Cradle to Gate Life Cycle Assessment of Oriented Strandboard Production from the Southeast

Maureen Puettmann, WoodLife Environmental Consultants, LLC
Elaine Oneil, University of Washington
Earl Kline, Oregon State University
Leonard Johnson, Professor Emeritus, University of Idaho

December 2012
Updated April 2013

1 Background

CORRIM, the Consortium for Research on Renewable Industrial Materials, has derived life cycle inventory (LCI) data for major wood products and wood production regions in the United States. The life cycle inventory data covers each stage of processing from forest regeneration to the finished product, packaged and ready for shipment. Research has covered nine major forest products including both structural and nonstructural uses and four major supply regions. In this report we focus on oriented strandboard (OSB) produced in the US Southeast (SE) region, which includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia. 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, and boiler, resin, and electrical grid data that have been developed since the original mill surveys were conducted in 1999 and 2000. The updated LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2.0 (Simapro version 4.0) (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 reports by Kline (2004, 2005) and Johnson et al. (2005). Updates in this report from the original reports include: North American resin data (Franklin 2010 and Wilson 2009), wood combustion boiler updates, and electricity grid updates (Goemans 2010), with results expressed per unit of final product (1 m^3 oriented strandboard), and an LCIA. Updates to the forestry operations report (Johnson et al. 2005) include electricity grid updates and an LCIA using the TRACI 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 OSB from manufacturers 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 OSB based on current manufacturing practices in Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia. It covers the impacts in terms of input materials, fuels, and electricity through to the outputs of product, co-products, emissions and waste (Kline 2004). The logs used for 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). The report does not consider how the wood was used which requires a comparison to the impact of substitute products.

3 Description of Product

Oriented strandboard evolved from waferboard in the late 1970s. OSB is manufactured by processing a log into strands of predetermined length, width, and uniform thickness. Oriented strandboard is an engineered structural-use panel manufactured from thin wood strands bonded together with water-resistant resins (Figure 1). It is used extensively for roof, wall, and floor sheathing in residential and commercial construction and for I-joists and rim boards. The wood strands typically have an aspect ratio (strand length divided by width) of at least three. Oriented strandboard panels are usually made up of three layers of strands, the outer faces having longer strands aligned in the long-direction of the panel and a core layer that is counter-aligned or laid randomly using the smaller strands or fines. The orientation of different layers of aligned strands gives OSB its unique characteristics, including greater bending strength and stiffness in the oriented or aligned direction. Control of strand size, orientation, and layered construction allows OSB to be engineered to suit different uses. Today, all building codes in the U.S. and Canada recognize OSB panels for the same uses as plywood on a thickness-by-thickness basis. Although OSB comes in a variety of grades and thickness, its commercial production is based on a thousand square feet (MSF) of 3/8-inch thickness equivalence (0.8849 m^3). Oriented strandboard can be made from hardwood and softwood species. In this assessment, it is assumed that OSB is made primarily from southern pine, comprised mainly of loblolly pine (*P. taeda* L.) and slash pine (*P. elliottii* Engelm.).

Figure 1 Oriented strandboard (OSB) panels.

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for OSB is one cubic meter[1] (1.0 m^3). A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building product cannot be stated (PCR 2011). For conversion of units from the US industry measure, 1.0 MSF (1000 square feet) is equal to 0.8849 m^3. All input and output data were allocated to the declared unit of product based on the mass of products and co-products in accordance with International Organization for Standardization (ISO) protocols (ISO 2006). As the analysis does not take the declared unit to the stage of being an installed building product no service life is assigned.

3.2 System Boundaries

The system boundary begins with regeneration of forest in the SE (Johnson et al. 2005) and ends with OSB packaged and ready for shipment from the manufacturing facility. The forest resources system boundary includes: planting the seedlings, forest management including site preparation on all hectares, fertilization and thinning on a subset of hectares, and final harvest. The transportation of logs from the woods to the mill is accounted for with the OSB manufacturing (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The OSB manufacturing complex is considered as a five step process: log handling and flaking, drying and screening, blending, mat formation, and pressing, finishing, and packaging (Figure 2). The manufacturing steps for OSB production were combined into one process.

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

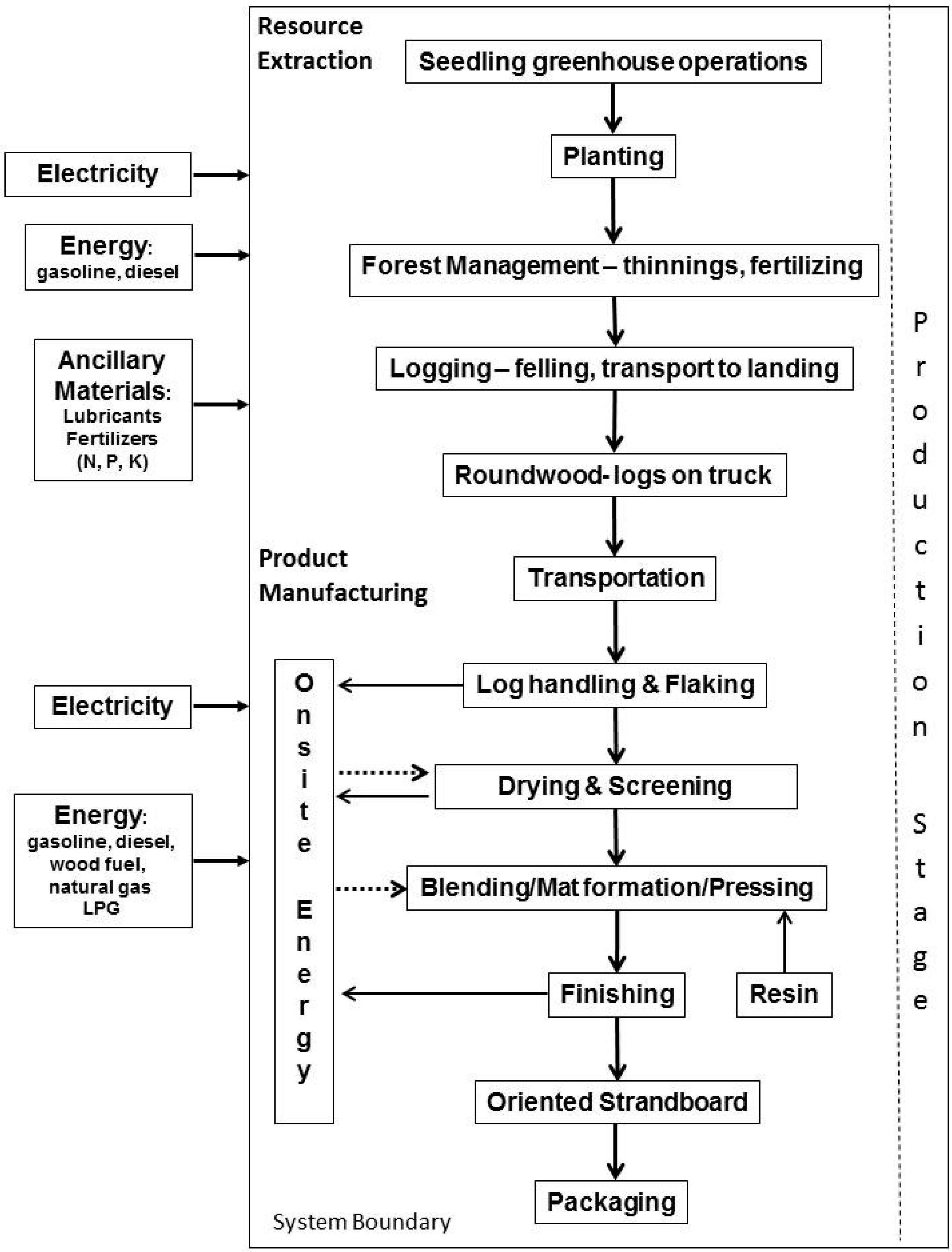

Figure 2 Cradle to gate life cycle stages for oriented strandboard, SE.

