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

Maureen Puettmann, WoodLife Environmental Consultants, LLC
Elaine Oneil, CORRIM

November 2012
Updated April 22, 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 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 Inland Northwest (INW) region. The INW regional data is a representative cross-section of forest growth and manufacturing processes in eastern Washington, Idaho, and Montana. 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 INW forestry operations, and boiler and electrical grid data that have been developed since the original mill surveys were conducted. 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 Wagner et al. (2009), Puettmann et al. (2010) and Oneil et al. (2010). Updates in this report from the original Wagner et al. (2009) and Puettmann et al. (2010) reports include: wood combustion boiler updates, electricity grid updates (Goemans 2010), and a LCIA. Updates to the forestry operations report 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 planed dry lumber from the manufacturing base located in the INW 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 INW region.

It covers the impacts in terms of input materials, fuels, and electricity through the outputs of product, co-products, and emissions (Wagner et al. 2009, Puettmann et al. 2010). The logs are obtained from the forest resource base located in eastern Washington, Idaho, and Montana as representative of the region. The scope of this study includes cradle-to-gate LCIs based on primary data (mill surveys) for producing planed, dry dimension (framing or construction) lumber from logs using practices and technology common to the INW region. Data for the LCA are based on manufacturing gate to gate LCI's from CORRIM reports (Wagner et al. 2009, Puettmann et al. 2010) and the forest resources cradle to gate LCI (Oneil et al. 2010). 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 INW (Oneil et al. 2010) and ends with planed dry lumber (Wagner et al. 2009, Puettmann et al. 2010) (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which included site preparation on all hectares 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.

[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.

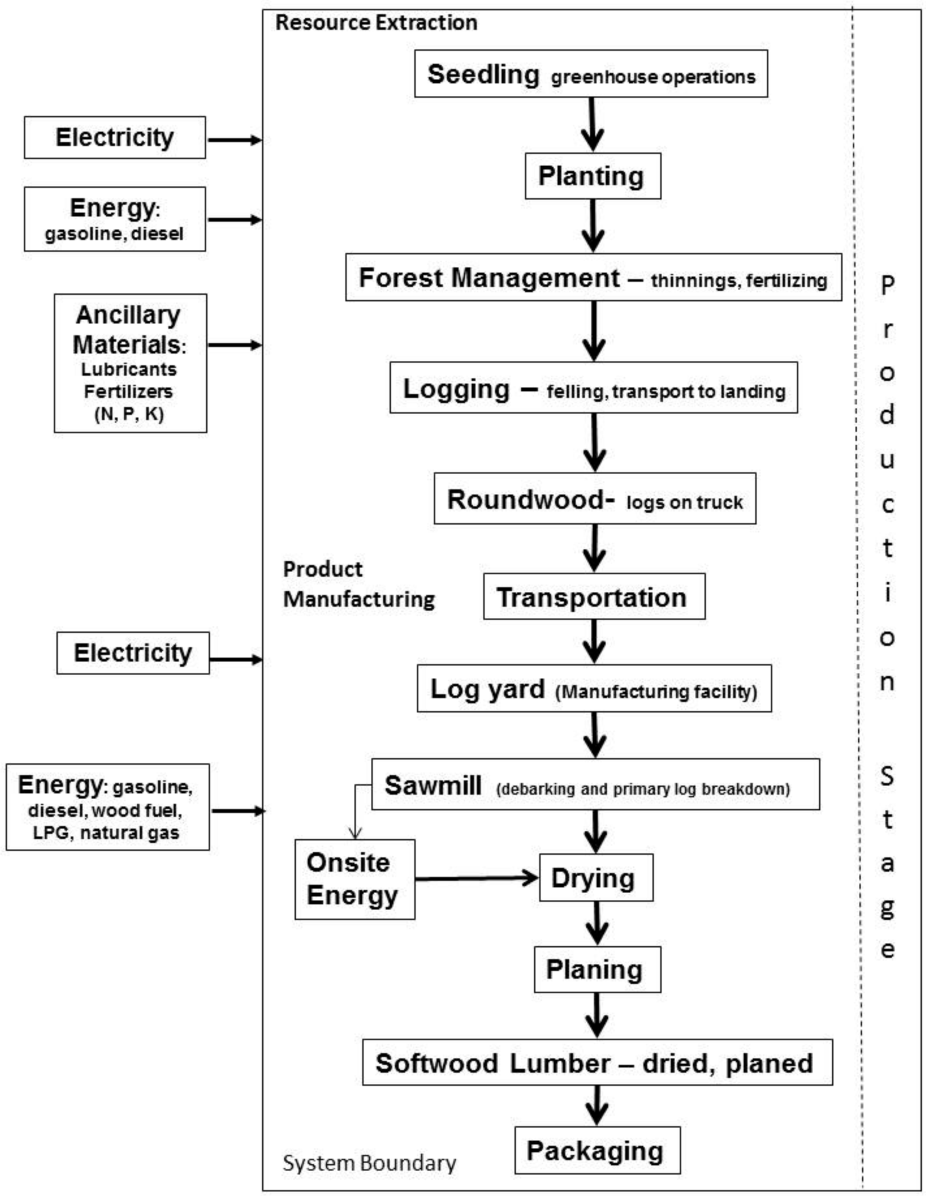

Figure 2 Cradle to gate life cycle stages for softwood lumber production, INW.

3.3 Description of data/Process Description

3.3.1 Forestry Operations

Forestry operations include growing seedlings, site preparation, planting, and harvest. The specific processes involved are reforestation: which includes seedling production, site preparation, planting, and thinning (where applicable), 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 the fuel and lubricants needed to power and maintain equipment for site preparation, 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 and disposed of through mechanical activities or prescribed fire.

Logs used in the production of softwood lumber in the Inland Northwest include in their life cycle the upstream activities associated with establishment, growth, and harvest of trees (Figure 1). 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 to enhance growth and productivity while the stand is growing can involve thinning, fertilization, or both. Because of low productivity and return on investment in the Inland Northwest, there are few operations that either thin or fertilize, therefore these operations were not modeled as part of the forest resources system.

The Inland Northwest has a complex mix of forest types, sites, stocking levels, age class distribution, harvest regimes, and ownership patterns. Most harvested volume comes from forest operations on state and private lands. A small percentage comes from harvests on federal lands (9.4%). To incorporate the breadth of management intent, harvest rate, and prescriptions used by different owner groups, a weighted average value that accounted for the relative volumes removed by broad categories of owner and forest type was developed. For all non-federal land managers in the region, reforestation is a statutory requirement as harvests are administered under state forest practices acts and this reforestation effort occurs either by planting or natural regeneration. Planting effort was accounted for on the relative number of acres where it occurred. In many cases harvesting removes only a portion of the trees in in 20-30 year cutting cycles until there is a final harvest; in other cases the forest is grown until mature and then clearcut. To ensure comparability, all modeled forest yield is based on an average crop cycle of 75 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 potential 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 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 LCI was structured from three general combinations of management intensity and site productivity (Table 1). Timber production scenarios were developed to describe conditions associated with the growth, removal, and reestablishment of trees based on common management regimes for each owner group and forest type combination. Tree growth for the scenarios was simulated using the Forest Vegetation Simulator (FVS) developed by the US Forest Service (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.

