Cradle to Gate Life Cycle Assessment of Softwood Lumber Production from the Pacific Northwest

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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 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 planed dry softwood lumber produced in the US Pacific Northwest (PNW) region. The PNW regional data is a representative cross-section of forest growth and manufacturing processes in western Washington and Oregon. This document updates the current wood product LCI's from a gate to gate to a cradle to gate LCI. Updates include the addition of PNW forestry operations, boiler, and electrical grid data that have been developed since the original mill surveys were conducted in the years 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 report by Milota (2004) and Milota et al. (2005) and Johnson et al. (2005). Updates in this report from the original Milota report include: wood combustion boiler updates, electricity grid updates (Goemans 2010), results expressed per unit of final product (1 m^3 planed dry softwood lumber), and a LCIA. Updates to the forestry operations report include electricity grid updates and a 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's. 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 planed dry lumber from the manufacturing base located in the PNW region of North America. These data are needed for the inclusion of the production process in life-cycle analyses of wood. The data were obtained through a scientifically sound and consistent process established by the Consortium for Research on Renewable Industrial Materials (CORRIM), following ISO14040 standards (ISO 2006).

The scope of this study was to develop an LCI and LCIA for the production of planed dry dimension (framing or construction) lumber from logs using practices and technology common to the PNW region. It covers the impacts in terms of input materials, fuels, and electricity through the outputs of product, co-products, and emissions (Milota et al. 2004). The logs are obtained from the forest resource base located in western Washington and Oregon as representative of the region. Data for the life cycle assessment (LCA) are based on manufacturing gate to gate LCI's from CORRIM reports (Milota 2004) and forest resources cradle to gate LCI's specific to the 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

Softwood lumber is used in construction for both structural and non-structural purposes. Softwood lumber has been produced into a wide variety of products from many different species. However, almost all softwood lumber is produced as dimension lumber which is nominally 38 mm to 89 mm thick (2 to 4 inches) and 89 mm to 305 mm wide (4 to 12 inches) (Figure 1). Dimension lumber and boards of some species may be green or dry but most lumber produced in the USA is dried. By definition, dry boards and dimension lumber has been seasoned or dried to a maximum moisture content of 19%. Lumber can also be produced either rough or surfaced (planed). Rough lumber serves as a raw material for further manufacture and also for some decorative purposes. For example, a roughsawn surface is common in post and timber products. Surfaced or planed lumber has been surfaced by a machine on one side or two sides, one edge or two edges or combinations of sides and edges. Lumber is surfaced to attain smoothness of surface and uniformity of size. This LCA report is for planed (surfaced), dry, dimension lumber produced from logs.

Figure 1 Dimension lumber.

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for lumber is one cubic meter (1.0 m^3). A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building product cannot be stated (PCR 2011). For conversion of units from the US industry measure, 1.0 MBF (1000 board feet[1]) is equal to 1.624 m3 (actual[2]). 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) protocol (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 Pacific Northwest (Johnson et al. 2005) and ends with planed dry lumber (Milota 2004, Milota et al. 2005) (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which included fertilization and thinning on a subset of hectares, final harvest with the transportation of logs, and lumber manufacturing (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The sawmill complex was divided into four process units: sawing, drying, energy generation, and planing (Figure 2). Separating the LCI into these unit processes is necessary to ensure accurate allocation of burdens among co-products as some of them leave the mill prior to drying which is the unit process that has the most significant environmental load.

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[1] Board feet – the basic unit of measure of lumber (US). One board foot is equal to a 1-inch board, 12 inches in width and 1 foot in length.

[2] Actual size – the finished size, as opposed to the nominal size, of a piece of lumber.

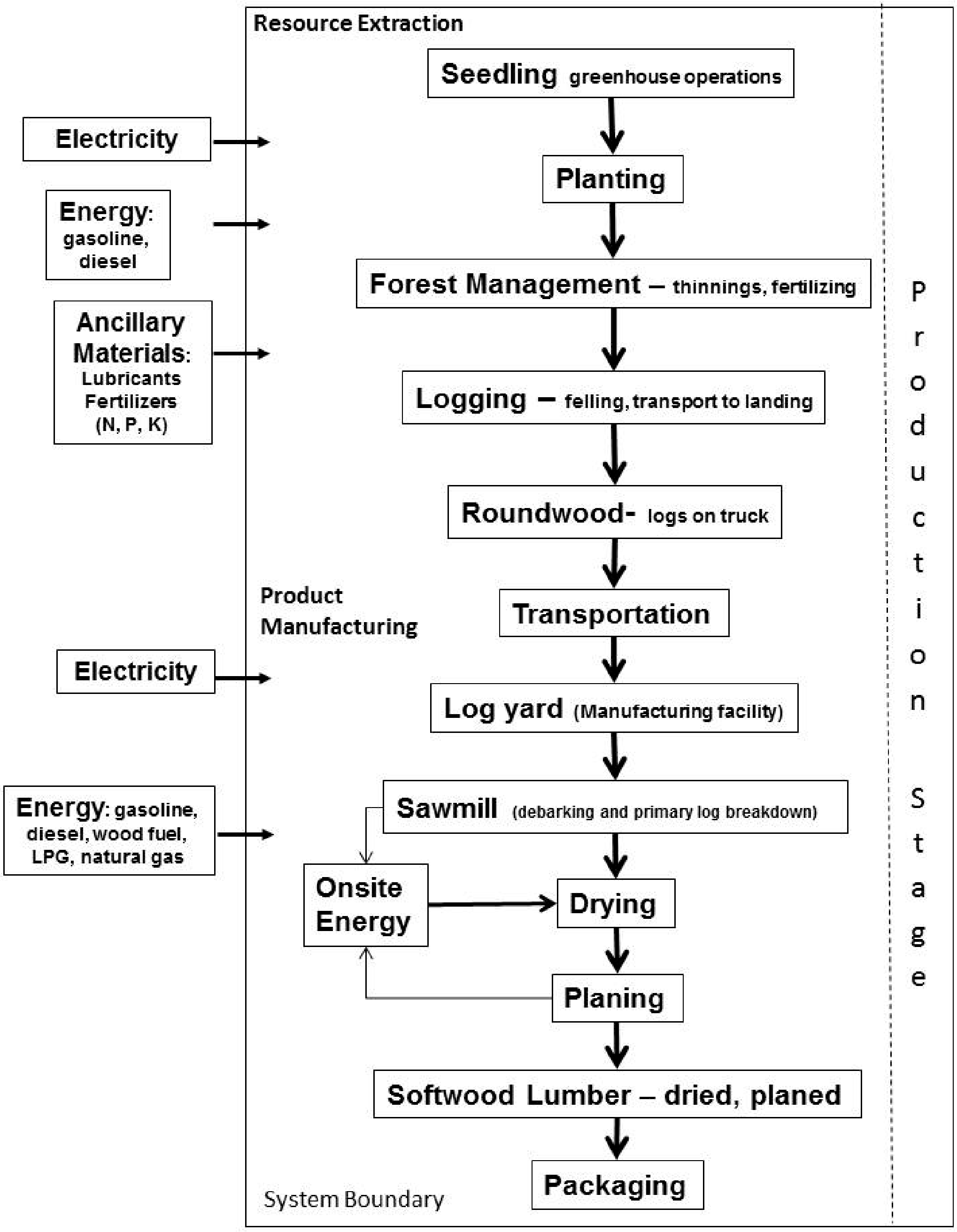

Figure 2 Cradle to gate life cycle stages for PNW softwood lumber.