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 lumber 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 softwood 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 (Table 1). 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 1). 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 inputs 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 1 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; and loading (moving logs from the ground to haul vehicles). Although all functions are required to remove logs from the woods, the specific order and location of the operations will vary by harvesting system 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.

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 capitalintensive 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 m^3 of logs produced. Harvest equipment operational efficiencies vary between thinning and final harvest (clearcut) which affects machine productivity and therefore emissions per m^3 of logs produced. To account for this, equipment usage was allocated between thinning operations and final harvest for those management regimes that use thinning (Table 2).

Table 2 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 3. 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 typically 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 3. 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 classes produces the expected log volume recovered from the forest resource as shown in Table 3. Allocating per ha values from Table 1 resulting in a total yield of 236 m^3/ha is used to carry forward the environmental burdens of the reforestation effort on a per m^3 basis.

Table 3 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 4).

Table 4 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). Logs are transported from the forest landing to OSB mill by truck. For the SE the average haul distance for logs is 143 km (Table 5). The one-way delivery distances for logs, resin, and wax are also included in Table 5. These distances are weighted averages of the survey data. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis and a green specific gravity[2] of 0.56.

Table 5 Average delivery distance (one-way) for materials to produce OSB in the SE region.

Material delivered to mill	Delivery Distance	
Material	km	miles
Logs with bark	143	89
Methylene diphenyl diisocyanate (MDI) resin	1,328	825
Wax	1,149	714
Phenol-formaldehyde (PF) resin	932	579

3.3.2.2 Energy use and generation

To produce OSB, heat and steam are used for drying wood strands and pressing of panels. The boiler processes (energy generation) encompass fuel storage, the boiler, and steam distribution system. Wood-fired, natural gas boilers, and oil boilers were used by SE OSB manufacturers (Table 6). For the wood boiler, wood waste from various OSB operations is used for fuel.

Table 6 Boiler energy requirements for OSB manufacturing, SE

Fuel Inputs	OSB Production	Percent contribution
	MJ/kg	
Wood fuel	4171.45	81.6%
Natural gas	910.11	17.8%
DFO	30.99	0.6%
TOTAL	5122.55	

Wood fuel provides for 82% of on-site heat energy requirement. The remainder of heat energy requirement is supplemented with natural gas, and fuel oil (DFO). For wood-based fuels, the mass of wood fuel used was collected by surveys and the combustion emissions were obtained from the USLCI database (NREL 2012) (Table 7). The wood fuel, natural gas, and DFO boiler processes were based on the US Environmental Protection Agency (EPA) AP-42, Compilation of Air Pollutant Emission Factors (EPA, 1998, 1999, 2006). The AP-42 emission factors assume no emission controls and therefore likely over-estimates the impact factors for wood emissions. Electricity usage onsite required for OSB

[2] Green specific gravity uses oven dry mass and green volume of the wood resource.

processing was 206 kWh. Wood waste for fuel generated during OSB production was 200 kg/m^3(unallocated).

Table 7 Wood Boiler Process

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler	1.00	kg
Materials/fuels		
Wood fuel, self generated	1.00	kg
Emissions to air		
Acetaldehyde	7.47E-06	kg
Acrolein	3.60E-05	kg
Antimony	7.11E-08	kg
Arsenic	1.98E-07	kg
Benzene	3.78E-05	kg
Beryllium	9.90E-09	kg
Cadmium	3.69E-08	kg
Carbon dioxide, biogenic	1.76E+00	kg
Carbon monoxide	5.40E-03	kg
Chlorine	7.11E-06	kg
Chromium	1.89E-07	kg
Cobalt	5.85E-08	kg
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	7.74E-14	kg
Formaldehyde	3.96E-05	kg
Hydrogen chloride	1.71E-04	kg
Lead	4.32E-07	kg
Manganese	1.44E-05	kg
Mercury	3.15E-08	kg
Metals, unspecified	3.85E-04	kg
Methane	1.89E-04	kg
Methane, dichloro-, HCC-30	2.61E-06	kg
Naphthalene	8.73E-07	kg
Nickel	2.97E-07	kg
Nitrogen oxides	1.17E-04	kg
Nitrogen oxides	1.98E-03	kg
Particulates, > 2.5 um, and < 10um	4.50E-03	kg
Phenols, unspecified	4.59E-07	kg
Selenium	2.52E-08	kg
Sulfur oxides	2.25E-04	kg
TOC, Total Organic Carbon	3.68E-05	kg

Other sources of energy for the production of OSB include electricity, diesel, and liquid propane gas (LPG), natural gas, and wood fuel from bark, fines, and other wood residue (Table 8). The electricity is used to operate all the steps in the manufacturing of OSB. Diesel fuel use is assumed to be used by log loaders in the "log handling" process. Forklift trucks used small amounts of LPG primarily in the "finishing" process (Figure 2). Final product density of OSB was 649 kg/m^3 including resin.

Table 8 Process for 1 m^3 OSB, SE.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Oriented strandboard	1.00	m^3	72.25
Wood Fuel (produced)	199.40	kg	23.36
Bark Mulch sold	23.07	kg	2.70
Fines sold	9.23	kg	1.08
Dust/scrap sold	5.13	kg	0.60
Resources	**Value**	**Unit/m^3**	
Water, cooling, surface	36.28	L	
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	205.67	kWh	
Natural gas, combusted in industrial boiler	23.90	m^3	
Wood waste, combusted in industrial boiler	199.40	kg	
LPG	3.03	L	
Diesel	0.08	L	
Gasoline	0.03	L	
Fuel oil (DFO), combusted in industrial boiler	0.80	L	
Roundwood	1.52	m^3	
Phenol Formaldehyde resin, (PF)	21.73	kg	
Methylene diphenyl diisocyanate resin (MDI)	4.18	kg	
Wax	9.89	kg	
Transport, Roundwood	207.39	tkm	
Transport, PF Resin	33.63	tkm	
Transport, MDI Resin	9.22	tkm	
Transport, Wax	18.88	tkm	
Waste Disposal to treatment (ash and wood)	2.22	kg	
Wrapping material - Packaging	0.460	kg	
Strap Protectors - Packaging	0.200	kg	
Strapping - Packaging	0.083	kg	
Spacers - Packaging	4.672	kg	
Emissions to air	**Value**	**Unit/m^3**	
CO2 (From VOC Combustion)	12.3022	kg	
VOC	1.1174	kg	

Emissions to air	Value	Unit/m^3	
Methanol	0.2035	kg	
Formaldehyde	0.0574	kg	
Acetaldehyde	0.0671	kg	
Acrolein	0.0241	kg	
Phenol	0.0124	kg	
MDI	0.0001	kg	

3.3.2.3 Methylene diphenyl di-isocyanate (MDI) resin

The LCI for the production of methylene diphenyl diisocyanate resin was based on a cradle-to-gate study on plastic resins and polyurethane precursors completed by Franklin Associates in 2010 (Franklin 2010). In this study, primary data was collected for MDI production in addition to the MDI precursors including olefins, benzene, chlorine/caustic soda, and nitric acid/nitrobenzene/aniline. For MDI production, data were gathered from four North American producers that represent roughly 95% of North American production capacity (Franklin 2010).

