+00
Radium-226	Bq	9.94E+01		9.94E+01
Radium-226/kg	kg	5.21E-11	3.91E-12	4.82E-11
Radium-228	Bq	2.36E+00		2.36E+00
Radium-228/kg	kg	2.67E-13	2.00E-14	2.47E-13
Rubidium	kg	2.36E-07		2.36E-07
Ruthenium-103	Bq	1.77E-05		1.77E-05
Scandium	kg	6.54E-06		6.54E-06
Selenium	kg	6.23E-05	1.10E-06	6.12E-05
Silicon	kg	4.85E-02		4.85E-02
Silver	kg	3.02E-03	2.27E-04	2.79E-03
Silver, ion	kg	3.04E-07		3.04E-07
Silver-110	Bq	1.18E-01		1.18E-01
Simazine	kg	1.01E-10		1.01E-10
Sodium formate	kg	7.45E-10		7.45E-10
Sodium, ion	kg	1.52E+01	1.10E+00	1.41E+01
Sodium-24	Bq	6.33E-04		6.33E-04
Solids, inorganic	kg	4.84E-03	8.20E-11	4.84E-03
Solved solids	kg	6.43E+01	4.82E+00	5.94E+01
Strontium	kg	7.95E-02	5.89E-03	7.36E-02
Strontium-89	Bq	2.25E-03		2.25E-03
Strontium-90	Bq	8.45E+01		8.45E+01
Styrene	kg	5.36E-09		5.36E-09
Sulfate	kg	6.41E-01	8.69E-03	6.32E-01
Sulfide	kg	1.31E-03	4.28E-06	1.30E-03
Sulfite	kg	3.81E-06		3.81E-06
Sulfur	kg	4.70E-03	2.86E-04	4.41E-03
Sulfuric acid	kg	8.01E-09		8.01E-09

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Surfactants	kg	2.40E-06		2.40E-06
Suspended solids, inorganic	kg	7.05E-04		7.05E-04
Suspended solids, unspecified	kg	2.15E+00	2.44E-01	1.91E+00
Tar	kg	8.14E-11	8.12E-13	8.06E-11
t-Butyl methyl ether	kg	6.82E-08		6.82E-08
t-Butylamine	kg	4.74E-05		4.74E-05
Technetium-99m	Bq	1.93E-03		1.93E-03
Tellurium-123m	Bq	1.79E-03		1.79E-03
Tellurium-132	Bq	4.85E-06		4.85E-06
Terbufos	kg	1.52E-10		1.52E-10
Tetradecane	kg	3.50E-05	2.62E-06	3.23E-05
Thallium	kg	8.97E-06	1.04E-06	7.93E-06
Thorium-228	Bq	4.71E+00		4.71E+00
Thorium-230	Bq	2.14E+01		2.14E+01
Thorium-232	Bq	3.34E-02		3.34E-02
Thorium-234	Bq	1.57E-01		1.57E-01
Tin	kg	2.20E-04	2.14E-05	1.98E-04
Tin, ion	kg	4.67E-06		4.67E-06
Titanium, ion	kg	7.81E-04	7.56E-05	7.05E-04
TOC, Total Organic Carbon	kg	2.86E-01		2.86E-01
Toluene	kg	2.55E-03	1.71E-04	2.38E-03
Toluene, 2-chloro-	kg	9.53E-05		9.53E-05
Tributyltin compounds	kg	4.68E-08		4.68E-08
Triethylene glycol	kg	4.70E-07		4.70E-07
Trimethylamine	kg	3.10E-14		3.10E-14
Tungsten	kg	5.78E-06		5.78E-06
Uranium alpha	Bq	9.02E+00		9.02E+00
Uranium-234	Bq	1.88E-01		1.88E-01
Uranium-235	Bq	3.10E-01		3.10E-01
Uranium-238	Bq	5.99E-01		5.99E-01
Urea	kg	5.66E-13		5.66E-13
Vanadium	kg	3.95E-05	2.94E-06	3.66E-05
Vanadium, ion	kg	2.20E-05		2.20E-05
VOC, volatile organic compounds, unspecified origin	kg	8.64E-06		8.64E-06
Waste water/m3	m3	1.84E-03		1.84E-03
Xylene	kg	1.20E-03	9.14E-05	1.11E-03
Yttrium	kg	9.72E-06	7.29E-07	8.99E-06
Zinc	kg	1.74E-03	1.84E-04	1.56E-03

Substance	Unit	Total	Forestry Operations	I-Joists Production (Wrapped up)
Zinc, ion	kg	4.33E-04		4.33E-04
Zinc-65	Bq	8.59E-03		8.59E-03
Zirconium-95	Bq	9.95E-05		9.95E-05