3.3 Description of data/Process Description

3.3.1 Forestry Operations

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

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

In the PNW most harvested volume comes from forest operations on private lands where investment in timber is the precursor to harvest. For all non-federal land managers in the region, reforestation is a statutory requirement as harvests are administered under state forest practices acts. Harvested lands are reforested for the next crop cycle with the sequence of treatments from planting to harvest averaging 45 years. Forestry operations and their associated impacts are not stationary and will change based on both past and prospective technologies, evolving forest management procedures, and market demands. Given that the nature of productivity gains is not confirmed or well developed, this assessment was based on data representing the current state of the art in forest operations: it does not discount future operations or estimate potential productivity gains from future technologies. Outputs representing quantities of product, measures of consumed resources, and the emissions associated with those consumed resources were developed as a weighted average across the hectares managed for timber production. These quantities of product are used as inputs to the 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). Management intensities ranged from little intervention on low site productivity lands to higher management intensities involving combinations of fertilization and thinning on high productivity lands. Associated with each combination of management intensity and site productivity is an estimated yield of biomass based on forest growth and yield generated using the Forest Vegetation Simulator (FVS) growth and yield model (Wykoff 1986). FVS is developed from empirical data on forest growth and provides a reasonable estimate of standing and harvested biomass along with other stand attributes through time from seedling establishment to final harvest of the forest stand at rotation age.

3.3.1.1 Regeneration (seedling production and planting process)

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

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

Table 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	12	12	12	12
Seedlings, at greenhouse	p[1]	988	1,482	1,482	1,275
Nitrogen in fertilizer					
In Seedlings	kg	0.04	0.06	0.06	0.05
On Site	kg	-	-	396.78	47.61
Phosphorous in fertilizer		-	-	-	-
In Seedlings	kg	0.07	0.11	0.11	0.09
On Site	kg	-	-	67.25	8.07
Potassium in fertilizer		-	-	-	-
In Seedlings	kg	0.17	0.26	0.26	0.22
On Site	kg	-	-	-	-

[1] p = individual seedling

3.3.1.2 Equipment

Timber harvesting activities include four components: felling (severing the standing tree from the stump); processing (bucking, limbing and/or topping) which involves removal of non-merchantable limbs and tops and cutting of the tree into merchantable and transportable log lengths; secondary transportation (called skidding on gentle slopes and yarding on steep slopes),which is a transportation step that moves trees or logs from the point of felling to a loading point near a haul road; 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.

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

Variations in harvest equipment size affect machine productivity and therefore emissions per 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		
Chain saw	NA	100%
Cable yarder, large	NA	100%
Loader	NA	100%
Medium intensity		
Chain saw	19.6%	80.4%
Cable yard, medium	19.6%	
Cable yarder, large		80.4%
Loader	19.6%	80.4%
High intensity		
Chain saw	12.6%	87.5%
Cable yard, medium	12.6%	
Cable yarder, large		87.5%
Loader	12.6%	87.5%

3.3.1.3 Thinning and Final Harvest Process

A single estimate of the average volume harvested per unit area was developed by weighting three combinations of site productivity and management intensity (Table 3) based on the relative percentage of the land base they occupy. Site productivity as measured by site index, the height of dominant trees at 50 years, and ownership class was obtained from the U.S. Forest Service Resource Planning Assessment database (USDA 2000, Mills 2001). A combination of these data and expert opinion were used to categorize the number of private forest hectares into a management intensity classes. The management intensity and site productivity classes used in the Forest Service analysis were associated with, and were represented by three general management intensity combinations. Specific assumptions associated with these three scenarios are outlined in Table 3. In the PNW, 42% of the lands were classified in the lowest productivity/ management intensity class, 46% in the middle class, and 12% in the highest management intensity class. The allocation of forested area to management intensity/site productivity class produces the log volume recovered from the forest resource as shown in Table 3. Allocating per ha values from Table 1 to the total yield of 501 m^3/ha is used to carry forward the environmental burdens of the reforestation effort on a per m^3 basis.

Table 3 Input assumptions for three levels of management intensity in the PNW.

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

Fuel consumption and energy use for forest resource management processes were averaged by the percent area in each class to develop weighted average values for the PNW region by major process (Table 4).

Table 4 Fuel consumption for PNW forest resource management processes (regeneration, thinning, and harvest).

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

3.3.2 Wood Product Manufacturing

3.3.2.1 Transportation Process

Transportation is the first process of product manufacturing (Figure 2). Logs typically arrive at the mill by truck. Based on mill surveys the average haul distance from the forestry operations (landing) to sawmills in the PNW region was 113 km with a weighted average roundwood moisture content of 83.43% oven dry basis[3]. Transportation is incorporated into the primary log breakdown process (3.3.2.3 Sawing).

Table 5 Average delivery distance (one-way) for materials to sawmill, PNW.

Material delivered to mill	Delivery Distance (km)	
	km	miles
Logs with bark	113	70

3.3.2.2 Energy use and generation

Steam used for drying green lumber in PNW softwood lumber mills was produced using three fuels: 58.2% from wood-based residues, 41.7% from natural gas, and 0.1% from diesel. The USLCI database was used for boiler processes inputting natural gas, diesel, or wood fuel (NREL 2012). These boiler processes are based on the US Environmental Protection Agency (EPA) AP-42, Compilation of Air Pollutant Emission Factors (EPA 1998, 2006, 2010). The AP-42 emission factors assume no emission controls and therefore likely over-estimates the impact factors for wood emissions.

The wood boiler used self-generated wood waste (Table 6 and 7). One kg of wood material based on an oven dry basis for moisture content contained 20.9 MJ of energy and produced 14 MJ of steam which is equivalent to a 67% thermal efficiency. This thermal efficiency is in good agreement with Wilén et al. (1996). Some PNW sawmills reported a small amount of co-generated electricity equal to producing 2.3% of the electricity used in mill complex. The on-site electricity generation was modeled as an avoided product in the SimaPro models. The wood-based fuel mix was 81% bark, 13% hog fuel (wood waste), and 6% sawdust.

Table 6 Boiler inputs for drying per 1 m3 of dry planed softwood lumber, PNW

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product
Wood waste	kg	76.55	20.9	1,597
Natural gas	m^3	19.85	54.4	756

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[3] MC dry basis = 100 x (Wet Wt. - Dry Wt.) / Dry Wt.; MC wet basis = 100 x (Wet Wt .- Dry Wt.) / Wet Wt.

Table 7 Wood Boiler Process.

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler	1.00	kg
Avoided products		
Electricity, at Grid	0.0048	kWh
Materials/fuels		
Fuel wood, green	0.13	kg
Bark, green	0.81	kg
Sawdust, green	0.06	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

The total energy allocated to the planed dry lumber includes purchased energy and embodied energy for the wood-based fuel consumed in the boilers. Natural gas is by far the largest source of purchased energy for the manufacture of PNW lumber because 41.7% of the steam for drying is generated from natural gas.

Electricity is used to operate saws and conveyers, and the other fuels are used in log and lumber handling equipment, such as forklifts. Electrical use in PNW lumber mills for the sawing process represents approximately 53% of that used by the mill complex.

3.3.2.3 Log Yard

The log yard process included unloading log trucks, scaling logs (measuring logs for volume), storing logs in decks, water spraying logs to prevent dry-out and blue stain, and transporting logs to the sawmill. Inputs may include gasoline, diesel, and electricity. Outputs include logs with bark. Inputs into this process are incorporated into the primary log breakdown stage (3.4.2.3 Sawing). All flow analyses of wood and bark in the process were determined on an oven-dry weight basis and a green specific gravity[4] of 0.45.