The LCI data generated in the MDI study were 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. Instead, 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 (www.lcacommons.gov) under the process name "Methylene diphenyl diisocyanate, resin, at plant, CTR".

3.3.2.4 Phenol-formaldehyde resin

The LCI for the production of phenol-formaldehyde (PF) resin covers its lifecycle from in-ground resources, including the production and delivery of input chemicals and fuels, through to the manufacturing of the resin as shipped to the customer (Wilson 2009). It examines the use of all resources, fuels and electricity and all emissions to air, water and land and it includes feedstock of natural gas and crude oil used to produce the chemicals. The PF resin survey data were from 13 plants in U.S. that represented 62% of total production for the year 2005 (Wilson 2009). Total annual production was 779,063,000 kg (1,717,500,000 lb) of neat resin at 47.4% non-volatile solids content. The inputs to produce 1.0 kg of neat phenol-formaldehyde (PF) resin at 47.4% non-volatile solids content consist of the two primary chemicals: 0.244 kg of phenol and .209 kg of methanol, and a lesser amount of sodium hydroxide (0.061 kg), and 0.349 kg of water. Electricity is used for processing such as fans and pumps, and for operating emissions control equipment. Natural gas is used for boiler fuel and emission control equipment, and propane fuel is used in forklifts.

3.3.2.5 Oriented Strandboard Production

To manufacture OSB, debarked logs are sliced into long, thin wood elements called strands. The strands are dried, blended with resin and wax, and formed into thick, loosely consolidated mats that are pressed under heat and pressure into large panels. During stranding, logs are debarked and then sent to a soaking pond or directly to the stranding process. This process uses over 25% of the electrical needs of the entire OSB manufacturing process. Green strands are dried in dryers (Stark et al. 2010). Dried strands are blended with adhesive and wax. This sub-unit requires a large electrical input and uses up to 80% of the heat requirements of OSB processing. Due to high temperature drying, this unit contributes the primary source of volatile organic compounds (VOC). The strands with adhesive applied are sent to mat formers. Once the mat is formed, it is hot-pressed. Hot-pressing consolidates the mat by heating it at 177 to 204 °C (350 to 400 °F), which cures the resin in 3–5 minutes. The final step is finishing the OSB panel. This involves sawing to size, sanding and packaging the material for shipping. This step consumes the least amount of energy but produces a stream of OSB board scrap and sander/ machining dust. This scrap and dust are sometimes sold as a co-product or disposed of in landfills.

3.3.2.6 Packaging

Materials used for packaging OSB for shipping are shown in Table 9.

Table 9 Materials used in packaging and shipping per m^3 SE OSB.

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

Packing materials represent only 0.83% of the cumulative mass of the model flow. The wooden spacers make up the bulk of this mass, representing 86 percent of the total packaging material. The wrapping material, strap protectors, and strapping made up, 8, 4, and 2 percent of the packaging by mass.

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.

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 16 and would be included in the impact assessment. Table 16 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

Total US production of OSB was 10.5 million m^3 (11.9 million MSF 3/8-inch) in 2001 (APA 2001). Almost two-thirds of that total OSB production equaling 7.0 million m^3 (7.9 million MSF) was reported in the SE region (APA 2001). This study collected data from four representative plants that represent larger scale production facilities in the SE 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 in conformance with ISO 14040 and CORRIM research protocol (ISO 2006). Details of this study for OSB production and the overall CORRIM project can be found in Kline (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 OSB producers from the SE, with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). The data were gathered through primary surveys that were sent out to OSB production facilities. To conduct the survey of OSB manufacturers in the SE region, all OSB manufacturing plants (22 plants total) were sent a LCI survey in 2000. Of these, four plants (18%) responded with complete data in terms of OSB and by-products production, raw materials, electricity and fuel use, and emissions. Surveyed LCI data represent 1999 production data.

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 with one caveat. With the collapse of the US housing market, a lot of smaller inefficient mills were closed during 2006-2010 therefore any future mill surveys are likely to show even better environmental performance than is represented here.

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 m^3 of production.

Survey data was converted from cubic feet to cubic meters. One thousand square feet, 3/8-inch thick panel (MSF) is equivalent to 0.8849 cubic meters of OSB. To obtain a mass balance of wood into OSB production and product and co-products out, the oven-dry OSB density was assumed to be 649 kg/m^3 (40.5 lb/ft^3). Air emission data related to the effectiveness of various emission control technologies were taken from the National Council for Air and Stream Improvement Technical Bulletin No. 772 (NCASI 1999).

The survey data were converted to a production basis and production-weighted averages were calculated for inputs to OSB 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.

All data from the mill survey were weighted-averaged for the plants based on production of each plant in comparison to the total production for the year. Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero; if unknown, it was not included in the weighted-average calculations. Missing data were carefully noted so they were not averaged as zeros.

6.3 Allocation rules

Allocation was based on the mass of the products and co-products. SE OSB does not have a value differential 10 times greater than the value of the main co-product that is sold outside the mill at today's prices.

6.4 LCI Results

Life cycle inventory results for OSB are presented by two life stages, 1) forestry operations, 2) OSB production which encompasses resin production (Tables 10-14). The majority of the raw material energy consumption and emissions occur during wood production with only a small portion arising from forestry operations. Raw material energy requirements are presented in Table 10 for 1 m^3 of softwood OSB. Air emissions are reported in Table 11, water emissions are reported in Table 12 and solid waste emissions are reported in Table 13.

Table 10 Raw material energy consumption per 1 m^3 of OSB in the SE region.

Fuel	Total	Forestry Operations	OSB Production
	kg/m^3		
Coal, in ground	62.1247	0.2530	61.8717
Gas, natural, in ground	36.7072	0.9169	35.7904
Oil, crude, in ground	30.9274	3.8137	27.1137
Uranium oxide, in ore	0.0017	0.0000	0.0017
Wood waste	190.5675	0.0000	190.5675

Table 11 Air emissions released per 1 m^3 of OSB in the SE region.

Air Emission[1/]	Total	Forestry Operations	OSB Production
	kg/m^3		
Carbon dioxide, biogenic	334.9927	0.0108	334.9819
Carbon dioxide, fossil	248.1750	12.5755	235.5996
Carbon dioxide	18.4636	0.5581	17.9055
Sulfur dioxide	1.7445	0.0288	1.7157
Nitrogen oxides	1.3237	0.2249	1.0989
VOC, volatile organic compounds	1.1135	0.0066	1.1069
Carbon monoxide	1.0617	0.0000	1.0617
Particulates, > 2.5 um, and < 10um	0.8779	0.0069	0.8710
Methane	0.7346	0.0260	0.7086
Carbon monoxide, fossil	0.4411	0.1123	0.3288
Methanol	0.1915	0.0000	0.1915
Sulfur oxides	0.1211	0.0125	0.1086
Methane, fossil	0.1133	0.0027	0.1107
Particulates, unspecified	0.1080	0.0015	0.1065
Metals, unspecified	0.0732	0.0000	0.0732
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0711	0.0075	0.0635
Hydrogen chloride	0.0648	0.0001	0.0647
Acetaldehyde	0.0647	0.0001	0.0647
Formaldehyde	0.0619	0.0001	0.0619
Acrolein	0.0296	0.0000	0.0296
Isoprene	0.0253	0.0003	0.0250
Benzene	0.0168	0.0001	0.0167
Cumene	0.0134	0.0000	0.0134
Phenol	0.0117	0.0000	0.0117
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0117	0.0003	0.0113
TOC, Total Organic Carbon	0.0099	0.0000	0.0099
Particulates, < 2.5 um	0.0086	0.0000	0.0086
Dinitrogen monoxide	0.0059	0.0033	0.0026
Propene	0.0051	0.0002	0.0049
N-Nitrodimethylamine	0.0045	0.0000	0.0045
Particulates, < 10 um	0.0044	0.0000	0.0044
Hydrogen fluoride	0.0040	0.0000	0.0040
Manganese	0.0028	0.0000	0.0028
Radionuclides (Including Radon)	0.0025	0.0000	0.0025