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 INW 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 INW were planted by hand. The only energy factors associated with planting were related to travel to and from the planting site. Not all forest types and management scenarios used planting and thinning treatments, so these inputs were weighted to reflect their relative input values across all acres by region and management intensity.

Stand treatment options for the Inland Northwest were developed by Elaine Oneil at the University of Washington. They were based on knowledge of common management scenarios used by landowners in the region that were modeled based on a representative cross section of FIA inventory data to match the 30 year average harvest rates by state and landowner type for the region. No onsite fertilization or pre-commercial thinning operations were modeled as part of these management alternatives.

Table 1 Inputs to the regeneration phase including site preparation and planting per hectare (ha) of forest.

		State and Private - Dry	State and Private – Moist/Cold	National Forest - All	Weighted Average
		Reforesting 1 ha			
Diesel and Gasoline	L	59.7	76.9	30.0	67.3
Seedlings, at greenhouse	p[1]	618	865	1,082	811
Nitrogen fertilizer					
In Seedlings	kg	0.026	0.037	0.046	0.035
On Site	kg	-	-	-	-
Phosphorous fertilizer					
In Seedlings	kg	0.044	0.062	0.078	0.058
On Site	kg	-	-	-	-
Potassium					
In Seedlings	kg	0.108	0.152	0.190	0.142
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 flatter terrain 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. In the Inland Northwest both cable yarding and ground based skidding are used for commercial thinning and final harvest operations. They were modeled as a percentage of production for the forest resources LCI. This split between systems is not common or modeled in any other region. 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.

Ground based 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. Cable yarding systems occur on steep slope conditions that dictate the use of 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).

Variations in harvest equipment and size affect machine productivity and therefore emissions per m^3 of logs produced. Harvest equipment operational efficiencies also 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, and weighted for the relative number of acres that can be expected to use either type of system (Table 2).

Table 2 Equipment allocation by treatment and forest type/owner group

Management Intensity	Ground Based Operations	Cable Based Operations
State and Private Dry Forests		
Large Feller Buncher	100%	NA
Medium Skidder	100%	NA
Slide Boom Delimber	100%	NA
Large Loader	90%	10%
Hand Felling	NA	100%
Medium Skyline	NA	100%
State and Private – Moist and Cold Forests		
Large Feller Buncher	100%	NA
Medium Skidder	100%	NA
Slide Boom Delimber	100%	NA
Large Loader	70%	30%
Hand Felling	NA	100%
Medium Skyline	NA	100%
National Forests – All types		
Large Feller Buncher	100%	NA
Medium Skidder	100%	NA
Slide Boom Delimber	100%	NA
Large Loader	50%	50%
Hand Felling	NA	100%
Medium Skyline	NA	100%

3.3.1.3 Thinning and Final Harvest Process

Scenarios developed for the Inland Northwest used a subset of the United States Forest Service (USFS) Forest Inventory and Analysis (FIA) data covering eastern Washington, Idaho and Montana. FIA Plots for three owner groups (state and local, private, federal) were segregated into dominant habitat types and the median stand by habitat type was chosen to represent the diversity of forest types in the region and current management intensity for each of the ownership categories. For the Inland Northwest historical harvest rates by ownership and region were applied across the forest types to arrive at a representative volume harvested per acre. Base case management intensities ranged from understory thinning for fire safety on a subset of National Forest lands to clearcutting on the higher productivity lands of industrial forest owners. An estimated yield of log volume, biomass, and carbon was determined for each owner group by habitat type. This volume was aggregated by forest group (dry, moist, cold) and management intensity. After the simulations were run, the similarities between removal volumes and effective harvest regimes permitted a further aggregation into three management scenarios and intensities: state and private – dry forests, state and private – moist and cold forests, and National Forests. Specific assumptions associated with these three scenarios are outlined in Table 3.

Table 3 Input assumptions for three levels of forest management intensity in the INW region.

Ownership / Forest Type / Prescription Scenarios	State and Private - Dry	State and Private – Moist/Cold	National Forest - All	Weighted Average
	per hectare			
Rotation Age (years)	76	66	87	-
Planting Density - Trees/ha	618	865	1,082	811
Fertilization	None	None	None	
Pre-commercial Thin	None	None	None	
Commercial thin - m^3/ha	108	131	0	112
Final harvest m^3/ha	108	131	62	117
at Year	76	66	87	71
Total Harvest -m^3/ha	217	261	62	229
Total Harvest at 75 years (reference year) - m^3/ha	214	297	54	249
Sawlog[3] - %	48.5%	48.5%	25.1%	46%
Sawlog - m^3/ha	105	127	16	110
Hewsaw[4] (Ton wood) - %	32.0%	32.0%	29.7%	32%
Hewsaw (Tonwood) - m3/ha	69	84	18	73
Total log to lumber - %	80.5%	80.5%	54.8%	78%
Total log to lumber - m^3/ha	174	210	34	183
Pulpwood - %	19.5%	19.5%	45.2%	22%
Pulpwood - m^3/ha	42	51	28	46
Percent Ground Based Harvest	90.0%	70.0%	50.0%	74%
Percent Cable Harvest	10.0%	30.0%	50.0%	26%
Percent Total Volume in Treatment Category	30.1%	60.5%	9.4%	100%

These three categories were used to develop a weighted average representing a composite input value for the region. National Forests comprise a substantial portion of the Inland Northwest's forest land base, but contribute only a limited amount of timber volume. In calculating output variables, results were weighted by volume produced regionally in each of the management categories to account for the substantially different management intensity that is occurring on National Forests relative to other timber producing lands. Summaries from the aggregated average by volume harvested were forwarded to the manufacturing modules for incorporation in their life cycle analysis. Allocating per ha values from Table 1 to the total yield of 249 m^3/ha (volume at reference year of 75) is used to carry forward the environmental burdens of the reforestation effort on a per m^3 basis.

[3] Sawlog, large diameter log that is scaled, destined for sawmill.
[4] Hewsaw low recovery log, not scaled, sold by mass, destined for sawmill.

The primary output product for this analysis is a log destined for a lumber mill. Pulpwood logs are only removed from the woods where markets are sufficiently strong to pay for their removal. In the Inland Northwest, most of the feedstock for pulp and paper mills comes from the residual material from the manufacturing plants for the primary wood products (lumber, plywood, and OSB) and allocation is done at that stage of the LCI. A primary co-product, non-merchantable slash, is generally left in the woods or at a landing. This material is disposed of through mechanical activities and/or prescribed fire.

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 INW region by major process (Table 4).

Table 4 Fuel consumption for INW forest resource management processes (regeneration and harvest).

	Unit	Fuel Consumption per m^3
Seedling, Site Prep, Plant, Pre-commercial Thinning		
Diesel and gasoline	L	0.337
Lubricants	L	0.006
Electricity	kWh	0.526
Commercial Thinning and Final Harvest		
Diesel	L	2.949
Lubricants	L	0.053
Total Forest Extraction Process		
Diesel and gasoline	L	3.286
Lubricants	L	0.059
Electricity	kWh	0.526

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. For the INW the average haul distance is 129 km from the forest landing to the mill with a roundwood moisture content of 60% oven dry basis[5].