3.3.2.4 Sawing

The sawmill process included debarking logs, sawing logs into rough-green lumber, chipping portions of logs that did not make lumber, sorting rough-green lumber into size classes, and stacking rough-green lumber for drying. Inputs include logs with bark and electricity. Outputs include green lumber, green sawdust, green chips, bark, and green fuel wood. Table 8 lists the inputs and outputs for the sawing processes which produce 1m^3 of rough sawn green lumber. The actual sizes are 41.3 mm x 150 mm. This is a larger size than the finished lumber to allow for shrinkage and planing. Rough cut lumber is 78.1% hemlock and 21.9% Douglas-fir with an average weighted average mass of 452 kg/m^3, which represents 56.8% of the mass of the products and co-products. All of the wood fuel and bark and 7% of the sawdust are sent to the boiler. The chips and balance of the sawdust are sold off-site.

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

Table 8 Unit process inputs/outputs for sawing for the production of 1 m^3 of rough green lumber (includes log yard activities), PNW.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Sawn lumber, rough, green	1.00	m^3	56.9
Sawdust, green	68.59	kg	8.53
Pulp chips, green	212.07	kg	26.7
Bark, green	61.74	kg	7.77
Fuel wood, green	0.8231	kg	0.10
Resources	**Value**	**Unit/m^3**	
Water, cooling, surface	56.95	L	
Water, cooling, ground	85.95	L	
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	48.03	kWh	
Diesel	0.9385	L	
LPG	0.0003	L	
Gasoline	0.0980	L	
Roundwood w/ bark	1.8080	m^3	
Transport	159.48	tkm	
Emissions to air	**Value**	**Unit/m^3**	
Particulates, SPM	1.17E-02	kg	
VOC, volatile organic compounds	3.21E-02	kg	
Particulates, <10 µm	1.21E-01	kg	
Acetaldehyde	4.87E-04	kg	
Acrolein	7.50E-07	kg	
Methanol	8.31E-04	kg	
Phenol	8.61E-05	kg	
Formaldehyde	7.21E-08	kg	
Emissions to soil	**Value**	**Unit/m^3**	
Bark	1.9408	kg	

Chip production varies among the mills from 341 to 408 kg per 1.914 m^3 of rough green lumber. The amounts of other co-products from sawing varied considerably, though sometimes that is because of the way mills define their co-products. For example, bark or sawdust are called hog fuel by some mills, but not by others because the end uses are different.

Water is mainly used in the process for wetting logs when they are stored prior to sawing. This varied from zero to 350 kg. The high variability arises because not all mills sprinkle logs to control decay processes.

3.3.2.5 Kiln Drying Process

The kiln drying process included loading rough-green stacked lumber into kilns, drying rough-green lumber, and unloading rough-dry stacked lumber from the kilns. The boiler processes included steam production for the dry kilns. Inputs include green lumber, electricity, diesel, and wood fuel. Outputs include dry lumber. The major non-lumber inputs to drying are steam and electricity (Table 9). Electrical use in the dryer represents approximately 17% of that used by the mill complex. Steam comes from the three boiler types in the proportions described above for the PNW softwood lumber processes. Diesel in equipment is used for machinery, such as forklifts and to transport lumber between the sawmill and kilns when the kilns are located at a different site. The average haul distance to the dryers for the surveyed mills was 13 km. Some air emissions are attributed to drying, including VOCs that are emitted by the wood.

Table 9 Unit process inputs/outputs for kiln drying to produce 1 m^3 of rough dry softwood lumber, PNW.

Products	**Value**	**Unit/m^3**
Sawn Lumber, rough, kiln dried	1	m^3
Materials/fuels		
Electricity, at Grid	28.25	kWh
Natural gas, combusted in industrial boiler	19.85	m^3
Diesel, combusted in industrial boiler	0.05	L
Diesel	0.24	L
Wood waste, combusted in industrial boiler	76.55	kg
Sawn lumber, rough, green	452.00	kg
Emissions to air		
Particulates, unspecified	0.0048	kg
VOC, volatile organic compounds	0.0494	kg
Waste to treatment		
Dummy Disposal, inert solid waste, to inert material landfill/US	0.0056	kg

3.3.2.6 Planing

The planer process included un-stacking rough-dry lumber, planing rough-dry lumber, grading planed lumber, sorting graded lumber, packaging graded lumber, and loading graded lumber for shipment. Inputs include dry lumber, electricity, diesel, and LPG. In the PNW region (Table 10), the planing process produced 1 m^3 of planed, dry lumber from rough dry lumber. Electricity is used to operate the planer, saws, conveyers, and other equipment and the other fuels that are used in lumber handling equipment, such as forklifts. Plastic film, cardboard corners, and steel strapping are used to package the product for shipping and are included in the planning process (Table 10). Surveys indicated that all other materials, such as paints for end-sealing, used in the process were minor and have been excluded according the PCR. All co-products are sold offsite.

Table 10 Unit process inputs/outputs for planing to produce 1 m^3 of planed dry softwood lumber, PNW.

Products	**Value**	**Unit/m^3**	**Allocation**
Sawn Lumber, softwood, planed, kiln dried	1	m^3	86%
Sawdust, dry	6.99	kg	1%
Pulp chips, dry	28.53	kg	6%
Planer shavings, dry	36.92	kg	7%
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	17.46	kWh	
Diesel	0.3525	L	
LPG	0.0001	L	
Sawn Lumber, kiln dried	524.32	kg	
Wrapping material - Packaging	5.90	package	
Strap Protectors - Packaging	1.70	kg	
Strapping - Packaging	0.15	kg	
Spacers - Packaging	-		
Emissions to air	**Value**	**Unit/m^3**	
VOC, volatile organic compounds	0.0103	kg	
Particulates, unspecified	0.0236	kg	
Waste to treatment	**Value**	**Unit/m^3**	
Dummy Disposal, inert solid waste, to inert material landfill	0.0026	kg	

3.3.2.7 Packaging

Materials used for packaging planed, dry lumber for shipping are shown in Table 11.

Table 11 Materials used in packaging and shipping per m^3, PNW.

Material	Value	Unit
Wrapping Material – HDPE and LDPE laminated paper	0.590	kg
Metal Strapping	0.147	kg
Cardboard strap protectors	0.170	kg
Wooden spacers	-	kg

Packing materials represent 1.06% of the cumulative mass of the model flow. Mills reported plastic wrap, which is used to protect planed dry lumber from rain and humidity, on a square foot (ft^2) basis. The wrap was weighed to convert the reported values to mass. The mass of the plastic wrap is 0.804% of the mass of the product. Linerboard is used to make paper corners to protect lumber from strap damage, on a square foot basis. The linerboard mass is 0.232% of the mass of the product. Strapping was reported in pounds. Strapping is used to hold the packages of planed lumber together. The strapping mass is 0.02% of the mass of the product.

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 13 and would be included in the impact assessment. Table 13 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 the Appendix (Section 13) of this report.

5 Data quality requirements

This study collected data from representative mills in the PNW region. The sawmill complexes responding were of average technology for the region and were primarily using band saws. For PNW softwood lumber production, the survey was for dimension lumber produced in the states of Oregon and Washington, west of the Cascade Mountains. The main wood species consider were Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) with a regional softwood lumber production of approximately 21 million cubic meters, 70% of which is dimension lumber. A small amount of true fir (Abies spp.) may also be included with the western hemlock. The total production of the PNW responding mills was 1.91 million m^3 or 13% of the PNW regional production.