Air Emission[1/]	Total	Forestry Operations	OSB Production
Ammonia	0.0020	0.0005	0.0015
Chlorine	0.0014	0.0000	0.0014
Barium	0.0014	0.0000	0.0014
Organic substances, unspecified	0.0010	0.0000	0.0010
Aldehydes, unspecified	0.0008	0.0002	0.0007
Hydrocarbons, unspecified	0.0005	0.0000	0.0005
Methane, dichloro-, HCC-30	0.0005	0.0000	0.0005
Toluene	0.0005	0.0000	0.0004
Magnesium	0.0003	0.0000	0.0003
Xylene	0.0003	0.0000	0.0003
Naphthalene	0.0002	0.0000	0.0002
Nitrogen, total	0.0001	0.0001	0.0000
Dimethyl ether	0.0001	0.0000	0.0001

1/ Due to the extensive list of emissions, those 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 (Table 12). No mill in the survey discharged any process water. The water sprayed on logs is collected and recycled or soaks into the ground. Water used at the boiler and kilns is evaporated. A complete list of all emissions to water is located in the Appendix (Section 13) of this report.

Table 12 Emissions to water released per 1 m^3 of OSB in the SE region.

Water Emission[1/]	Total	Forestry Operations	OSB Production
	kg/m^3		
Solved solids	9.8647	0.7888	9.0759
Chloride	7.9858	0.6395	7.3463
Sodium, ion	2.2507	0.1803	2.0704
Calcium, ion	0.7102	0.0569	0.6533
Suspended solids, unspecified	0.3113	0.0400	0.2713
COD, Chemical Oxygen Demand	0.2846	0.0059	0.2787
BOD5, Biological Oxygen Demand	0.2486	0.0032	0.2454
Lithium, ion	0.1616	0.0045	0.1572
Magnesium	0.1389	0.0111	0.1277
Dissolved solids	0.1388	0.0000	0.1388
Barium	0.1303	0.0178	0.1124
TOC, Total Organic Carbon	0.0595	0.0000	0.0595
DOC, Dissolved Organic Carbon	0.0594	0.0000	0.0594
Sulfate	0.0564	0.0014	0.0549

Water Emission[1/]	Total	Forestry Operations	OSB Production
Bromide	0.0473	0.0038	0.0436
Cumene	0.0322	0.0000	0.0322
Iron	0.0230	0.0027	0.0204
Benzene	0.0223	0.0000	0.0223
Fluoride	0.0163	0.0160	0.0003
Phosphate	0.0121	0.0121	0.0001
Strontium	0.0121	0.0010	0.0111
Propene	0.0119	0.0000	0.0119
Aluminium	0.0067	0.0000	0.0067
Oils, unspecified	0.0049	0.0004	0.0045
Ammonia	0.0033	0.0003	0.0030
Aluminum	0.0032	0.0013	0.0019
Manganese	0.0008	0.0000	0.0007
Boron	0.0007	0.0001	0.0006
Sulfur	0.0006	0.0000	0.0005
Silver	0.0005	0.0000	0.0004
Toluene	0.0004	0.0000	0.0003
Zinc	0.0003	0.0000	0.0002
Acid as H+	0.0002	0.0000	0.0002
Benzoic acid	0.0002	0.0000	0.0002
Detergent, oil	0.0002	0.0000	0.0002
Xylene	0.0002	0.0000	0.0002
Chromium	0.0002	0.0000	0.0001
Dissolved organics	0.0001	0.0000	0.0001
Solved solids	9.8647	0.7888	9.0759
Chloride	7.9858	0.6395	7.3463
Sodium, ion	2.2507	0.1803	2.0704
Calcium, ion	0.7102	0.0569	0.6533
Suspended solids, unspecified	0.3113	0.0400	0.2713
COD, Chemical Oxygen Demand	0.2846	0.0059	0.2787
BOD5, Biological Oxygen Demand	0.2486	0.0032	0.2454
Lithium, ion	0.1616	0.0045	0.1572
Magnesium	0.1389	0.0111	0.1277
Dissolved solids	0.1388	0.0000	0.1388
Barium	0.1303	0.0178	0.1124
TOC, Total Organic Carbon	0.0595	0.0000	0.0595
DOC, Dissolved Organic Carbon	0.0594	0.0000	0.0594
Sulfate	0.0564	0.0014	0.0549

Water Emission[1/]	Total	Forestry Operations	OSB Production
Bromide	0.0473	0.0038	0.0436
Cumene	0.0322	0.0000	0.0322
Iron	0.0230	0.0027	0.0204
Benzene	0.0223	0.0000	0.0223
Fluoride	0.0163	0.0160	0.0003
Phosphate	0.0121	0.0121	0.0001
Strontium	0.0121	0.0010	0.0111
Propene	0.0119	0.0000	0.0119
Aluminium	0.0067	0.0000	0.0067
Oils, unspecified	0.0049	0.0004	0.0045
Ammonia	0.0033	0.0003	0.0030
Aluminum	0.0032	0.0013	0.0019
Manganese	0.0008	0.0000	0.0007
Boron	0.0007	0.0001	0.0006
Sulfur	0.0006	0.0000	0.0005
Silver	0.0005	0.0000	0.0004
Toluene	0.0004	0.0000	0.0003
Zinc	0.0003	0.0000	0.0002
Acid as H+	0.0002	0.0000	0.0002
Benzoic acid	0.0002	0.0000	0.0002
Detergent, oil	0.0002	0.0000	0.0002
Xylene	0.0002	0.0000	0.0002
Chromium	0.0002	0.0000	0.0001
Dissolved organics	0.0001	0.0000	0.0001

1/ Due to the extensive list of emissions, those emissions less than 10^{-4} are not shown.

Most of the solid waste generated for OSB production were a result from fuel production and combustion used for extraction and manufacturing of fuels (Table 13). The production of OSB resulted in ash from the boilers and some wood waste sent to unspecified disposal treatment facility. The total solid waste generated at the OSB mill was 4% of the total waste or 1.63 kg/m^3.

Table 13 Waste to treatment per 1 m^3 of OSB in the SE region.

Waste to treatment	Total	Forestry Operations	OSB Production
	kg/m^3		
Solid Waste	39.57	0.23	39.35

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 14. 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 14 Selected impact indicators, characterization models, and impact categories.

Impact Indicator	Characterization Model	Impact Category
Greenhouse gas (GHG) emissions	Calculate total emissions in the reference unit of CO_2 equivalents for CO_2, methane, and nitrous oxide.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the stratosphere including CFC's HCFC's, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total hydrogen ion (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 these reasons, indicators should not be combined or added. Table 15 provides the environmental impacts by category for OSB produced in the SE 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 15. For GWP, 95 percent of the CO_2 equivalent emissions come from producing OSB, with remainder assigned to forestry operations.