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

Material delivered to mill	Delivery Distance (km)	
	km	**miles**
Logs with bark	129	80

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

3.3.2.2 Energy use and generation

Steam in INW mills was all produced using both self-generated wood waste and natural gas, 54 and 46% respectively. The USLCI database was used for boiler processes inputting natural gas, and 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). 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 dry wood material oven dry basis moisture content contained 20.9 MJ of energy. Approximately 50% of the bark generated during debarking, as well as other wood waste sources generated at the sawing process, were used as wood fuel in the boiler for steam generation. The total wood fuel burned was 110 kg/m^3 at 50 percent moisture content on a wet basis or 55 kg/m^3 of oven-dry weight wood fuel (Table 6). Total heat energy requirement for INW softwood lumber was 2,564 MJ/m^3.

Table 6 Boiler inputs for producing per 1 m3 of dry planed softwood lumber, INW.

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product
Wood waste	kg	55	20.90	1,149.50
Natural gas	m^3	26	54.40	1,414.40

Table 7 Wood Boiler Process.

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler	1.00	kg
Materials/fuels		
Wood fuel, green	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

Cumulative process energy for electric power allocated to one cubic meter (436 kg) of planed-dried softwood lumber was 60 kWh/m^3. Total electricity consumed during the entire lumber production process per cubic meter of planed-dried softwood lumber, was allocated to the log yard (4.09%), sawmill (27.24%), kiln drying (23.95%), and planing (44.72%) processes respectively.

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 include gasoline, diesel, and electricity (Table 8). Outputs include logs with bark. Water is mainly used in the process for wetting logs when they are stored prior to sawing. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis and a green specific gravity[6] of 0.41.

Table 8 Unit process inputs/outputs for log yard activities to produce 1 m^3 of green logs, INW.

Products	Value	Unit/m^3	Allocation (%)
Roundwood	1.00	m^3	93.12
Bark	32.59	kg	6.88
Resources	**Value**	**Unit/m^3**	
Water, cooling, surface	19.32	L	
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	1.7684	kWh	
Diesel	1.3010	L	
Gasoline	0.0283	L	
Residual fuel oil	0.0396	L	
Roundwood + Bark	1.0739	m^3	
Transport (roundwood w/ bark)	97.7697	tkm	
Emissions to air	**Value**	**Unit/m^3**	
Particulates, unspecified	0.0838	kg	
Hydrocarbons, unspecified	0.0002	kg	
Emissions to soil		**Unit/m^3**	
Solid waste to treatment[7]	5.6448	kg	

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 9 lists the inputs and outputs for the sawing processes which produce 1m^3 of rough sawn green lumber. The actual sizes are 38 mm thick with a width of 150 mm. This is a larger size than the finished lumber to allow for shrinkage and planing. Rough cut lumber has mass of 436 kg/m3, which represents 56.97 percent of the mass of the products and co-products. Approximately 70 percent of the sawdust and bark are sent to the boiler with the rest being sold off-site. 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.

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

[7] Unspecified treatment. One mill report rock and mud to landfill which accounted for 321.449 kg. Due to this "unconventional" material disposal, we have omitted this disposal from the LCI.

Table 9 Unit process inputs/outputs for sawing for the production of 1 m^3 of rough green lumber, INW.

Products	Value	Unit/m^3	Allocation (%)
Sawn lumber, rough, green	1.00	m^3	56.97
Pulp chips, green	216.24	kg	25.84
Sawdust, green	51.92	kg	6.19
Bark, green	28.15	kg	3.37
Wood fiber, green	3.31	kg	0.40
Wood fuel, green	60.49	kg	7.23
Materials/fuels	**Value**	**Unit/m^3**	
Roundwood w/bark	1.92	m^3	
Electricity, at Grid	20.76	kWh	
Diesel	0.0402	L	
Gasoline	0.1381	L	
Residual fuel oil	0.0781	L	
Emissions to air	**Value**	**Unit/m^3**	
	-		

3.3.2.5 Kiln Drying

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. Inland Northwest softwood lumber is typically dried to a moisture content of 15%. The major non-lumber inputs to drying are steam and electricity (Table 10). Electrical use in the dryer represents approximately 25% of that used by the mill complex. Steam comes from wood and natural gas boilers. Diesel in equipment is used for machinery, such as forklifts. Some air emissions are attributed to drying, including VOCs that are emitted by the wood.

Table 10 Unit process inputs/outputs for kiln drying to produce 1 m^3 of rough dry softwood lumber, INW.

Products	Value	Unit/m^3
Sawn Lumber, rough, kiln dried	1.00	m^3
Materials/fuels		
Electricity, at Grid	16.70	kWh
Diesel, combusted in industrial boiler	0.13	L
Residual fuel oil	0.08	L
Wood waste, combusted in industrial boiler	55.30	kg
Natural gas, combusted in industrial boiler	25.60	m^3
Sawn lumber, rough, green	436.00	kg
Emissions to air		
Acetaldehyde	0.0020	kg
Formaldehyde	0.0006	kg
Methanol	0.0225	kg
VOC, volatile organic compounds	0.1680	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, and diesel. In the INW region (Table11), 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. The planed dry lumber had a dry mass of 436 kg, which represents 86.1% of the co-product mass from this unit process. Approximately 4% more lineal feet of lumber enters the planer than leaves due to end trimming to improve grade. Lumber is bundled and banded and some is wrapped for shipping.

Table 11 Unit process inputs/outputs for planing process to produce 1 m^3 of planed dry softwood lumber, INW.

Products	Value	Unit/m^3	Allocation
Sawn Lumber, softwood, planed, kiln dried	1.00	m^3	91%
Sawdust, dry	36.55	kg	8%
Chips, dry	3.97	kg	1%
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	34.09	kWh	
Diesel	0.436	L	
Gasoline	0.063	L	
Residual fuel oil	0.102	L	
Sawn Lumber, kiln dried	1.093	m^3	
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**	
	-		

3.3.2.7 Packaging

Materials used for packaging lumber for shipping are shown in Table 12.

Table 12 Materials used in packaging and shipping per m^3, INW lumber

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 1.24% 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 14 and would be included in the impact assessment. Table 14 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

This study focused upon production practices from eastern Washington, Idaho and western Montana. Softwood lumber species in the region include grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), western red cedar (*Thuja plicata*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and western hemlock (*Tsuga heterophylla*). Total annual softwood lumber production for the INW region in 2005 was 4,866,000 cubic meters (m^3) (WWPA 2006). This production represents 8 percent of the total U.S. softwood lumber production. Four softwood lumber mills from eastern Washington and Idaho were selected based on their production as representative mills from the INW. The combined annual production of the four representative plants was 755,852 m^3 in 2005/2006 or about 16 percent of the total production within the INW region reported over one calendar year. Total U.S. softwood lumber production in 2006 was 80 million cubic meters (Warren 2007).

An external critical review of the survey procedures, data, analysis, and report was done for conformance with CORRIM and ISO 14040 standards (Puettmann 2009; Wilson 2009). 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 protocol. Complete details of this study for lumber production and the overall CORRIM project can be found in Wagner et al. (2009) and Lippke et al. (2004), respectively.