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 are scientifically sound, and are in conformance with ISO 14040 (ISO 2006) and CORRIM research protocols. Complete details of this study for lumber production and the overall CORRIM project can be found in Milota (2004) and Lippke et al. (2004), respectively.

6 Life cycle inventory analysis

6.1 Data collection

Primary data for the LCI was collected through surveys in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production and emissions data provided by lumber producers from the PNW, with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). Four mills (of seven surveyed) provided data for 1999 or 2000 in terms of lumber and co-product production, raw materials, electricity, and fuel use, and on-site emissions released.

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.

The primary data in the PNW survey indicated that 78.1 percent of the planed dry lumber produced was western hemlock and 21.9 percent is Douglas-fir. For hemlock, 95 percent is sold dry compared to 18 percent for Douglas-fir. Comparing these results to secondary data published by the Western Wood

Products Association (WWPA 2000) indicates that the survey data reflects relative amounts of products produced. PNW U.S. mills often produce both green and dry planed lumber and are not able to separate sawing and planing material inputs and outputs for green versus dry lumber production. However, the differences are minor and the annual data for these processes can represent dry lumber production. The major differences are that green lumber bypasses drying and the finished planed green sizes are slightly larger to account for future shrinkage.

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 1) the applicable fuel and oil consumption rates were developed for each equipment component within the harvesting system (Table 2). These data were derived from existing studies for the types of harvesting equipment used in the region and included both published information and personal interviews with timber harvesting contractors (Biltonen 2002; Hochrein and Kellogg 1988; Jorgenson 2002; Keegan et al. 1995; Kellogg and Bettinger. 1995; Kellogg et al. 1996; Lawson 2002; Ledoux 1984; Reynolds 2002; Stevens and Clarke 1974). Production and consumption factors of the harvesting system were calculated by adding the emissions for each piece of equipment used per m^3 of production

PNW mills reported logs in units of Westside Scribner board feet. These were converted to a cubic measurement using values in Briggs (1994). The resulting log volumes sawn per unit of production calculated for each mill varied by 8% around the production-weighted mean of 3.05 m^3. This variance is to be expected because of uncertainties associated with dependence on log diameter when converting the Scribner measure to an actual volume. It is considered a relatively small margin of error. As a second check, log mass into the process was within 8% of the sum of the co-products mass from the sawing unit process. This is also a small margin of error given that mills have a much better ability to accurately measure the products and co-products than the logs

Most planed dry lumber reported in the surveys was 38 mm in thickness with widths from 63 to 286 mm. The weighted average width was 152 mm. The closest commercial width to the western average was 140 mm. Therefore, the volume of planed, dry lumber produced was assumed to be all 38 by 140 mm, corresponding to U.S. nominal 2 x 6-inch lumber.

The survey results for each unit process were converted to a production basis (e.g., logs used per m^3 of lumber produced) and production-weighted averages were calculated for each material. This approach resulted in a sawmill complex that represents a composite of the mills surveyed, but may not represent any mill in particular. The USLCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 7+ (Pré Consultants 2012) was used as the accounting program to track all of the materials.

Missing data is defined as data not reported in surveys by the softwood lumber facilities. 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

All allocation was based on the mass of the products and co-products. PNW lumber 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 lumber are presented by two life stages, 1) forestry operations, 2) lumber production (Tables 13-15). The majority of the raw material energy consumption occurs during wood production with only a small portion arising from forestry operations. Raw material energy requirements are presented in Table 12 for 1 m^3 of softwood lumber. Air emissions are reported in Table 13, water emissions are reported in Table 14 and solid waste emissions are reported in Table 15.

Table 12 Raw material energy consumption per 1 m^3 of dry planed softwood lumber, PNW

Fuel	Total	Forestry Operations	Wood Production
	kg/m^3		
Coal, in ground	12.5554	0.1534	12.4020
Gas, natural, in ground	20.7703	0.1379	20.6324
Oil, crude, in ground	6.7166	2.6104	4.1062
Uranium oxide, in ore	0.0003	0.0000	0.0003
Wood waste	76.3625	0.0000	76.3625

Of the crude oil used in the PNW softwood lumber processes, 18% is attributable to natural gas extraction, 5% is burned in the boiler, and the remaining 77% is used for diesel to power machinery such as skidders and forklifts. The coal in the PNW softwood lumber processes is 13% attributable to the production of steel to make the strapping, 66% to the extraction of natural gas, and the balance of 21%, to electrical generation. Similarly, uranium in the PNW softwood lumber processes is 78% attributed to natural gas extraction, 5% attributed to steel production, and the balance to electrical generation.

Table 13 Air emissions released per 1 m^3 of dry planed softwood lumber, PNW.

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m3		
Carbon dioxide, biogenic	135.0000	0.0071	135.0000
Carbon dioxide, fossil	102.0000	9.0100	93.4000
Sulfur dioxide	0.6830	0.0059	0.6770
Nitrogen oxides	0.5650	0.1630	0.4020
Carbon monoxide	0.4120	0.0000	0.4120
Particulates, > 2.5 um, and < 10um	0.3560	0.0050	0.3510
Methane	0.3430	0.0122	0.3310
Particulates, < 2.5 um	0.2960	0.0000	0.2960
Carbon monoxide, fossil	0.2190	0.0819	0.1370
VOC, volatile organic compounds	0.1080	0.0044	0.1030
Particulates, < 10 um	0.0802	0.0000	0.0802

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m3		
Particulates, unspecified	0.0448	0.0009	0.0439
Methane, fossil	0.0426	0.0009	0.0416
Sulfur oxides	0.0412	0.0091	0.0321
Metals, unspecified	0.0294	0.0000	0.0294
Carbon dioxide	0.0246	0.0245	0.0000
Hydrogen chloride	0.0196	0.0001	0.0195
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0147	0.0055	0.0093
Isoprene	0.0118	0.0002	0.0116
Particulates, SPM	0.0078	0.0000	0.0078
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0073	0.0001	0.0073
Formaldehyde	0.0031	0.0001	0.0031
Benzene	0.0030	0.0000	0.0029
TOC, Total Organic Carbon	0.0028	0.0000	0.0028
Acrolein	0.0028	0.0000	0.0028
Manganese	0.0011	0.0000	0.0011
Acetaldehyde	0.0009	0.0000	0.0009
Hydrogen fluoride	0.0008	0.0000	0.0008
Dinitrogen monoxide	0.0007	0.0002	0.0005
Methanol	0.0006	0.0000	0.0006
Chlorine	0.0005	0.0000	0.0005
Radionuclides (Including Radon)	0.0004	0.0000	0.0004
Aldehydes, unspecified	0.0003	0.0001	0.0002
Methane, dichloro-, HCC-30	0.0002	0.0000	0.0002
Ammonia	0.0002	0.0001	0.0001
Propene	0.0002	0.0001	0.0000

[1/] Due to large amount of air emissions, total 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 14). No mill in the survey discharged any process water. Most sawmills operate with this restriction. 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 14 Emissions to water released per 1 m^3 of dry planed softwood lumber, PNW.