Table 15 Environmental performance of 1 m^3 of OSB in the SE region.

Impact category	Unit	Total	Forestry Operations	OSB Production
Global warming potential (GWP)	kg CO_2 equiv	289.59	14.83	274.76
Acidification Potential	H+ moles equiv	151.17	11.16	140.01
Eutrophication Potential	kg N equiv	0.1171	0.0394	0.0777
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000
Smog Potential	kg O3 equiv	38.69	5.61	33.08
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**OSB Production**
Non-renewable fossil	MJ	5076.89	230.03	4846.86
Non-renewable nuclear	MJ	665.32	2.20	663.11
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	19.64	0.24	19.40
Renewable, biomass	MJ	3991.14	0.00	3991.14
Material resources consumption (non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**OSB Production**
Non-renewable materials	kg	2.84	0.00	2.84
Renewable materials	kg	656.07	0.00	656.07
Fresh water	L	466.04	0.05	465.99
Waste generated	**Unit**	**Total**	**Forestry Operations**	**OSB Production**
Solid waste	kg	39.57	0.23	39.35

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 CO2 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, 290 kg CO_2e were released in the production of 1 m^3 of OSB. That same 1 m^3 of OSB stores 1,142 kg CO_2e (Table 16).

Table 16 Carbon balance per 1 m^3 oriented strandboard, SE.

	kg CO_2 equivalent
released forestry operations	14.83
released manufacturing	274.76
CO_2 eq. stored in product	1,142.33

9 Conclusions

The cradle to gate LCA for OSB 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 SE region. The survey data are representative of the processes and production volumes consistent with trade association data.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The OSB manufacturing process has some onsite emissions from drying flakes and pressing panels with the resin. These emissions were reported by the mills in the surveys. Of the total CO_2 emissions, both biogenic and fossil, 57 percent were biogenic based emitted from the combustion of wood fuel.

Energy use for manufacturing OSB is dominated by the combustion of wood fuel (biomass), which is comprised of wood and bark waste generated during the manufacture of OSB. Wood fuel represented 82% of the mill site use of heat energy. Energy generated by renewable fuels, such as woody biomass, represents about 38 percent of the total energy from cradle to gate. Total nonrenewable fossil fuel use was 49 percent of the total energy from cradle to gate. Resins used in OSB manufacturing almost exclusively dependent upon fossil fuels for both energy and feedstock. Forestry operations consumed exclusively (99%) fossil fuels. Oriented strandboard production alone consumed 42 percent of the total energy from biomass (wood fuel) and 51 percent from nonrenewable fossil fuels.

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, 290 kg CO_2e were released in the production of 1 m^3 of OSB. That same 1 m^3 of OSB stores 1,142 kg CO_2e.

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. 1 p.

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.

Environmental Protection Agency (EPA). 2006. Emissions Factors & AP 42, *Compilation of Air Pollutant Emission Factors.* AP 42, Fifth Edition, Volume I. Chapter 1: External Combustion Sources. Wood Residue Combustion in Boilers. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s06.pdf

Environmental Protection Agency (EPA). 1999. Emissions Factors & AP 42, *Compilation of Air Pollutant Emission Factors.* AP 42, Fifth Edition, Volume I. Chapter 1: External Combustion Sources. Fuel Oil Combustion. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf.

Environmental Protection Agency (EPA). 1998. Emissions Factors & AP 42, *Compilation of Air Pollutant Emission Factors.* AP 42, Fifth Edition, Volume I. Chapter 1: External Combustion Sources. Natural Gas Combustion.. http://www.epa.gov/ttn/chief/ap42/EIIP/POINTSRC/Ii02.pdf.

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.

Goemans, C. 2010. Athena Institute, NREL US LCI Database – N.A. Electricity Generation by Fuel Type Update & Template Methodology. http://www.nrel.gov/lci/database/.

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 CORRIM Phase I Final Report. Module E. January 2004. 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.

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

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

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 Council For Air And Stream Improvement, Inc. (NCASI). 1999. Volatile organic compound emissions from wood products manufacturing facilities, Part V–Oriented strandboard. Technical Bulletin No. 772. Research Triangle Park, NC. 98 pp.

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.

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

Stark, Nicole M.; Cai, Zhiyong; Carll, Charlie G. 2010. Wood Handbook, Chapter 11: Wood-Based Composite Materials-Panel Products- Glued-Laminated Timber, Structural Composite Lumber, and Wood-Nonwood Composite Materials. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 11-1 - 11-28. Chapter 11.

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 E. Southeastern Oriented Strandboard Production. Kline, 28 January, 2004.

Wilson, J.B. 2009. Resins: A life cycle inventory of manufacturing resins used in the wood composites industry. CORRIM Phase II Final Report. January 2009. 103pp.

13 Appendix

13.1 Air Emissions

Table A.1 Air emissions released per1 m^3 of oriented strandboard (OSB), SE.

Air Emissions	Unit	Total	Forestry Operations	OSB Production
2,4-D	kg	2.66E-09		2.66E-09
2-Chloroacetophenone	kg	9.47E-10	3.02E-11	9.17E-10
5-methyl Chrysene	kg	5.90E-10	2.44E-12	5.87E-10
Acenaphthene	kg	1.37E-08	5.65E-11	1.36E-08
Acenaphthylene	kg	6.70E-09	2.77E-11	6.67E-09
Acetaldehyde	kg	6.47E-02	5.14E-05	6.47E-02
Acetochlor	kg	3.68E-08		3.68E-08
Acetophenone	kg	2.03E-09	6.46E-11	1.97E-09
Acrolein	kg	2.96E-02	6.23E-06	2.96E-02
Alachlor	kg	3.63E-09		3.63E-09
Aldehydes, unspecified	kg	8.32E-04	1.55E-04	6.77E-04
Ammonia	kg	2.00E-03	5.04E-04	1.49E-03
Ammonium chloride	kg	9.27E-05	3.07E-07	9.24E-05
Anthracene	kg	5.63E-09	2.33E-11	5.61E-09
Antimony	kg	1.40E-05	1.99E-09	1.40E-05
Arsenic	kg	4.92E-05	6.13E-08	4.91E-05
Ash	kg	8.62E-05		8.62E-05
Atrazine	kg	7.18E-08		7.18E-08
Barium	kg	1.35E-03		1.35E-03
Bentazone	kg	2.93E-10		2.93E-10
Benzene	kg	1.68E-02	6.31E-05	1.67E-02
Benzene, chloro-	kg	2.98E-09	9.48E-11	2.88E-09
Benzene, ethyl-	kg	2.30E-07	4.05E-10	2.29E-07
Benzo(a)anthracene	kg	2.14E-09	8.86E-12	2.14E-09
Benzo(a)pyrene	kg	1.02E-09	4.21E-12	1.01E-09
Benzo(b,j,k)fluoranthene	kg	2.95E-09	1.22E-11	2.94E-09
Benzo(ghi)perylene	kg	7.24E-10	2.99E-12	7.21E-10
Benzyl chloride	kg	9.47E-08	3.02E-09	9.17E-08
Beryllium	kg	2.53E-06	3.07E-09	2.52E-06
Biphenyl	kg	4.56E-08	1.88E-10	4.54E-08
Bromoform	kg	5.28E-09	1.68E-10	5.11E-09
Bromoxynil	kg	6.42E-10		6.42E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	1.17E-02	3.23E-04	1.13E-02
Butadiene	kg	2.70E-06	2.62E-06	7.63E-08
Cadmium	kg	9.28E-06	1.56E-08	9.26E-06