6 Life cycle inventory results

6.1 Data collection

The logs are obtained from the forest resource base located in eastern Washington, eastern Oregon, Idaho and western Montana. The forest resources cradle to gate LCI (Oneil et al. 2010) is based on secondary data. The secondary data were derived using the USFS Forest Inventory and Analysis (FIA) census data for eastern Washington, Idaho, and Montana and applying harvest treatments and volume removals consistent with the 30 year average harvest rates for the region. These data were developed to represent the wood basket that would service manufacturing facilities for the region surveyed during the mill survey.

Primary softwood lumber production data was collected by written surveys and covered operations of the mills for one full calendar year, including summer and winter operations. A copy of the mill surveys can be found in the full report of this study (Wagner et al. 2009). This study relied almost exclusively on production and emissions data provided by lumber producers from the INW, with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). Four lumber manufacturing plants from within the region provided data for this study. Data for packaging was obtained from field sampling and personal communications with manufacturers.

6.2 Calculation rules

All seedlings in the INW were planted by hand. The only energy factors associated with planting were related to travel to and from the planting site. Inputs were calculated per seedling and were then multiplied by the number of planted seedlings per unit area specified for each of the three management scenarios to determine inputs per unit area. Fuel consumption was calculated based on per ha estimates of equipment fuel consumption for piling and burning operations and travel to and from the planting site. Total fuel consumption per unit area were divided by the final harvested volume per unit area to establish the contribution of site preparation, seedlings, and planting to the consumption factors 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 systems (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.

Two different log scales (Scribner Decimal C East Side and weight) used by the four mills gave log inputs in either thousand board feet (Mbf) or short tons[8]. An average log conversion of 1.622 cubic meters per Mbf was based upon lumber actual size (38 x 140 mm or 1.5 x 5.5 inches). All flow analyses of the product and co-products in the process were determined on an oven-dry weight basis. Following CORRIM guidelines, an overall wood mass balance was determined for material input to material output which was within 5%. Wood only (no bark) log mass was calculated based on the previous assumption of 1.622 cubic meters per Mbf and an average oven-dry density (wood only) of 436 kg per m^3.

Mill production data collected through surveys was in accordance with ISO standards (ISO 2006) and CORRIM research guidelines. A weighted average of all data was developed from the mill survey based on production of each plant in comparison to the total production for the year. This produced a composite mill that was representative of the region. A single green and dry wood density was derived using published values and based on their weighted percentage of each species (Bergman et al. 2010). The weighted-average green and dry (12% moisture content) specific gravities were 0.41 and 0.44, respectively. The weighted-average green and dry (12% moisture content) densities were 409 kg/m3 and 436 kg/m^3, respectively. 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 zero

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

[8] One short ton = 0.9071847 metric tons

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.

6.3 Allocation rules

All allocation was based on the mass of the products and co-products. INW 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 14-16). 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 13 for 1 m^3 of softwood lumber. Air emissions are reported in Table 14, water emissions are reported in Table 15 and solid waste emissions are reported in Table 16.

Table 13 Raw material energy consumption per 1 m^3 of dry planed softwood lumber, INW

Fuel	Total	Forestry Operations	Wood Production
	kg/m^3		
Coal, in ground	10.7897	0.1942	10.5955
Gas, natural, in ground	24.4827	0.1264	24.3563
Oil, crude, in ground	8.2830	3.0000	5.2830
Uranium oxide, in ore	0.0002	0.0000	0.0002
Wood waste	55.8080	0.0000	55.8080

Table 14 Air emissions released per 1 m^3 of dry planed softwood lumber, INW.

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m^3		
Carbon dioxide, fossil	112.2340	9.7905	102.4435
Carbon dioxide, biogenic	98.4056	0.0093	98.3963
Sulfur dioxide	0.7528	0.0057	0.7471
Nitrogen oxides	0.5904	0.1768	0.4135
Methane	0.3847	0.0128	0.3719
Carbon monoxide	0.3020	0.0000	0.3020
Carbon monoxide, fossil	0.2731	0.0883	0.1848
Particulates, > 2.5 um, and < 10um	0.2655	0.0054	0.2601
Particulates, < 2.5 um	0.2149	0.0000	0.2149
VOC, volatile organic compounds	0.2022	0.0047	0.1975
Particulates, unspecified	0.1049	0.0010	0.1039

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m³		
Methane, fossil	0.0503	0.0009	0.0493
Sulfur oxides	0.0419	0.0098	0.0321
Methanol	0.0226	0.0000	0.0226
Metals, unspecified	0.0214	0.0000	0.0214
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0173	0.0059	0.0114
Hydrogen chloride	0.0151	0.0001	0.0150
Isoprene	0.0102	0.0002	0.0099
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0086	0.0000	0.0086
Formaldehyde	0.0030	0.0001	0.0029
Acetaldehyde	0.0025	0.0000	0.0025
Benzene	0.0022	0.0000	0.0021
TOC, Total Organic Carbon	0.0020	0.0000	0.0020
Acrolein	0.0020	0.0000	0.0020
Dinitrogen monoxide	0.0010	0.0000	0.0010
Manganese	0.0008	0.0000	0.0008
Hydrogen fluoride	0.0007	0.0000	0.0007
Carbon dioxide	0.0005	0.0001	0.0004
Chlorine	0.0004	0.0000	0.0004
Aldehydes, unspecified	0.0003	0.0001	0.0002
Hydrocarbons, unspecified	0.0003	0.0000	0.0003
Radionuclides (Including Radon)	0.0003	0.0000	0.0003
Propene	0.0002	0.0001	0.0001
Ammonia	0.0002	0.0001	0.0001
Methane, dichloro-, HCC-30	0.0001	0.0000	0.0001

[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 15). 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 15 Emissions to water released per 1 m³ of dry planed softwood lumber, INW.

Water emission[1/]	Total	Forestry Operations	Wood Production
	kg/m³		
Solved solids	6.2492	0.5005	0.0000
Nitrogen, total	5.0658	0.4058	0.0000

Water emission[1/]	Total	Forestry Operations	Wood Production
	kg/m^3		
Phenol	1.4287	0.1144	0.0000
Waste water/m3	0.6986	0.0000	0.0000
Benzene, ethyl-	0.4507	0.0361	0.0000
Hexadecane	0.1541	0.0298	0.0000
Dodecane	0.1190	0.0006	0.0000
Cadmium, ion	0.0881	0.0071	0.0000
Phosphorus	0.0677	0.0133	0.0000
p-Cresol	0.0460	0.0039	0.0000
m-Xylene	0.0301	0.0024	0.0000
Decane	0.0259	0.0021	0.0000
o-Cresol	0.0153	0.0009	0.0000
Phenol, 2,4-dimethyl-	0.0119	0.0019	0.0000
Vanadium	0.0076	0.0006	0.0000
Tetradecane	0.0048	0.0010	0.0000
Acids, unspecified	0.0029	0.0003	0.0000
Molybdenum	0.0019	0.0002	0.0000
Cobalt	0.0004	0.0000	0.0000
Antimony	0.0004	0.0000	0.0000
Phosphorus, total	0.0003	0.0000	0.0000
Naphthalene	0.0002	0.0000	0.0000
Benzenes, alkylated, unspecified	0.0002	0.0000	0.0000
Ammonium, ion	0.0002	0.0000	0.0000
Naphthalene, 2-methyl-	0.0001	0.0000	0.0000
Eicosane	0.0001	0.0000	0.0000
Octadecane	0.0001	0.0000	0.0000
Beryllium	0.0001	0.0000	0.0000

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

Surveys reported some solid waste that is collected from the log-yard and cannot be sent to the boiler because it is mixed with dirt and rock as well as upstream waste flows generated from fuel production (Table 16). There was also a small portion of ash reported from the boilers. The total solid waste generated at the INW mills was 96% of the total waste.