Water emission	**Total**	**Forestry Operations**	**Wood Production**
	kg/m^3		
Solved solids	5.2800	0.4680	4.8100
Chloride	4.2800	0.3800	3.9000
Sodium, ion	1.2100	0.1070	1.1000
Calcium, ion	0.3800	0.0338	0.3470
Suspended solids, unspecified	0.1310	0.0276	0.1030
Lithium, ion	0.1010	0.0007	0.1000
Magnesium	0.0744	0.0066	0.0678
Barium	0.0568	0.0123	0.0445
COD, Chemical Oxygen Demand	0.0358	0.0036	0.0321
Bromide	0.0254	0.0023	0.0231
BOD5, Biological Oxygen Demand	0.0208	0.0019	0.0189
Sulfate	0.0146	0.0009	0.0137
Iron	0.0101	0.0018	0.0083
Strontium	0.0065	0.0006	0.0059
Aluminum	0.0040	0.0009	0.0031
Oils, unspecified	0.0038	0.0002	0.0036
Ammonia	0.0016	0.0002	0.0014
Fluoride	0.0008	0.0007	0.0001
Phosphate	0.0005	0.0005	0.0000
Boron	0.0004	0.0000	0.0003
Sulfur	0.0003	0.0000	0.0003
Silver	0.0002	0.0000	0.0002
Manganese	0.0002	0.0000	0.0002
Benzene	0.0002	0.0000	0.0002
Toluene	0.0002	0.0000	0.0002
Sulfide	0.0001	0.0000	0.0001
Benzoic acid	0.0001	0.0000	0.0001
Detergent, oil	0.0001	0.0000	0.0001
Zinc	0.0001	0.0000	0.0001

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

Solid emissions include ash generated at the boiler and in the extraction of natural gas. Some waste that is collected from the log-yard and cannot be sent to the boiler because it is mixed with dirt is also included (Table 15).

Table 15 Waste to treatment per 1 m^3 of dry planed softwood lumber, PNW.

Waste to treatment	Total	Forestry Operations	Wood Production
	kg/m^3		
Solid waste	12.8068	0.1445	12.6622

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 16. Environmental impacts are determined using the TRACI method (Bare et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (PCR 2011).

Table 16 Selected impact indicators, characterization models, and impact categories.

Impact Indicator	Characterization Model	Impact Category
Greenhouse gas (GHG) emissions	Calculate total emissions in the reference unit of CO_2 equivalents for CO_2, methane, and nitrous oxide.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the stratosphere including CFC's HCFC's, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total 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. All are presented as equals. Additionally, each impact indicator value is stated in units that are not comparable to others. For the same reasons, indicators should not be combined or added. Table 17 provides the environmental impact by category for softwood lumber produced in the PNW 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 17. For GWP, 92 percent of the CO_2 equivalent emissions come from producing lumber, with remainder assigned to forestry operations.

Table 17 Environmental performance of 1 m^3 planed dry softwood lumber, PNW.

Impact category	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Global warming potential (GWP)	kg CO_2 equiv	112.29	9.41	102.88
Acidification Potential	H+ moles equiv	60.38	7.31	53.07
Eutrophication Potential	kg N equiv	0.0297	0.0089	0.0207
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000
Smog Potential	kg O3 equiv	14.63	4.07	10.56
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable fossil	MJ	1764.90	130.30	1634.60
Non-renewable nuclear	MJ	97.14	1.37	95.77
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	72.95	0.23	72.72
Renewable, biomass	MJ	1597.26	0.00	1597.25
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable materials[5]	kg	0.1138	0.0078	0.1060
Renewable materials	kg	466.04	0.00	466.04
Fresh water	L	105.74	9.01	96.73
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Solid waste	kg	12.81	0.14	12.66

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[5] Limestone, in ground has been removed from a precombustion wood fuel extraction process (NREL 2012). This process was used for "purchased wood fuel" as reported by some wood product manufacturers. As noted in the process documentation the data was collected from pulp and paper mills using fluidized bed boilers. Fluidized bed boilers are not used in the solid wood products industry.

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, 112 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 829 kg CO_2e (Table 18).

Table 18 Carbon per 1 m^3 softwood lumber, PNW

	kg CO_2 equivalent
released forestry operations	9.41
released manufacturing	102.88
CO_2 eq. stored in product	828.66

9 Conclusions

The cradle to gate LCA for softwood lumber includes the LCI of forest resources that relies on secondary and tertiary data and the LCI of manufacturing that relies on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest operations in the region that would produce the relative amounts of Douglas-fir and hemlock lumber that are reported as outputs for the region. The survey data are representative of the lumber sizes and production volumes consistent with trade association production data. Many materials, such as paints, and anti-stain chemicals are used in small quantities and comprise less than 0.1% of the product mass. They were not included in the LCIA.

Emissions from the forest resources LCI are small relative to manufacturing emissions. At the mill site emissions to land and water are small. Mill site airborne emissions originate mainly at the boiler and are a function of the fuel burned. Electrical energy use is greatest in the sawmill with overall energy use and emissions dominated by the drying process.

Wood fuel represented 58 percent of the mill site use of heat energy. Energy generated by renewable fuels, such as woody biomass, represents about 45 percent of the total energy from cradle to gate. Of the renewable biomass fuels, 99 percent was wood fuel from the lumber production. Total nonrenewable fossil fuel use was 58 percent of the total energy from cradle to gate. Forestry operations consumed exclusively (99%) fossil fuels. Lumber production alone consumed 47 percent of the total energy from biomass (wood fuel) and 48 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, 112 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 829 kg CO_2e.

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11 Critical Review

11.1 Internal Review

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

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

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

11.2 External Review

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

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

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.

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.

Briggs, D. G. 1994. Forest products measurements and conversion factors with special emphasis on the U.S. Pacific Northwest. College of Forest Resources. University of Washington, Seattle, WA. Contribution No. 75.

Environmental Protection Agency (EPA). 2010. 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). 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). 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 .

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/.

Hochrein, P. & L.D. Kellogg, 1988, Production and cost comparison for three skyline thinning systems, Western Journal of Applied Forestry, 3(4):120-123.

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.

Jorgenson, Gary. 2002. Horizon Helicopters, Pilot, Laclede, Idaho, Personal Interview.

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.

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

Ledoux, C. 1984. Production rates and costs of cable yarding wood residue from clearcut units, Forest Products Journal, 34(4):55-60.

Lippke B. and J. Comnick, 2002, Stand Management Scenarios for the Pacific Northwest. Personal Communication.

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 PNW and SE from the 2000 Resources Planning Act Assessment of Forest and Rangelands. Personal Communication.

Milota, M.R. 2004. Softwood lumber—Pacific Northwest Region. In CORRIM Phase I Final Report Module B. Life-cycle environmental performance of renewable building materials in the context of residential construction. University of Washington, Seattle, WA. Http://www.corrim.org/reports/. 75 pp.

Milota, M.R, C.D. West, and I.D. Hartley. 2005. Gate-to-gate life cycle inventory of softwood lumber production. Wood and Fiber Sci. 37 CORRIM Special Issue. Pp. 47-57.

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.

Schlosser, W. E., J. H. Bassman, P. R. Wandschneider, and R. L. Everett. 2003. A carbon balance assessment for containerized Larix gmelinii seedlings in the Russian Far East. Forest Ecology and Management 173:335-351.

Stevens, P. & E. Clarke. 1974. Helicopters for logging: characteristics, operation, and safety considerations. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-20. Portland, Oregon. 16p.

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

Wilen, C., A. Moilanen, and E. Kurkela. 1996. Biomass feedstock analyses. Technical Research Center of Finland. VTT Publications No. 282. 25 pp.

Wenny, David. 2003. Fertilizer treatments of seedlings at the University of Idaho Forest Nursery. Personal Communication.

Werner, Frank. 2004. Review in conformity with ISO 14044FF. Module B. Softwood Lumber–Pacific Northwest region. Milota, M.R. 10 December, 2004.

