**CORRIM: Phase II Final Report**

# Module B

# Life Cycle Inventory of Inland Northwest Softwood Lumber Manufacturing

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## Executive Summary

The objective of this study was to conduct a gate-to-gate life-cycle inventory (LCI) of softwood lumber manufacturing in the Inland Northwest Region of the United States (U.S.) representing eastern Washington, eastern Oregon, Idaho and western Montana. Representative softwood lumber mills for the study survey were located in eastern Washington and Idaho. This was a follow-up study to another LCI study conducted for Pacific Northwest softwood lumber and southern pine lumber (Milota 2004; Milota et al. 2004; Milota et al. 2005). In the Inland Northwest Region, softwood lumber species can include a mix of 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*). This study focused upon production practices in the Inland Northwest Region where softwood lumber production generally consists of debarking logs, sawing logs into lumber, drying green lumber in dry kilns, planing dried or green lumber, grading planed lumber, and packaging graded lumber for shipment. Softwood lumber is typically used for framing and finishing residential structures, and it is nominally 1 or 2 inches (actual 19 or 38 mm (0.75 or 1.5 inches)) thick, 4 to 12 inches (actual 89 to 286 mm (3.5 to 11.25 inches)) wide, and 8 to 20 feet (2.44 to 6.10 m) long.

Four softwood lumber mills from eastern Washington and Idaho were selected based on their production as representative mills from the Inland Northwest Region. These lumber manufacturing plants were surveyed to obtain a record of all inputs and outputs associated with the production process. Input data collected included material transportation distances, raw material consumption, and the use of wood fuels (wood and bark), electricity, and fossil fuels. Output data quantified softwood lumber products, co-products of chips, shavings, bark, and sawdust, as well as emissions to land, water and air. The combined annual production of the four representative plants was 466 million board feet (MMBF - based on nominal board foot measurements – 320 MMBF solid wood) (755,852 $m^3$ – solid wood) in 2005/2006 or about 16 percent of the total production within the Inland Northwest Region reported over one calendar year..

The process of producing softwood lumber was modeled in SimaPro7.1.6 as a four sub-unit process. A multi-unit process approach modeled the LCI of softwood lumber manufacturing to better assess the environmental impacts. The unit processes included (1) log yard activities, (2) sawmilling (green lumber production), (3) dry kilns which connects two additional sub-process for wood and natural gas boilers, and (4) planer mill. The rationale for this approach is that this type of model will be useful in analyzing ways to improve process efficiency, optimize operations, and find means to reduce environmental impacts. These objectives cannot be achieved using a simple “black-box” approach. With the recent attention given to conservation of raw materials, awareness of price volatility and increases in the electricity and fuels cost, and the substantial cost of emissions mitigation, it has become imperative to address these concerns. The LCI data presented will be useful as a benchmark to assess environmental performance and economic feasibility of process improvements.

To produce one cubic meter (m3) (436 kg/m3 or 27 lb/ft3) of planed-dried lumber (the most common softwood lumber output type), the lumber manufacturing plants needed 1.78 m3 1 (=778 kg) or 63 ft3 (=2,784 lb/MBF)) of logs. Co-product bark volume was 58 kg/m3 (206 lb/MBF). Electricity usage was 62 kWh (100 kWh/MBF) which was consumed primarily in sawmill dry kilns and planer processes. By far the leading source of energy for electricity production in the region was hydroelectric representing 71.5 %. Wood fuel at 55 kg/m3 or 1,151 MJ/m3 (1,768,932 BTU/MBF) and natural gas 26 m3 or 1,396

[1] Based on a 12% specific gravity (oven dry mass and volume at 12%)

MJ/m3 (2,145,443 BTU/MBF) were the primary energy sources consumed for lumber drying. Wood fuel and natural gas contributed 54% and 46%, respectively, of the fuel consumed in the boiler process.

In this study, the production of 436 kg, or one cubic meter, of planed-dried lumber required 778 kg (2,784 lb/MBF) of logs (wood mass entering mill) resulting in a recovery efficiency of 56%. Pulp chip production comprised the largest segment of co-product production with 221 kg (789 lb/MBF) or 29%, and sawdust was second with 52 kg (185 lb/MBF) or 7%.

Emissions and emissions mitigation are becoming increasingly important in terms of plant operations and manufacturing costs. Life-cycle inventory emissions are presented for two scenarios: (1) cumulative emissions (production, transportation and combustion of all fuels and electricity) including those generated on-site for softwood lumber, and (2) on-site production emissions generated from the production softwood lumber (survey collected data and on-site fuel combustion emission). Allocations were made on a mass basis for products and co-products produced in the lumber manufacturing process. Therefore, inputs as collected by surveys and outputs (emissions) generated by the SimaPro model are allocated to the production of one cubic meter (436 kg) of planed-dried softwood lumber. Emissions associated with the production of co-products were not included in the LCI results for the lumber.