Table 16 Waste to treatment per 1 m^3 of dry planed softwood lumber, INW

Waste to treatment	Total	Forestry Operations	Wood Production
	kg/m^3		
Solid waste[9]	15.12	0.16	14.96

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 17. 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 17 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

[9] An additional 348.94 kg of solid waste was generated from logyard activities. Due to this "unconventional" material disposal, we have omitted this disposal from the LCI.

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 18 provides the environmental impact by category for softwood lumber produced in the INW 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 18. For GWP, 92 percent of the CO_2 equivalent emissions come from producing lumber production, with remainder assigned to forestry operations.

Table 18 Environmental performance of 1 m^3 planed dry softwood lumber, INW

Impact category	Unit	Total	Forestry Operations	Wood Production
Global warming potential (GWP)	kg CO_2 equiv	123.41	10.14	113.27
Acidification Potential	H+ moles equiv	64.75	7.88	56.88
Eutrophication Potential	kg N equiv	0.0314	0.0084	0.02
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000
Smog Potential	kg O3 equiv	15.58	4.41	11.17
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable fossil	MJ	1991.80	148.47	1843.33
Non-renewable nuclear	MJ	83.44	1.74	81.70
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	60.65	0.39	60.26
Renewable, biomass	MJ	1167.45	0.00	1167.45
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable materials[10]	kg	0.0943	0.00	0.0943
Renewable materials	kg	428.24	0.00	428.24
Fresh water	L	20.09	0.00	20.09
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Solid waste	kg	15.12	0.16	14.96

[10] Limestone, in ground has been removed from a pre-combustion 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 were 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, 123 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 799 kg CO_2e (Table 19).

Table 19 Carbon per 1 m^3 planed dry softwood lumber, INW.

	kg CO_2 equivalent
released forestry operations	10.14
released manufacturing	113.27
CO_2 eq. stored in product	799.33

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 produce Douglas-fir, grand fir, lodgepole pine, ponderosa pine, western larch, western red cedar, and western hemlock. The survey data are representative of the lumber sizes and production volumes consistent with trade association production data. Softwood lumber production from the INW region required 1.11 m^3 or 484 kg of roundwood (wood and bark) harvested from INW forest per cubic meter of lumber.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The lumber manufacturing process has few on-site emissions from sawing and planing. The dryer emits small amounts of VOCs from wood and the boiler has emissions associated with burning wood.

Total energy use in lumber manufacturing is driven by the drying process which consumes 80% of all energy; however, the INW mills generated 54% of the required heat energy from wood residues produced onsite. The majority of the cradle to gate energy consumption comes from non-renewable fossil fuels (60%) and renewable biomass (35%).

Solid waste generated was high for this region due to the reporting of mud and rock removed from the log yard. The log yard waste was 96 percent of the total waste from cradle to gate. Removal of this waste from the assessment put the total solid waste for INW softwood lumber in the same range as softwood lumber production from other regions in the US.

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, 123 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 799 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.

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.

Bergman, Richard, Cai, Zhiyong, Carll, Charlie G., Clausen, Carol A, Dietenberger, Mark A, Falk, Robert H, Frihart, Charles R, Glass, Samuel V, Hunt, Christopher G, Ibach, Rebecca E., Kretschmann, David E., Rammer, Douglas R., Ross, Robert J. 2010. Handbook, Wood as an Engineering Material (All Chapters). Forest Products Laboratory. Wood handbook - Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 508 p.

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

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/.

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.

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

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.

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

Oneil, E.E., L.R. Johnson, B.R. Lippke, J.B. McCarter, M.E. McDill, P.A. Roth, and J.C. Finley. 2010. Life-cycle impacts of inland northwest and northeast/north central forest resources. Wood and Fiber Sci., 42(CORRIM Special Issue) pp. 15-28.

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

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

Puettmann, M.E. 2009. Review of SimaPro process models for conformity to ISO standards and review of final CORRIM reports. Internal review.

Puettmann, M.E., F.G. Wagner, and L. Johnson. 2010. Life cycle inventory of softwood lumber from the inland northwest US. Wood and Fiber Sci., 42(CORRIM Special Issue) pp. 52-66.

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.

Wagner F., Puettmann M.E., Johnson L.R. 2009. Life cycle inventory of Inland Northwest softwood lumber manufacturing. In CORRIM Phase II Report Module B Life-cycle environmental performance of renewable building materials in the context of residential building construction. P.O. Box 3521000, Seattle, WA 98195. Oct. 2008. 89 pp.

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

Western Wood Products Association (WWPA). 2006. Statistical Yearbook of the Western Lumber Industry. Western Wood Products Association, Portland, OR. 30 p.

Wilson, J.B. 2009. Review of process models for energy and mass balances and review of final CORRIM reports. Internal review.

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, INW.

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
2,4-D	kg	1.25E-09	0.00E+00	1.25E-09
2-Chloroacetophenone	kg	2.30E-10	2.92E-13	2.30E-10
5-methyl Chrysene	kg	1.02E-10	1.87E-12	1.01E-10
Acenaphthene	kg	2.38E-09	4.33E-11	2.33E-09
Acenaphthylene	kg	1.16E-09	2.12E-11	1.14E-09
Acetaldehyde	kg	2.50E-03	4.06E-05	2.46E-03
Acetochlor	kg	1.73E-08	0.00E+00	1.73E-08
Acetophenone	kg	4.93E-10	6.25E-13	4.92E-10
Acrolein	kg	2.01E-03	4.92E-06	2.01E-03
Alachlor	kg	1.70E-09	0.00E+00	1.70E-09
Aldehydes, unspecified	kg	3.42E-04	1.22E-04	2.20E-04
Ammonia	kg	2.00E-04	6.15E-05	1.38E-04
Ammonium chloride	kg	1.16E-05	2.42E-07	1.14E-05
Anthracene	kg	9.78E-10	1.78E-11	9.60E-10
Antimony	kg	4.04E-06	1.53E-09	4.04E-06
Arsenic	kg	1.31E-05	4.72E-08	1.30E-05
Atrazine	kg	3.36E-08	0.00E+00	3.36E-08
Barium	kg	1.94E-07	0.00E+00	1.94E-07
Bentazone	kg	1.37E-10	0.00E+00	1.37E-10
Benzene	kg	2.19E-03	4.95E-05	2.15E-03
Benzene, chloro-	kg	7.23E-10	9.17E-13	7.22E-10
Benzene, ethyl-	kg	3.11E-09	1.91E-11	3.09E-09
Benzo(a)anthracene	kg	3.73E-10	6.79E-12	3.66E-10
Benzo(a)pyrene	kg	1.77E-10	3.22E-12	1.74E-10
Benzo(b,j,k)fluoranthene	kg	5.12E-10	9.33E-12	5.03E-10
Benzo(ghi)perylene	kg	1.26E-10	2.29E-12	1.23E-10
Benzyl chloride	kg	2.30E-08	2.92E-11	2.30E-08
Beryllium	kg	6.62E-07	2.33E-09	6.60E-07
Biphenyl	kg	7.92E-09	1.44E-10	7.77E-09
Bromoform	kg	1.28E-09	1.63E-12	1.28E-09
Bromoxynil	kg	3.01E-10	0.00E+00	3.01E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	8.62E-03	4.45E-05	8.57E-03
Butadiene	kg	3.42E-06	2.07E-06	1.35E-06
Cadmium	kg	2.91E-06	1.12E-08	2.90E-06
Carbofuran	kg	2.57E-10	0.00E+00	2.57E-10