Air Emissions	Unit	Total	Forestry Operations	OSB Production
Carbofuran	kg	5.49E-10		5.49E-10
Carbon dioxide	kg	1.85E+01	5.58E-01	1.79E+01
Carbon dioxide, biogenic	kg	3.35E+02	1.08E-02	3.35E+02
Carbon dioxide, fossil	kg	2.48E+02	1.26E+01	2.36E+02
Carbon disulfide	kg	1.76E-08	5.60E-10	1.70E-08
Carbon monoxide	kg	1.06E+00	3.93E-05	1.06E+00
Carbon monoxide, fossil	kg	4.41E-01	1.12E-01	3.29E-01
Chloride	kg	7.71E-10	8.27E-12	7.63E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	2.42E-07		2.42E-07
Chlorine	kg	1.36E-03		1.36E-03
Chloroform	kg	7.99E-09	2.54E-10	7.73E-09
Chlorpyrifos	kg	4.22E-09		4.22E-09
Chromium	kg	4.40E-05	4.47E-08	4.39E-05
Chromium VI	kg	2.12E-06	8.75E-09	2.11E-06
Chrysene	kg	2.68E-09	1.11E-11	2.67E-09
Cobalt	kg	1.46E-05	7.90E-08	1.45E-05
Copper	kg	3.32E-07	8.12E-10	3.31E-07
Cumene	kg	1.34E-02	2.28E-11	1.34E-02
Cyanazine	kg	6.33E-10		6.33E-10
Cyanide	kg	3.38E-07	1.08E-08	3.28E-07
Dicamba	kg	3.73E-09		3.73E-09
Dimethenamid	kg	8.81E-09		8.81E-09
Dimethyl ether	kg	1.01E-04		1.01E-04
Dinitrogen monoxide	kg	5.85E-03	3.27E-03	2.58E-03
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	2.83E-06		2.83E-06
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	2.14E-11	2.58E-13	2.11E-11
Dipropylthiocarbamic acid S-ethyl ester	kg	6.03E-09		6.03E-09
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	1.47E-07		1.47E-07
Ethane, 1,1,1-trichloro-, HCFC-140	kg	4.56E-09	4.44E-10	4.12E-09
Ethane, 1,2-dibromo-	kg	1.62E-10	5.17E-12	1.57E-10
Ethane, 1,2-dichloro-	kg	5.41E-09	1.72E-10	5.24E-09
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	kg	1.47E-07		1.47E-07
Ethane, chloro-	kg	5.68E-09	1.81E-10	5.50E-09
Ethene, tetrachloro-	kg	1.17E-06	5.63E-09	1.17E-06
Ethene, trichloro-	kg	1.19E-13		1.19E-13
Ethylene dibromide	kg	6.74E-09		6.74E-09
Fluoranthene	kg	1.90E-08	7.87E-11	1.90E-08
Fluorene	kg	2.44E-08	1.01E-10	2.43E-08
Fluoride	kg	1.44E-05	6.49E-06	7.92E-06
Formaldehyde	kg	6.19E-02	7.98E-05	6.19E-02
Furan	kg	1.31E-10	4.85E-13	1.30E-10

Air Emissions	Unit	Total	Forestry Operations	OSB Production
Glyphosate	kg	7.92E-09		7.92E-09
Heat, waste	MJ	1.40E+01		1.40E+01
Hexane	kg	9.07E-09	2.89E-10	8.78E-09
Hydrazine, methyl-	kg	2.30E-08	7.33E-10	2.23E-08
Hydrocarbons, unspecified	kg	5.35E-04	1.77E-06	5.33E-04
Hydrogen	kg	1.00E-05		1.00E-05
Hydrogen chloride	kg	6.48E-02	1.39E-04	6.47E-02
Hydrogen fluoride	kg	4.02E-03	1.64E-05	4.00E-03
Hydrogen sulfide	kg	2.49E-11	2.67E-13	2.47E-11
Indeno(1,2,3-cd)pyrene	kg	1.64E-09	6.76E-12	1.63E-09
Iron	kg	4.15E-07		4.15E-07
Isophorone	kg	7.85E-08	2.50E-09	7.60E-08
Isoprene	kg	2.53E-02	2.71E-04	2.50E-02
Kerosene	kg	4.44E-05	1.47E-07	4.42E-05
Lead	kg	9.57E-05	8.10E-08	9.56E-05
Magnesium	kg	2.95E-04	1.22E-06	2.94E-04
Manganese	kg	2.75E-03	8.99E-08	2.75E-03
MCPA	kg	4.96E-11		4.96E-11
Mercaptans, unspecified	kg	2.93E-05	9.34E-07	2.84E-05
Mercury	kg	9.28E-06	1.73E-08	9.26E-06
Metals, unspecified	kg	7.32E-02	3.07E-14	7.32E-02
Methacrylic acid	kg	6.15E-10		6.15E-10
Methacrylic acid, methyl ester	kg	2.09E-09	8.62E-11	2.00E-09
Methane	kg	7.35E-01	2.60E-02	7.09E-01
Methane, bromo-, Halon 1001	kg	2.17E-08	6.90E-10	2.10E-08
Methane, chlorodifluoro-, HCFC-22	kg	1.89E-06		1.89E-06
Methane, chlorotrifluoro-, CFC-13	kg	3.46E-08		3.46E-08
Methane, dichloro-, HCC-30	kg	5.06E-04	9.06E-08	5.05E-04
Methane, dichlorodifluoro-, CFC-12	kg	2.29E-09	4.43E-10	1.85E-09
Methane, fossil	kg	1.13E-01	2.66E-03	1.11E-01
Methane, monochloro-, R-40	kg	7.17E-08	2.28E-09	6.94E-08
Methane, tetrachloro-, CFC-10	kg	5.51E-07	4.43E-11	5.51E-07
Methanol	kg	1.91E-01		1.91E-01
Methyl ethyl ketone	kg	5.28E-08	1.68E-09	5.11E-08
Methyl methacrylate	kg	5.10E-12		5.10E-12
Methylene diisocyanate	kg	7.73E-05		7.73E-05
Metolachlor	kg	2.91E-08		2.91E-08
Metribuzin	kg	1.35E-10		1.35E-10
Naphthalene	kg	1.67E-04	1.69E-08	1.67E-04
Nickel	kg	7.60E-05	9.89E-07	7.50E-05
Nickel compounds	kg	1.89E-06		1.89E-06