Western Wood Products Association. 2000. 1999 WWPA Statistical Yearbook of the Western Lumber Industry. Portland, OR.

Wykoff, William R. July 1986. Supplement to the user's Guide for the Stand Prognosis Model---Version 5.0. Gen. Tech. Report-INT-281. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Research Station. 40 p.

13 Appendix

13.1 Air Emissions

Table A.1 Air emissions released per 1 m^3 of dry planed softwood lumber, PNW.

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
2,4-D	kg	6.15E-12		6.15E-12
2-Chloroacetophenone	kg	2.01E-11	1.55E-12	1.86E-11
5-methyl Chrysene	kg	1.19E-10	1.57E-12	1.17E-10
Acenaphthene	kg	2.75E-09	3.63E-11	2.72E-09
Acenaphthylene	kg	1.35E-09	1.78E-11	1.33E-09
Acetaldehyde	kg	9.44E-04	3.75E-05	9.06E-04
Acetochlor	kg	8.53E-11		8.53E-11
Acetophenone	kg	4.31E-11	3.32E-12	3.98E-11
Acrolein	kg	2.76E-03	4.54E-06	2.75E-03
Alachlor	kg	8.39E-12		8.39E-12
Aldehydes, unspecified	kg	2.85E-04	1.13E-04	1.72E-04
Ammonia	kg	1.82E-04	7.54E-05	1.07E-04
Ammonium chloride	kg	1.35E-05	2.03E-07	1.33E-05
Anthracene	kg	1.13E-09	1.50E-11	1.12E-09
Antimony	kg	5.53E-06	1.28E-09	5.53E-06
Arsenic	kg	1.75E-05	4.06E-08	1.74E-05
Atrazine	kg	1.66E-10		1.66E-10
Bentazone	kg	6.78E-13		6.78E-13
Benzene	kg	2.96E-03	4.58E-05	2.91E-03
Benzene, chloro-	kg	6.33E-11	4.87E-12	5.84E-11
Benzene, ethyl-	kg	2.70E-10	2.08E-11	2.50E-10
Benzo(a)anthracene	kg	4.32E-10	5.70E-12	4.26E-10
Benzo(a)pyrene	kg	2.05E-10	2.71E-12	2.02E-10
Benzo(b,j,k)fluoranthene	kg	5.94E-10	7.84E-12	5.86E-10
Benzo(ghi)perylene	kg	1.46E-10	1.92E-12	1.44E-10
Benzyl chloride	kg	2.01E-09	1.55E-10	1.86E-09
Beryllium	kg	8.85E-07	2.00E-09	8.83E-07
Biphenyl	kg	9.17E-09	1.21E-10	9.05E-09
Bromoform	kg	1.12E-10	8.64E-12	1.04E-10
Bromoxynil	kg	1.49E-12		1.49E-12
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	7.30E-03	5.15E-05	7.25E-03
Butadiene	kg	2.57E-06	1.91E-06	6.56E-07
Cadmium	kg	3.62E-06	9.90E-09	3.61E-06
Carbofuran	kg	1.27E-12		1.27E-12
Carbon dioxide	kg	2.46E-02	2.45E-02	3.45E-05

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Carbon dioxide, biogenic	kg	1.35E+02	7.12E-03	1.35E+02
Carbon dioxide, fossil	kg	1.02E+02	9.01E+00	9.34E+01
Carbon disulfide	kg	3.74E-10	2.88E-11	3.45E-10
Carbon monoxide	kg	4.12E-01	3.35E-06	4.12E-01
Carbon monoxide, fossil	kg	2.19E-01	8.19E-02	1.37E-01
Chloride	kg	3.60E-10	5.45E-12	3.55E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	3.13E-09		3.13E-09
Chlorine	kg	5.43E-04		5.43E-04
Chloroform	kg	1.70E-10	1.31E-11	1.57E-10
Chlorpyrifos	kg	9.78E-12		9.78E-12
Chromium	kg	1.65E-05	2.91E-08	1.65E-05
Chromium VI	kg	4.26E-07	5.63E-09	4.21E-07
Chrysene	kg	5.40E-10	7.13E-12	5.33E-10
Cobalt	kg	5.20E-06	5.56E-08	5.15E-06
Copper	kg	1.86E-08	4.99E-10	1.81E-08
Cumene	kg	1.52E-11	1.17E-12	1.41E-11
Cyanazine	kg	1.47E-12		1.47E-12
Cyanide	kg	7.19E-09	5.54E-10	6.64E-09
Dicamba	kg	8.63E-12		8.63E-12
Dimethenamid	kg	2.04E-11		2.04E-11
Dinitrogen monoxide	kg	6.66E-04	1.53E-04	5.13E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.25E-11	2.05E-17	1.25E-11
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	4.89E-12	1.79E-13	4.71E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	1.40E-11		1.40E-11
Ethane, 1,1,1-trichloro-, HCFC-140	kg	7.03E-10	2.64E-10	4.38E-10
Ethane, 1,2-dibromo-	kg	3.45E-12	2.66E-13	3.19E-12
Ethane, 1,2-dichloro-	kg	1.15E-10	8.86E-12	1.06E-10
Ethane, chloro-	kg	1.21E-10	9.30E-12	1.11E-10
Ethene, tetrachloro-	kg	2.36E-07	3.68E-09	2.32E-07
Ethene, trichloro-	kg	4.47E-10		4.47E-10
Fluoranthene	kg	3.83E-09	5.06E-11	3.78E-09
Fluorene	kg	4.91E-09	6.48E-11	4.85E-09
Fluoride	kg	7.14E-07	2.93E-07	4.21E-07
Formaldehyde	kg	3.14E-03	5.82E-05	3.08E-03
Furan	kg	2.67E-11	3.26E-13	2.64E-11
Glyphosate	kg	1.83E-11		1.83E-11
Hexane	kg	1.93E-10	1.48E-11	1.78E-10
Hydrazine, methyl-	kg	4.89E-10	3.76E-11	4.51E-10
Hydrocarbons, unspecified	kg	7.78E-05	1.17E-06	7.67E-05
Hydrogen	kg	3.46E-09		3.46E-09
Hydrogen chloride	kg	1.96E-02	9.14E-05	1.95E-02