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Carbon dioxide	kg	4.66E-04	1.01E-04	3.65E-04
Carbon dioxide, biogenic	kg	9.84E+01	9.31E-03	9.84E+01
Carbon dioxide, fossil	kg	1.12E+02	9.79E+00	1.02E+02
Carbon disulfide	kg	4.27E-09	5.42E-12	4.27E-09
Carbon monoxide	kg	3.02E-01	2.02E-06	3.02E-01
Carbon monoxide, fossil	kg	2.73E-01	8.83E-02	1.85E-01
Chloride	kg	3.10E-10	7.13E-12	3.03E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	2.35E-08	0.00E+00	2.35E-08
Chlorine	kg	3.96E-04	0.00E+00	3.96E-04
Chloroform	kg	1.94E-09	2.46E-12	1.94E-09
Chlorpyrifos	kg	1.98E-09	0.00E+00	1.98E-09
Chromium	kg	1.25E-05	3.36E-08	1.25E-05
Chromium VI	kg	3.68E-07	6.70E-09	3.61E-07
Chrysene	kg	4.66E-10	8.48E-12	4.57E-10
Cobalt	kg	3.95E-06	6.11E-08	3.89E-06
Copper	kg	1.28E-08	5.49E-10	1.22E-08
Cumene	kg	1.74E-10	2.21E-13	1.74E-10
Cyanazine	kg	2.97E-10	0.00E+00	2.97E-10
Cyanide	kg	8.22E-08	1.04E-10	8.21E-08
Dicamba	kg	1.75E-09	0.00E+00	1.75E-09
Dimethenamid	kg	4.13E-09	0.00E+00	4.13E-09
Dinitrogen monoxide	kg	1.01E-03	1.07E-05	9.99E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.33E-09	0.00E+00	1.33E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	4.25E-12	2.01E-13	4.04E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	2.83E-09	0.00E+00	2.83E-09
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1.43E-09	2.82E-10	1.15E-09
Ethane, 1,2-dibromo-	kg	3.94E-11	5.00E-14	3.94E-11
Ethane, 1,2-dichloro-	kg	1.31E-09	1.67E-12	1.31E-09
Ethane, chloro-	kg	1.38E-09	1.75E-12	1.38E-09
Ethene, tetrachloro-	kg	2.04E-07	4.31E-09	1.99E-07
Ethene, trichloro-	kg	5.59E-14	0.00E+00	5.59E-14
Fluoranthene	kg	3.31E-09	6.02E-11	3.25E-09
Fluorene	kg	4.24E-09	7.72E-11	4.16E-09
Fluoride	kg	1.74E-06	1.84E-08	1.72E-06
Formaldehyde	kg	2.99E-03	6.30E-05	2.93E-03
Furan	kg	2.28E-11	3.92E-13	2.24E-11
Glyphosate	kg	3.71E-09	0.00E+00	3.71E-09
Hexane	kg	2.20E-09	2.79E-12	2.20E-09
Hydrazine, methyl-	kg	5.59E-09	7.09E-12	5.58E-09
Hydrocarbons, unspecified	kg	3.16E-04	1.40E-06	3.14E-04
Hydrogen	kg	1.18E-07	0.00E+00	1.18E-07

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Hydrogen chloride	kg	1.51E-02	1.08E-04	1.50E-02
Hydrogen fluoride	kg	6.97E-04	1.27E-05	6.84E-04
Hydrogen sulfide	kg	1.00E-11	2.31E-13	9.80E-12
Indeno(1,2,3-cd)pyrene	kg	2.84E-10	5.17E-12	2.79E-10
Iron	kg	1.94E-07	0.00E+00	1.94E-07
Isophorone	kg	1.91E-08	2.42E-11	1.90E-08
Isoprene	kg	1.02E-02	2.34E-04	9.94E-03
Kerosene	kg	5.57E-06	1.16E-07	5.45E-06
Lead	kg	2.65E-05	5.14E-08	2.64E-05
Magnesium	kg	5.12E-05	9.33E-07	5.03E-05
Manganese	kg	8.04E-04	6.93E-08	8.04E-04
MCPA	kg	2.32E-11	0.00E+00	2.32E-11
Mercaptans, unspecified	kg	7.13E-06	8.57E-09	7.12E-06
Mercury	kg	2.34E-06	9.08E-09	2.33E-06
Metals, unspecified	kg	2.14E-02	2.65E-14	2.14E-02
Methacrylic acid, methyl ester	kg	6.57E-10	8.34E-13	6.56E-10
Methane	kg	3.85E-01	1.28E-02	3.72E-01
Methane, bromo-, Halon 1001	kg	5.26E-09	6.67E-12	5.25E-09
Methane, dichloro-, HCC-30	kg	1.47E-04	6.95E-08	1.47E-04
Methane, dichlorodifluoro-, CFC-12	kg	9.61E-10	3.48E-10	6.13E-10
Methane, fossil	kg	5.03E-02	9.44E-04	4.93E-02
Methane, monochloro-, R-40	kg	1.74E-08	2.21E-11	1.74E-08
Methane, tetrachloro-, CFC-10	kg	3.88E-10	3.48E-11	3.53E-10
Methanol	kg	2.26E-02	0.00E+00	2.26E-02
Methyl ethyl ketone	kg	1.28E-08	1.63E-11	1.28E-08
Methyl methacrylate	kg	1.61E-13	0.00E+00	1.61E-13
Metolachlor	kg	1.36E-08	0.00E+00	1.36E-08
Metribuzin	kg	6.32E-11	0.00E+00	6.32E-11
Naphthalene	kg	4.91E-05	1.26E-08	4.91E-05
Nickel	kg	2.16E-05	7.65E-07	2.08E-05
Nitrogen oxides	kg	5.90E-01	1.77E-01	4.14E-01
Nitrogen, total	kg	2.45E-08	2.28E-08	1.67E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.73E-02	5.91E-03	1.14E-02
N-Nitrodimethylamine	kg	1.25E-14	0.00E+00	1.25E-14
Organic acids	kg	4.27E-08	8.90E-10	4.18E-08
Organic substances, unspecified	kg	3.82E-05	5.27E-07	3.76E-05
PAH, polycyclic aromatic hydrocarbons	kg	1.47E-05	8.89E-06	5.81E-06
Paraquat	kg	2.76E-10	0.00E+00	2.76E-10
Parathion, methyl	kg	2.09E-10	0.00E+00	2.09E-10
Particulates, < 10 um	kg	7.53E-06	0.00E+00	7.53E-06
Particulates, < 2.5 um	kg	2.15E-01	0.00E+00	2.15E-01