Air Emissions	Unit	Total	Forestry Operations	OSB Production
Nitrogen oxides	kg	1.32E+00	2.25E-01	1.10E+00
Nitrogen, total	kg	1.26E-04	1.26E-04	3.56E-09
Nitrous oxide	kg	1.87E-06		1.87E-06
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	7.11E-02	7.53E-03	6.35E-02
N-Nitrodimethylamine	kg	4.51E-03		4.51E-03
Organic acids	kg	3.41E-07	1.13E-09	3.39E-07
Organic substances, unspecified	kg	1.02E-03	6.88E-07	1.02E-03
PAH, polycyclic aromatic hydrocarbons	kg	1.14E-05	1.13E-05	1.70E-07
Paraquat	kg	5.89E-10		5.89E-10
Parathion, methyl	kg	4.45E-10		4.45E-10
Particulates	kg	4.73E-05		4.73E-05
Particulates, < 10 um	kg	4.43E-03		4.43E-03
Particulates, < 2.5 um	kg	8.64E-03		8.64E-03
Particulates, > 2.5 um, and < 10um	kg	8.78E-01	6.90E-03	8.71E-01
Particulates, unspecified	kg	1.08E-01	1.55E-03	1.06E-01
Pendimethalin	kg	3.03E-09		3.03E-09
Permethrin	kg	2.72E-10		2.72E-10
PFC (perfluorocarbons)	kg	1.89E-05		1.89E-05
Phenanthrene	kg	7.24E-08	2.99E-10	7.21E-08
Phenol	kg	1.17E-02	6.90E-11	1.17E-02
Phenols, unspecified	kg	8.88E-05	4.58E-08	8.87E-05
Phorate	kg	1.40E-10		1.40E-10
Phosphate	kg	2.88E-06	2.88E-06	x
Phthalate, diisooctyl-	kg	2.24E-09		2.24E-09
Phthalate, dioctyl-	kg	7.64E-09	3.15E-10	7.32E-09
Polycyclic organic matter, unspecified	kg	8.80E-08		8.80E-08
Potassium	kg	7.36E-05		7.36E-05
Propanal	kg	5.14E-08	1.64E-09	4.98E-08
Propene	kg	5.12E-03	1.73E-04	4.94E-03
Propylene oxide	kg	1.35E-07		1.35E-07
Pyrene	kg	8.85E-09	3.66E-11	8.81E-09
Radioactive species, unspecified	Bq	1.51E+06	6.04E+03	1.50E+06
Radionuclides (Including Radon)	kg	2.48E-03	8.22E-06	2.47E-03
Selenium	kg	4.01E-05	1.54E-07	3.99E-05
Simazine	kg	1.91E-09		1.91E-09
Sodium	kg	1.70E-06		1.70E-06
Styrene	kg	3.38E-09	1.08E-10	3.28E-09
Sulfur	kg	8.95E-06		8.95E-06
Sulfur dioxide	kg	1.74E+00	2.88E-02	1.72E+00
Sulfur oxides	kg	1.21E-01	1.25E-02	1.09E-01
Sulfur, total reduced	kg	5.25E-06		5.25E-06

Air Emissions	Unit	Total	Forestry Operations	OSB Production
Sulfuric acid	kg	1.89E-08		1.89E-08
Sulfuric acid, dimethyl ester	kg	6.50E-09	2.07E-10	6.29E-09
Tar	kg	8.68E-10	9.30E-12	8.58E-10
t-Butyl methyl ether	kg	4.74E-09	1.51E-10	4.59E-09
Terbufos	kg	4.76E-09		4.76E-09
TOC, Total Organic Carbon	kg	9.92E-03		9.92E-03
Toluene	kg	4.59E-04	2.74E-05	4.31E-04
Toluene, 2,4-dinitro-	kg	3.79E-11	1.21E-12	3.67E-11
Vinyl acetate	kg	1.03E-09	3.28E-11	9.96E-10
VOC, volatile organic compounds	kg	1.11E+00	6.61E-03	1.11E+00
Xylene	kg	2.70E-04	1.91E-05	2.51E-04
Zinc	kg	3.52E-06	2.32E-06	1.20E-06

13.2 Water Emissions

Table 17 Emissions to water released per 1 m^3 of oriented strandboard (OSB), SE.

Water Emission	Unit	Total	Forestry Operations	OSB Production
2,4-D	kg	1.14E-10		1.14E-10
2-Hexanone	kg	1.45E-06	1.16E-07	1.33E-06
2-Propanol	kg	4.94E-09		4.94E-09
4-Methyl-2-pentanone	kg	9.28E-07	7.44E-08	8.54E-07
Acetochlor	kg	1.58E-09		1.58E-09
Acetone	kg	2.21E-06	1.77E-07	2.03E-06
Acid as H+	kg	2.33E-04		2.33E-04
Acidity, unspecified	kg	1.10E-14		1.10E-14
Acids, unspecified	kg	7.02E-06	1.74E-10	7.02E-06
Alachlor	kg	1.55E-10		1.55E-10
Aluminium	kg	6.71E-03		6.71E-03
Aluminum	kg	3.24E-03	1.29E-03	1.94E-03
Ammonia	kg	3.35E-03	3.10E-04	3.04E-03
Ammonia, as N	kg	8.14E-09	8.73E-11	8.05E-09
Ammonium, ion	kg	1.98E-05	6.56E-08	1.98E-05
Antimony	kg	5.68E-06	8.06E-07	4.88E-06
Arsenic, ion	kg	5.88E-05	1.01E-05	4.87E-05
Atrazine	kg	3.08E-09		3.08E-09
Barium	kg	1.30E-01	1.78E-02	1.12E-01
Bentazone	kg	1.26E-11		1.26E-11
Benzene	kg	2.23E-02	2.97E-05	2.23E-02
Benzene, 1-methyl-4-(1-methylethyl)-	kg	2.21E-08	1.77E-09	2.03E-08
Benzene, ethyl-	kg	2.09E-05	1.67E-06	1.92E-05

Water Emission	Unit	Total	Forestry Operations	OSB Production
Benzene, pentamethyl-	kg	1.66E-08	1.33E-09	1.52E-08
Benzenes, alkylated, unspecified	kg	5.13E-06	7.07E-07	4.42E-06
Benzoic acid	kg	2.25E-04	1.80E-05	2.07E-04
Beryllium	kg	2.61E-06	2.52E-07	2.35E-06
Biphenyl	kg	3.32E-07	4.58E-08	2.86E-07
BOD5, Biological Oxygen Demand	kg	2.49E-01	3.21E-03	2.45E-01
Boron	kg	6.95E-04	5.56E-05	6.39E-04
Bromide	kg	4.73E-02	3.79E-03	4.36E-02
Bromoxynil	kg	1.66E-11		1.66E-11
Cadmium, ion	kg	9.83E-06	2.49E-06	7.35E-06
Calcium, ion	kg	7.10E-01	5.69E-02	6.53E-01
Carbofuran	kg	2.35E-11		2.35E-11
CFCs, unspecified	kg	4.94E-09		4.94E-09
Chloride	kg	7.99E+00	6.40E-01	7.35E+00
Chloroform	kg	3.94E-09		3.94E-09
Chlorpyrifos	kg	1.81E-10		1.81E-10
Chromate	kg	6.57E-13		6.57E-13
Chromium	kg	1.79E-04	4.05E-05	1.38E-04
Chromium VI	kg	7.07E-07	1.36E-07	5.70E-07
Chromium, ion	kg	8.69E-05	4.20E-06	8.27E-05
Cobalt	kg	4.90E-06	3.92E-07	4.51E-06
COD, Chemical Oxygen Demand	kg	2.85E-01	5.94E-03	2.79E-01
Copper	kg	1.98E-07		1.98E-07
Copper, ion	kg	6.36E-05	8.33E-06	5.53E-05
Cumene	kg	3.22E-02		3.22E-02
Cyanazine	kg	2.71E-11		2.71E-11
Cyanide	kg	2.00E-08	1.28E-09	1.87E-08
Decane	kg	6.45E-06	5.16E-07	5.94E-06
Detergent, oil	kg	2.08E-04	1.54E-05	1.93E-04
Dibenzofuran	kg	4.20E-08	3.37E-09	3.86E-08
Dibenzothiophene	kg	3.50E-08	2.87E-09	3.22E-08
Dicamba	kg	1.60E-10		1.60E-10
Dimethenamid	kg	3.78E-10		3.78E-10
Dipropylthiocarbamic acid S-ethyl ester	kg	1.56E-10		1.56E-10
Dissolved organics	kg	1.49E-04		1.49E-04
Dissolved solids	kg	1.39E-01		1.39E-01
Disulfoton	kg	9.32E-12		9.32E-12
Diuron	kg	2.62E-12		2.62E-12
DOC, Dissolved Organic Carbon	kg	5.94E-02	5.33E-13	5.94E-02
Docosane	kg	2.36E-07	1.89E-08	2.17E-07
Dodecane	kg	1.22E-05	9.79E-07	1.13E-05