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Hydrogen fluoride	kg	8.10E-04	1.07E-05	7.99E-04
Hydrogen sulfide	kg	1.16E-11	1.76E-13	1.15E-11
Indeno(1,2,3-cd)pyrene	kg	3.29E-10	4.35E-12	3.25E-10
Isophorone	kg	1.67E-09	1.28E-10	1.54E-09
Isoprene	kg	1.18E-02	1.79E-04	1.16E-02
Kerosene	kg	6.47E-06	9.70E-08	6.37E-06
Lead	kg	3.56E-05	4.50E-08	3.55E-05
Magnesium	kg	5.94E-05	7.84E-07	5.86E-05
Manganese	kg	1.10E-03	6.04E-08	1.10E-03
MCPA	kg	1.15E-13		1.15E-13
Mercaptans, unspecified	kg	6.21E-07	4.76E-08	5.74E-07
Mercury	kg	2.99E-06	8.01E-09	2.98E-06
Metals, unspecified	kg	2.94E-02	2.02E-14	2.94E-02
Methacrylic acid, methyl ester	kg	5.75E-11	4.43E-12	5.31E-11
Methane	kg	3.43E-01	1.22E-02	3.31E-01
Methane, bromo-, Halon 1001	kg	4.60E-10	3.54E-11	4.25E-10
Methane, dichloro-, HCC-30	kg	2.01E-04	6.20E-08	2.01E-04
Methane, dichlorodifluoro-, CFC-12	kg	7.98E-10	3.22E-10	4.76E-10
Methane, fossil	kg	4.26E-02	9.32E-04	4.16E-02
Methane, monochloro-, R-40	kg	1.52E-09	1.17E-10	1.41E-09
Methane, tetrachloro-, CFC-10	kg	8.27E-10	3.22E-11	7.95E-10
Methanol	kg	5.51E-04		5.51E-04
Methyl ethyl ketone	kg	1.12E-09	8.64E-11	1.04E-09
Methyl methacrylate	kg	5.94E-16		5.94E-16
Metolachlor	kg	6.74E-11		6.74E-11
Metribuzin	kg	3.12E-13		3.12E-13
Naphthalene	kg	6.70E-05	1.15E-08	6.70E-05
Nickel	kg	2.74E-05	7.02E-07	2.67E-05
Nitrogen oxides	kg	5.65E-01	1.63E-01	4.02E-01
Nitrogen, total	kg	5.54E-06	5.54E-06	8.24E-12
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.47E-02	5.46E-03	9.29E-03
N-Nitrodimethylamine	kg	9.98E-11		9.98E-11
Organic acids	kg	4.95E-08	7.44E-10	4.88E-08
Organic substances, unspecified	kg	3.38E-05	4.42E-07	3.34E-05
PAH, polycyclic aromatic hydrocarbons	kg	1.10E-05	8.22E-06	2.82E-06
Paraquat	kg	1.36E-12		1.36E-12
Parathion, methyl	kg	1.03E-12		1.03E-12
Particulates, < 10 um	kg	8.02E-02		8.02E-02
Particulates, < 2.5 um	kg	2.96E-01		2.96E-01
Particulates, > 2.5 um, and < 10um	kg	3.56E-01	5.01E-03	3.51E-01
Particulates, SPM	kg	7.79E-03		7.79E-03

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Particulates, unspecified	kg	4.48E-02	8.93E-04	4.39E-02
Pendimethalin	kg	7.01E-12		7.01E-12
Permethrin	kg	6.30E-13		6.30E-13
Phenanthrene	kg	1.46E-08	1.92E-10	1.44E-08
Phenol	kg	5.71E-05	3.54E-12	5.71E-05
Phenols, unspecified	kg	3.53E-05	3.23E-08	3.53E-05
Phorate	kg	3.23E-13		3.23E-13
Phosphate	kg	1.27E-07	1.27E-07	
Phthalate, dioctyl-	kg	2.10E-10	1.62E-11	1.94E-10
Propanal	kg	1.09E-09	8.41E-11	1.01E-09
Propene	kg	1.69E-04	1.26E-04	4.33E-05
Pyrene	kg	1.78E-09	2.35E-11	1.76E-09
Radioactive species, unspecified	Bq	3.07E+05	4.03E+03	3.03E+05
Radionuclides (Including Radon)	kg	3.61E-04	5.42E-06	3.56E-04
Selenium	kg	9.02E-06	9.94E-08	8.92E-06
Simazine	kg	4.43E-12		4.43E-12
Styrene	kg	7.19E-11	5.54E-12	6.64E-11
Sulfur	kg	2.07E-08		2.07E-08
Sulfur dioxide	kg	6.83E-01	5.88E-03	6.77E-01
Sulfur oxides	kg	4.12E-02	9.06E-03	3.21E-02
Sulfuric acid, dimethyl ester	kg	1.38E-10	1.06E-11	1.27E-10
Tar	kg	4.05E-10	6.13E-12	3.99E-10
t-Butyl methyl ether	kg	1.01E-10	7.75E-12	9.29E-11
Terbufos	kg	1.10E-11		1.10E-11
TOC, Total Organic Carbon	kg	2.81E-03		2.81E-03
Toluene	kg	2.69E-05	2.00E-05	6.86E-06
Toluene, 2,4-dinitro-	kg	8.05E-13	6.20E-14	7.43E-13
Vinyl acetate	kg	2.19E-11	1.68E-12	2.02E-11
VOC, volatile organic compounds	kg	1.08E-01	4.38E-03	1.03E-01
Xylene	kg	1.87E-05	1.39E-05	4.78E-06
Zinc	kg	1.15E-07	1.03E-07	1.20E-08

13.2 Water Emissions

Table 19 Emissions to water released per 1 m^3 of dry planed softwood lumber, PNW.

Water Emission	Unit	Total	Forestry Operations	Lumber Production
2-Hexanone	kg	7.73E-07	6.87E-08	7.04E-07
2-Propanol	kg	3.12E-10		3.12E-10
2,4-D	kg	2.64E-13		2.64E-13
4-Methyl-2-pentanone	kg	4.98E-07	4.42E-08	4.53E-07
Acetochlor	kg	3.65E-12		3.65E-12
Acetone	kg	1.18E-06	1.05E-07	1.08E-06
Acidity, unspecified	kg	6.13E-12		6.13E-12
Acids, unspecified	kg	1.84E-08	1.15E-10	1.83E-08
Alachlor	kg	3.60E-13		3.60E-13
Aluminium	kg	1.03E-07		1.03E-07
Aluminum	kg	4.03E-03	8.97E-04	3.13E-03
Ammonia	kg	1.63E-03	1.96E-04	1.43E-03
Ammonia, as N	kg	3.80E-09	5.75E-11	3.74E-09
Ammonium, ion	kg	-9.60E-04	4.33E-08	-9.60E-04
Antimony	kg	2.43E-06	5.60E-07	1.87E-06
Arsenic, ion	kg	2.79E-05	3.11E-06	2.47E-05
Atrazine	kg	7.12E-12		7.12E-12
Barium	kg	5.68E-02	1.23E-02	4.45E-02
Bentazone	kg	2.91E-14		2.91E-14
Benzene	kg	1.95E-04	1.76E-05	1.77E-04
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.18E-08	1.05E-09	1.08E-08
Benzene, ethyl-	kg	1.12E-05	9.92E-07	1.02E-05
Benzene, pentamethyl-	kg	8.87E-09	7.88E-10	8.08E-09
Benzenes, alkylated, unspecified	kg	2.13E-06	4.91E-07	1.63E-06
Benzo(a)pyrene	kg	4.38E-07		4.38E-07
Benzoic acid	kg	1.20E-04	1.07E-05	1.09E-04
Beryllium	kg	1.32E-06	1.60E-07	1.16E-06
Biphenyl	kg	1.38E-07	3.18E-08	1.06E-07
BOD5, Biological Oxygen Demand	kg	2.08E-02	1.92E-03	1.89E-02
Boron	kg	3.73E-04	3.30E-05	3.40E-04
Bromide	kg	2.54E-02	2.25E-03	2.31E-02
Bromoxynil	kg	3.84E-14		3.84E-14
Cadmium, ion	kg	4.16E-06	5.04E-07	3.66E-06
Calcium, ion	kg	3.80E-01	3.38E-02	3.47E-01
Carbofuran	kg	5.44E-14		5.44E-14
CFCs, unspecified	kg	3.12E-10		3.12E-10
Chloride	kg	4.28E+00	3.80E-01	3.90E+00