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Particulates, > 2.5 um, and < 10um	kg	2.65E-01	5.42E-03	2.60E-01
Particulates, unspecified	kg	1.05E-01	9.79E-04	1.04E-01
Pendimethalin	kg	1.42E-09	0.00E+00	1.42E-09
Permethrin	kg	1.27E-10	0.00E+00	1.27E-10
Phenanthrene	kg	1.26E-08	2.29E-10	1.23E-08
Phenol	kg	1.77E-06	6.67E-13	1.77E-06
Phenols, unspecified	kg	2.58E-05	3.52E-08	2.57E-05
Phorate	kg	6.54E-11	0.00E+00	6.54E-11
Phosphate	kg	5.09E-09	5.09E-09	
Phthalate, dioctyl-	kg	2.40E-09	3.04E-12	2.40E-09
Potassium	kg	3.45E-05	0.00E+00	3.45E-05
Propanal	kg	1.25E-08	1.58E-11	1.25E-08
Propene	kg	2.26E-04	1.37E-04	8.93E-05
Propylene oxide	kg	1.38E-11	1.38E-11	
Pyrene	kg	1.54E-09	2.80E-11	1.51E-09
Radioactive species, unspecified	Bq	2.62E+05	4.81E+03	2.57E+05
Radionuclides (Including Radon)	kg	3.11E-04	6.48E-06	3.05E-04
Selenium	kg	7.52E-06	1.18E-07	7.40E-06
Simazine	kg	8.96E-10	0.00E+00	8.96E-10
Sodium	kg	7.95E-07	0.00E+00	7.95E-07
Styrene	kg	8.22E-10	1.04E-12	8.21E-10
Sulfur	kg	4.19E-06	0.00E+00	4.19E-06
Sulfur dioxide	kg	7.53E-01	5.67E-03	7.47E-01
Sulfur oxides	kg	4.19E-02	9.81E-03	3.21E-02
Sulfur, total reduced	kg	2.46E-06	0.00E+00	2.46E-06
Sulfuric acid, dimethyl ester	kg	1.58E-09	2.00E-12	1.58E-09
Tar	kg	3.49E-10	8.02E-12	3.41E-10
t-Butyl methyl ether	kg	1.15E-09	1.46E-12	1.15E-09
Terbufos	kg	2.23E-09	0.00E+00	2.23E-09
TOC, Total Organic Carbon	kg	2.05E-03	0.00E+00	2.05E-03
Toluene	kg	3.58E-05	0.00E+00	1.42E-05
Toluene, 2,4-dinitro-	kg	9.20E-12	1.17E-14	9.19E-12
Vinyl acetate	kg	2.50E-10	3.17E-13	2.50E-10
VOC, volatile organic compounds	kg	2.02E-01	4.70E-03	1.98E-01
Xylene	kg	2.50E-05	1.51E-05	9.87E-06
Zinc	kg	2.06E-07	3.64E-09	2.03E-07

13.2 Water Emissions

Table 20 Emissions to water released per 1 m^3 of dry planed softwood lumber, INW.

Water Emission	Unit	Total	Forestry Operations	Lumber Production
2,4-D	kg	5.34E-11	0.00E+00	5.34E-11
2-Hexanone	kg	9.16E-07	7.34E-08	8.42E-07
2-Propanol	kg	2.31E-09	0.00E+00	2.31E-09
4-Methyl-2-pentanone	kg	5.89E-07	4.72E-08	5.42E-07
Acetochlor	kg	7.40E-10	0.00E+00	7.40E-10
Acetone	kg	1.40E-06	1.12E-07	1.29E-06
Acidity, unspecified	kg	5.16E-15	0.00E+00	5.16E-15
Acids, unspecified	kg	3.29E-06	1.50E-10	3.29E-06
Alachlor	kg	7.28E-11	0.00E+00	7.28E-11
Aluminium	kg	2.22E-05	0.00E+00	2.22E-05
Aluminum	kg	4.78E-03	9.69E-04	3.81E-03
Ammonia	kg	1.94E-03	2.10E-04	1.73E-03
Ammonia, as N	kg	3.27E-09	7.53E-11	3.20E-09
Ammonium, ion	kg	2.49E-06	5.18E-08	2.43E-06
Antimony	kg	2.89E-06	6.04E-07	2.29E-06
Arsenic, ion	kg	3.27E-05	3.09E-06	2.96E-05
Atrazine	kg	1.44E-09	0.00E+00	1.44E-09
Barium	kg	6.77E-02	1.33E-02	5.44E-02
Bentazone	kg	5.88E-12	0.00E+00	5.88E-12
Benzene	kg	2.35E-04	1.88E-05	2.16E-04
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.40E-08	1.12E-09	1.29E-08
Benzene, ethyl-	kg	1.32E-05	1.06E-06	1.22E-05
Benzene, pentamethyl-	kg	1.05E-08	8.42E-10	9.67E-09
Benzenes, alkylated, unspecified	kg	2.54E-06	5.30E-07	2.01E-06
Benzoic acid	kg	1.42E-04	1.14E-05	1.31E-04
Beryllium	kg	1.57E-06	1.71E-07	1.40E-06
Biphenyl	kg	1.64E-07	3.43E-08	1.30E-07
BOD5, Biological Oxygen Demand	kg	2.59E-02	2.06E-03	2.38E-02
Boron	kg	4.40E-04	3.53E-05	4.05E-04
Bromide	kg	3.01E-02	2.41E-03	2.76E-02
Bromoxynil	kg	7.78E-12	0.00E+00	7.78E-12
Cadmium, ion	kg	4.81E-06	4.58E-07	4.35E-06
Calcium, ion	kg	4.51E-01	3.61E-02	4.15E-01
Carbofuran	kg	1.10E-11	0.00E+00	1.10E-11
CFCs, unspecified	kg	2.31E-09	0.00E+00	2.31E-09
Chloride	kg	5.07E+00	4.06E-01	4.66E+00
Chlorpyrifos	kg	8.48E-11	0.00E+00	8.48E-11