Water Emission	Unit	Total	Forestry Operations	OSB Production
Eicosane	kg	3.37E-06	2.70E-07	3.10E-06
Fluorene	kg	5.56E-09		5.56E-09
Fluorene, 1-methyl-	kg	2.51E-08	2.02E-09	2.31E-08
Fluorenes, alkylated, unspecified	kg	2.97E-07	4.10E-08	2.56E-07
Fluoride	kg	1.63E-02	1.60E-02	3.21E-04
Fluorine	kg	1.51E-07	2.05E-08	1.30E-07
Furan	kg	1.81E-10		1.81E-10
Glyphosate	kg	3.40E-10		3.40E-10
Hexadecane	kg	1.34E-05	1.07E-06	1.23E-05
Hexanoic acid	kg	4.65E-05	3.72E-06	4.28E-05
Hydrocarbons, unspecified	kg	1.81E-07	6.68E-13	1.81E-07
Iron	kg	2.30E-02	2.65E-03	2.04E-02
Lead	kg	9.48E-05	1.20E-05	8.28E-05
Lead-210/kg	kg	2.30E-14	1.84E-15	2.12E-14
Lithium, ion	kg	1.62E-01	4.47E-03	1.57E-01
Magnesium	kg	1.39E-01	1.11E-02	1.28E-01
Manganese	kg	7.51E-04	1.97E-05	7.31E-04
MCPA	kg	2.13E-12		2.13E-12
Mercury	kg	2.08E-07	9.52E-08	1.13E-07
Metallic ions, unspecified	kg	4.74E-09	8.15E-12	4.73E-09
Methane, monochloro-, R-40	kg	8.89E-09	7.13E-10	8.18E-09
Methyl ethyl ketone	kg	1.78E-08	1.43E-09	1.64E-08
Metolachlor	kg	1.25E-09		1.25E-09
Metribuzin	kg	5.78E-12		5.78E-12
Molybdenum	kg	5.09E-06	4.07E-07	4.68E-06
m-Xylene	kg	6.71E-06	5.36E-07	6.17E-06
Naphthalene	kg	4.02E-06	3.22E-07	3.70E-06
Naphthalene, 2-methyl-	kg	3.51E-06	2.80E-07	3.23E-06
Naphthalenes, alkylated, unspecified	kg	8.41E-08	1.16E-08	7.25E-08
n-Hexacosane	kg	1.47E-07	1.18E-08	1.36E-07
Nickel	kg	4.86E-05	7.15E-06	4.14E-05
Nickel, ion	kg	5.72E-13		5.72E-13
Nitrate	kg	5.87E-07	5.85E-14	5.87E-07
Nitrate compounds	kg	2.59E-10	2.35E-12	2.57E-10
Nitric acid	kg	4.93E-07	5.28E-09	4.87E-07
Nitrogen, total	kg	6.97E-05	1.63E-07	6.96E-05
o-Cresol	kg	6.37E-06	5.09E-07	5.86E-06
Octadecane	kg	3.30E-06	2.64E-07	3.04E-06
Oils, unspecified	kg	4.86E-03	3.95E-04	4.47E-03
Organic substances, unspecified	kg	3.61E-09		3.61E-09
o-Xylene	kg	1.17E-08		1.17E-08

Water Emission	Unit	Total	Forestry Operations	OSB Production
Paraquat	kg	2.53E-11		2.53E-11
Parathion, methyl	kg	1.91E-11		1.91E-11
p-Cresol	kg	6.87E-06	5.50E-07	6.32E-06
Pendimethalin	kg	1.30E-10		1.30E-10
Permethrin	kg	1.17E-11		1.17E-11
Phenanthrene	kg	4.01E-08	4.40E-09	3.57E-08
Phenanthrenes, alkylated, unspecified	kg	3.49E-08	4.80E-09	3.01E-08
Phenol	kg	3.30E-05	6.04E-06	2.69E-05
Phenol, 2,4-dimethyl-	kg	6.20E-06	4.96E-07	5.71E-06
Phenols, unspecified	kg	7.26E-05	2.70E-06	6.99E-05
Phorate	kg	3.61E-12		3.61E-12
Phosphate	kg	1.21E-02	1.21E-02	7.22E-05
Phosphorus	kg	1.01E-05		1.01E-05
Phosphorus compounds, unspecified	kg	6.69E-08		6.69E-08
Phosphorus, total	kg	5.97E-06		5.97E-06
Process solvents, unspecified	kg	1.81E-08		1.81E-08
Propene	kg	1.19E-02		1.19E-02
p-Xylene	kg	1.17E-08		1.17E-08
Radioactive species, Nuclides, unspecified	Bq	2.88E+03	9.53E+00	2.87E+03
Radium-226/kg	kg	8.00E-12	6.40E-13	7.36E-12
Radium-228/kg	kg	4.09E-14	3.27E-15	3.77E-14
Selenium	kg	8.05E-06	1.79E-07	7.87E-06
Silver	kg	4.63E-04	3.72E-05	4.26E-04
Simazine	kg	8.20E-11		8.20E-11
Sodium, ion	kg	2.25E+00	1.80E-01	2.07E+00
Solids, inorganic	kg	1.25E-09	1.34E-11	1.24E-09
Solved solids	kg	9.86E+00	7.89E-01	9.08E+00
Strontium	kg	1.21E-02	9.65E-04	1.11E-02
Styrene	kg	9.64E-10		9.64E-10
Sulfate	kg	5.64E-02	1.42E-03	5.49E-02
Sulfide	kg	6.69E-05	7.01E-07	6.62E-05
Sulfur	kg	5.86E-04	4.69E-05	5.39E-04
Sulfuric acid	kg	1.58E-10		1.58E-10
Surfactants	kg	5.51E-07		5.51E-07
Suspended solids, unspecified	kg	3.11E-01	4.00E-02	2.71E-01
Tar	kg	1.24E-11	1.33E-13	1.23E-11
Terbufos	kg	1.23E-10		1.23E-10
Tetradecane	kg	5.37E-06	4.29E-07	4.94E-06
Thallium	kg	1.20E-06	1.70E-07	1.03E-06
Tin	kg	3.26E-05	3.50E-06	2.91E-05
Titanium, ion	kg	8.73E-05	1.24E-05	7.49E-05

Water Emission	Unit	Total	Forestry Operations	OSB Production
TOC, Total Organic Carbon	kg	5.95E-02		5.95E-02
Toluene	kg	3.51E-04	2.81E-05	3.23E-04
Vanadium	kg	6.10E-06	4.81E-07	5.61E-06
Waste water/m3	m3	1.49E-03		1.49E-03
Xylene	kg	1.84E-04	1.50E-05	1.69E-04
Yttrium	kg	1.49E-06	1.19E-07	1.37E-06
Zinc	kg	2.52E-04	3.02E-05	2.22E-04
Zinc, ion	kg	7.98E-07		7.98E-07