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Chlorpyrifos	kg	4.19E-13		4.19E-13
Chromate	kg	3.87E-10		3.87E-10
Chromium	kg	5.87E-05	2.39E-05	3.48E-05
Chromium VI	kg	2.46E-07	9.92E-08	1.47E-07
Chromium, ion	kg	5.14E-05	1.86E-06	4.95E-05
Cobalt	kg	2.62E-06	2.33E-07	2.39E-06
COD, Chemical Oxygen Demand	kg	3.58E-02	3.64E-03	3.21E-02
Copper, ion	kg	2.31E-05	3.14E-06	2.00E-05
Cyanazine	kg	6.28E-14		6.28E-14
Cyanide	kg	5.01E-05	7.59E-10	5.01E-05
Decane	kg	3.45E-06	3.07E-07	3.14E-06
Detergent, oil	kg	1.14E-04	8.87E-06	1.05E-04
Dibenzofuran	kg	2.25E-08	2.00E-09	2.05E-08
Dibenzothiophene	kg	1.87E-08	1.72E-09	1.69E-08
Dicamba	kg	3.70E-13		3.70E-13
Dimethenamid	kg	8.74E-13		8.74E-13
Dipropylthiocarbamic acid S-ethyl ester	kg	3.61E-13		3.61E-13
Disulfoton	kg	2.16E-14		2.16E-14
Diuron	kg	6.06E-15		6.06E-15
DOC, Dissolved Organic Carbon	kg	2.32E-11	3.52E-13	2.29E-11
Docosane	kg	1.27E-07	1.13E-08	1.15E-07
Dodecane	kg	6.55E-06	5.82E-07	5.97E-06
Eicosane	kg	1.80E-06	1.60E-07	1.64E-06
Fluorene, 1-methyl-	kg	1.35E-08	1.20E-09	1.23E-08
Fluorenes, alkylated, unspecified	kg	1.23E-07	2.84E-08	9.47E-08
Fluoride	kg	7.70E-04	7.09E-04	6.11E-05
Fluorine	kg	6.71E-08	1.40E-08	5.30E-08
Glyphosate	kg	7.86E-13		7.86E-13
Hexadecane	kg	7.15E-06	6.35E-07	6.51E-06
Hexanoic acid	kg	2.49E-05	2.21E-06	2.27E-05
Hydrocarbons, unspecified	kg	2.91E-11	4.40E-13	2.86E-11
Iron	kg	1.01E-02	1.79E-03	8.28E-03
Lead	kg	5.54E-05	6.13E-06	4.92E-05
Lead-210/kg	kg	1.23E-14	1.09E-15	1.12E-14
Lithium, ion	kg	1.01E-01	7.22E-04	1.00E-01
m-Xylene	kg	3.59E-06	3.19E-07	3.27E-06
Magnesium	kg	7.44E-02	6.60E-03	6.78E-02
Manganese	kg	2.15E-04	1.18E-05	2.03E-04
MCPA	kg	4.92E-15		4.92E-15
Mercury	kg	4.98E-08	1.34E-08	3.63E-08
Metallic ions, unspecified	kg	1.31E-07	5.37E-12	1.31E-07

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Methane, monochloro-, R-40	kg	4.77E-09	4.23E-10	4.34E-09
Methyl ethyl ketone	kg	9.53E-09	8.47E-10	8.68E-09
Metolachlor	kg	2.89E-12		2.89E-12
Metribuzin	kg	1.34E-14		1.34E-14
Molybdenum	kg	2.72E-06	2.42E-07	2.48E-06
n-Hexacosane	kg	7.90E-08	7.02E-09	7.20E-08
Naphthalene	kg	-1.20E-06	1.92E-07	-1.39E-06
Naphthalene, 2-methyl-	kg	1.88E-06	1.67E-07	1.71E-06
Naphthalenes, alkylated, unspecified	kg	3.48E-08	8.04E-09	2.68E-08
Nickel	kg	2.33E-05	2.94E-06	2.03E-05
Nickel, ion	kg	1.16E-07		1.16E-07
Nitrate	kg	5.40E-09	3.86E-14	5.40E-09
Nitrate compounds	kg	1.03E-10	1.55E-12	1.01E-10
Nitric acid	kg	2.30E-07	3.48E-09	2.26E-07
Nitrogen, total	kg	6.18E-05	1.08E-07	6.17E-05
o-Cresol	kg	3.41E-06	3.03E-07	3.10E-06
Octadecane	kg	1.77E-06	1.57E-07	1.61E-06
Oils, unspecified	kg	3.81E-03	2.42E-04	3.57E-03
Organic substances, unspecified	kg	1.25E-06		1.25E-06
p-Cresol	kg	3.67E-06	3.26E-07	3.35E-06
Paraquat	kg	5.85E-14		5.85E-14
Parathion, methyl	kg	4.42E-14		4.42E-14
Pendimethalin	kg	3.00E-13		3.00E-13
Permethrin	kg	2.70E-14		2.70E-14
Phenanthrene	kg	1.90E-08	2.90E-09	1.61E-08
Phenanthrenes, alkylated, unspecified	kg	1.44E-08	3.34E-09	1.11E-08
Phenol	kg	1.09E-05	4.39E-06	6.50E-06
Phenol, 2,4-dimethyl-	kg	3.32E-06	2.95E-07	3.02E-06
Phenols, unspecified	kg	4.41E-05	9.13E-07	4.32E-05
Phorate	kg	8.35E-15		8.35E-15
Phosphate	kg	5.33E-04	5.33E-04	-4.49E-07
Phosphorus	kg	1.13E-06		1.13E-06
Phosphorus compounds, unspecified	kg	1.55E-10		1.55E-10
Radioactive species, Nuclides, unspecified	Bq	4.19E+02	6.29E+00	4.12E+02
Radium-226/kg	kg	4.28E-12	3.80E-13	3.90E-12
Radium-228/kg	kg	2.19E-14	1.94E-15	1.99E-14
Selenium	kg	1.48E-06	1.24E-07	1.36E-06
Silver	kg	2.48E-04	2.21E-05	2.26E-04
Simazine	kg	1.90E-13		1.90E-13
Sodium, ion	kg	1.21E+00	1.07E-01	1.10E+00
Solids, inorganic	kg	5.85E-10	8.85E-12	5.76E-10

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Solved solids	kg	5.28E+00	4.68E-01	4.81E+00
Strontium	kg	6.45E-03	5.73E-04	5.88E-03
Styrene	kg	3.15E-13		3.15E-13
Sulfate	kg	1.46E-02	8.53E-04	1.37E-02
Sulfide	kg	1.49E-04	5.09E-07	1.48E-04
Sulfur	kg	3.14E-04	2.79E-05	2.86E-04
Sulfuric acid	kg	3.21E-07		3.21E-07
Suspended solids, unspecified	kg	1.31E-01	2.76E-02	1.03E-01
Tar	kg	5.79E-12	8.78E-14	5.71E-12
Terbufos	kg	2.85E-13		2.85E-13
Tetradecane	kg	2.87E-06	2.55E-07	2.61E-06
Thallium	kg	5.12E-07	1.18E-07	3.94E-07
Tin	kg	1.58E-05	2.29E-06	1.36E-05
Titanium, ion	kg	3.73E-05	8.59E-06	2.87E-05
TOC, Total Organic Carbon	kg	3.15E-09		3.15E-09
Toluene	kg	1.88E-04	1.67E-05	1.71E-04
Vanadium	kg	3.21E-06	2.86E-07	2.93E-06
Xylene	kg	9.81E-05	8.95E-06	8.91E-05
Yttrium	kg	7.98E-07	7.09E-08	7.27E-07
Zinc	kg	1.01E-04	2.08E-05	8.06E-05
Zinc, ion	kg	-5.09E-06		-5.09E-06