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Chromate	kg	3.08E-13	0.00E+00	3.08E-13
Chromium	kg	7.04E-05	2.55E-05	4.49E-05
Chromium VI	kg	2.96E-07	1.07E-07	1.89E-07
Chromium, ion	kg	6.07E-05	1.94E-06	5.87E-05
Cobalt	kg	3.11E-06	2.49E-07	2.86E-06
COD, Chemical Oxygen Demand	kg	4.60E-02	3.90E-03	4.21E-02
Copper, ion	kg	2.64E-05	3.21E-06	2.32E-05
Cyanazine	kg	1.27E-11	0.00E+00	1.27E-11
Cyanide	kg	1.02E-08	8.11E-10	9.35E-09
Decane	kg	4.09E-06	3.28E-07	3.76E-06
Detergent, oil	kg	1.35E-04	9.45E-06	1.25E-04
Dibenzofuran	kg	2.67E-08	2.14E-09	2.45E-08
Dibenzothiophene	kg	2.21E-08	1.84E-09	2.03E-08
Dicamba	kg	7.49E-11	0.00E+00	7.49E-11
Dimethenamid	kg	1.77E-10	0.00E+00	1.77E-10
Dipropylthiocarbamic acid S-ethyl ester	kg	7.31E-11	0.00E+00	7.31E-11
Disulfoton	kg	4.36E-12	0.00E+00	4.36E-12
Diuron	kg	1.23E-12	0.00E+00	1.23E-12
DOC, Dissolved Organic Carbon	kg	2.00E-11	4.60E-13	1.96E-11
Docosane	kg	1.50E-07	1.20E-08	1.38E-07
Dodecane	kg	7.76E-06	6.21E-07	7.13E-06
Eicosane	kg	2.14E-06	1.71E-07	1.96E-06
Fluorene, 1-methyl-	kg	1.60E-08	1.28E-09	1.47E-08
Fluorenes, alkylated, unspecified	kg	1.47E-07	3.07E-08	1.16E-07
Fluoride	kg	6.88E-05	2.92E-05	3.96E-05
Fluorine	kg	8.00E-08	1.52E-08	6.48E-08
Furan	kg	8.48E-11	0.00E+00	8.48E-11
Glyphosate	kg	1.59E-10	0.00E+00	1.59E-10
Hexadecane	kg	8.47E-06	6.78E-07	7.79E-06
Hexanoic acid	kg	2.95E-05	2.36E-06	2.71E-05
Hydrocarbons, unspecified	kg	8.48E-08	5.76E-13	8.48E-08
Iron	kg	1.19E-02	1.93E-03	9.97E-03
Lead	kg	5.28E-05	6.47E-06	4.64E-05
Lead-210/kg	kg	1.46E-14	1.17E-15	1.34E-14
Lithium, ion	kg	1.19E-01	6.25E-04	1.18E-01
Magnesium	kg	8.81E-02	7.06E-03	8.11E-02
Manganese	kg	2.23E-04	1.27E-05	2.10E-04
MCPA	kg	9.96E-13	0.00E+00	9.96E-13
Mercury	kg	5.40E-08	1.08E-08	4.32E-08
Metallic ions, unspecified	kg	2.17E-09	7.03E-12	2.16E-09
Methane, monochloro-, R-40	kg	5.64E-09	4.52E-10	5.19E-09

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Methyl ethyl ketone	kg	1.13E-08	9.04E-10	1.04E-08
Metolachlor	kg	5.84E-10	0.00E+00	5.84E-10
Metribuzin	kg	2.71E-12	0.00E+00	2.71E-12
Molybdenum	kg	3.22E-06	2.58E-07	2.97E-06
m-Xylene	kg	4.25E-06	3.40E-07	3.91E-06
Naphthalene	kg	2.55E-06	2.05E-07	2.34E-06
Naphthalene, 2-methyl-	kg	2.22E-06	1.78E-07	2.04E-06
Naphthalenes, alkylated, unspecified	kg	4.16E-08	8.68E-09	3.29E-08
n-Hexacosane	kg	9.36E-08	7.50E-09	8.61E-08
Nickel	kg	2.75E-05	3.04E-06	2.45E-05
Nickel, ion	kg	2.68E-13	0.00E+00	2.68E-13
Nitrate	kg	2.75E-07	5.04E-14	2.75E-07
Nitrate compounds	kg	8.83E-11	2.03E-12	8.63E-11
Nitric acid	kg	1.98E-07	4.56E-09	1.94E-07
Nitrogen, total	kg	1.57E-05	1.29E-07	1.56E-05
o-Cresol	kg	4.03E-06	3.23E-07	3.71E-06
Octadecane	kg	2.09E-06	1.68E-07	1.92E-06
Oils, unspecified	kg	2.86E-03	2.59E-04	2.60E-03
Organic substances, unspecified	kg	1.69E-09	0.00E+00	1.69E-09
Paraquat	kg	1.18E-11	0.00E+00	1.18E-11
Parathion, methyl	kg	8.94E-12	0.00E+00	8.94E-12
p-Cresol	kg	4.35E-06	3.49E-07	4.00E-06
Pendimethalin	kg	6.08E-11	0.00E+00	6.08E-11
Permethrin	kg	5.46E-12	0.00E+00	5.46E-12
Phenanthrene	kg	2.26E-08	3.12E-09	1.95E-08
Phenanthrenes, alkylated, unspecified	kg	1.72E-08	3.60E-09	1.36E-08
Phenol	kg	1.34E-05	4.75E-06	8.68E-06
Phenol, 2,4-dimethyl-	kg	3.93E-06	3.15E-07	3.61E-06
Phenols, unspecified	kg	5.14E-05	9.23E-07	5.05E-05
Phorate	kg	1.69E-12	0.00E+00	1.69E-12
Phosphate	kg	4.20E-05	2.13E-05	2.07E-05
Phosphorus	kg	4.74E-06	0.00E+00	4.74E-06
Phosphorus compounds, unspecified	kg	3.13E-08	0.00E+00	3.13E-08
Phosphorus, total	kg	2.80E-06	0.00E+00	2.80E-06
Process solvents, unspecified	kg	8.48E-09	0.00E+00	8.48E-09
Radioactive species, Nuclides, unspecified	Bq	3.61E+02	7.52E+00	3.53E+02
Radium-226/kg	kg	5.07E-12	4.06E-13	4.66E-12
Radium-228/kg	kg	2.59E-14	2.08E-15	2.39E-14
Selenium	kg	1.44E-06	1.35E-07	1.30E-06
Silver	kg	2.94E-04	2.36E-05	2.70E-04
Simazine	kg	3.84E-11	0.00E+00	3.84E-11

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Sodium, ion	kg	1.43E+00	1.14E-01	1.31E+00
Solids, inorganic	kg	5.04E-10	1.16E-11	4.92E-10
Solved solids	kg	6.25E+00	5.01E-01	5.75E+00
Strontium	kg	7.64E-03	6.13E-04	7.03E-03
Styrene	kg	1.07E-11	0.00E+00	1.07E-11
Sulfate	kg	1.53E-02	9.22E-04	1.44E-02
Sulfide	kg	2.80E-05	5.51E-07	2.75E-05
Sulfur	kg	3.72E-04	2.98E-05	3.42E-04
Sulfuric acid	kg	7.42E-11	0.00E+00	7.42E-11
Suspended solids, unspecified	kg	1.54E-01	2.98E-02	1.24E-01
Tar	kg	4.99E-12	1.15E-13	4.88E-12
Terbufos	kg	5.77E-11	0.00E+00	5.77E-11
Tetradecane	kg	3.40E-06	2.72E-07	3.13E-06
Thallium	kg	6.11E-07	1.27E-07	4.84E-07
Tin	kg	1.88E-05	2.46E-06	1.64E-05
Titanium, ion	kg	4.45E-05	9.27E-06	3.52E-05
TOC, Total Organic Carbon	kg	1.07E-07	0.00E+00	1.07E-07
Toluene	kg	2.22E-04	1.78E-05	2.04E-04
Vanadium	kg	3.81E-06	3.05E-07	3.50E-06
Waste water/m3	m3	6.99E-04	0.00E+00	6.99E-04
Xylene	kg	1.16E-04	9.56E-06	1.07E-04
Yttrium	kg	9.45E-07	7.57E-08	8.69E-07
Zinc	kg	1.19E-04	2.24E-05	9.70E-05
Zinc, ion	kg	3.74E-07	0.00E+00	3.74E-07