One source of emissions is the dried lumber itself. Volatile organic compounds (VOC) are driven from the heated lumber during drying and escape from the dry kiln process through vents or leaks in the kilns. Emissions of VOC were 0.167 kg per m3 (0.596 lb/MBF) of planed-dried lumber. Emissions also included carbon dioxide (CO2), both from the combustion of fossil fuels and from the combustion of biomass (wood fuel). Most of the CO2 (biomass derived) was generated by combustion of wood and bark in the boiler process. Emissions of CO2 biomass were 116 kg per m3 (415 lb/MBF) of planed-dried lumber. However, this impact is negated or greatly lessened by the growing of trees that remove CO2 from the atmosphere. Carbon dioxide (CO2 fossil) released from the combustion of fossil fuels (gasoline, diesel and natural gas) resulted in 71 kg per m3 (254 lb/MBF) of planed-dried lumber.

The quality of the data is considered highly defensible based on the amount of data collected for the four plants from the region. Additional data analysis (i.e., mass and energy balances), as well as regional comparisons, further supported the integrity of our findings. The unit process approach for modeling the LCI of lumber should prove useful for modeling other similar processes and should also be valuable as a tool to optimize operations. The LCI data can also be used as a benchmark to assess improvements.

All data will be publically available through CORRIM outlets and in the US LCI Database (USLCI 2008). A summary of the report will also be developed as a refereed journal article.

## Table of Contents Page

## List of Figures Page



## List of Tables Page

# Introduction

## Background

This report has been produced as part of the CORRIM's (Consortium for Research on Renewable Industrial Materials) (CORRIM 2008) Phase II reports on the life cycle inventory (LCI) and life cycle assessment (LCA) studies on wood based products produced in the United States. CORRIM's goal is to provide a database of information for quantifying the environmental impacts and economic costs of wood building materials through the stages of tree planting, growing, harvesting, manufacturing, construction, use, and demolition of buildings in the United States.

CORRIM has been organized to update and expand a 1976 report by the National Academy of Science regarding the impacts of producing and using renewable materials. The original report focused specifically on the energy impacts associated with using various renewable materials. Since the 1976 report was written a variety of environmental issues and energy-related concerns have surfaced, yet little scientific or quantifiable information regarding these issues and concerns has been generated. Without a scientifically sound database of the environmental and economic impacts associated with using renewable materials, it is difficult for policymakers to arrive at informed decisions affecting the forestry and wood manufacturing industries. Moreover, individual industries, including those that use wood as a raw material have little information available to them that could provide a basis for strategic planning and investments to improve their environmental stewardship.

The specific interest of this report is a gate-to-gate life cycle inventory of softwood lumber production from the Inland Northwest region of the United States (Figure 1). The primary data for this report incorporates site-specific data collected from four representative sawmills from the region's use surveys. The data represents twelve months of lumber production over 2005-2006 production years. Secondary data from published databases for the production of electricity, fuels, and ancillary materials has also been incorporated in this analysis (FAL 2001).

The significance of this study is that all environmental impacts from gate-to-gate are detailed providing an objective overview of softwood lumber production from the Inland Northwest region of the United States in terms of their environmental impact.

This study adheres to ISO 14044 guidelines (ISO 2006) and CORRIM's guidelines for conducting LCI's on wood products (CORRIM 2001).

The benefits of this study include:

- Providing a benchmark for the softwood lumber mills to improve upon production practices to improve will improved environmental efficiencies.
- Filling the gap between production practices and environmental improvement by assisting the wood products industry to better understand their processes from a life cycle environmental perspective.
- Contributing to the U.S. LCI database (USLCI 2008);

## Previous LCI studies on softwood lumber production

Until the CORRIM work, LCA studies of wood products and building materials have in general focused only on energy consumption and associated impacts related to raw material extraction, product manufacture, and building construction. A few studies have examined thermal performance of different building materials–e.g., wall types, windows, and doors. However, interest has recently extended to a wider range of issues.

In Phase I of CORRIM product LCI's Milota (2004) and Milota et al. (2004) documented the environmental impacts of softwood lumber production from the Pacific Northwest and the southeast United States production regions, respectively. Their reports included information on production, energy use and emissions associated with lumber production processes. In the Pacific Northwest (PNW) report 13% of the regions production was represented in the LCI, while in the southeast (SE) study, 9.4% of the region's production was represented in the study.

Representation of each region is listed below:

- Total number of mills represented in the studies
  - PNW = 4
  - SE = 4
- Total production of mills represented
  - PNW = 1,120,000 MBF (1000 board feet)
  - SE = 72,300 MBF
- Representation of industry production for 1999 or 2000 in region
  - PNW = 13%
  - SE = 9.4%

Resource requirement (logs) for the production of MBF from the PNW region was 108 ft3 or 3.06 m3 (wood and bark) and the SE region was 138 ft3 or 3.91 m3 (wood and bark) . Both studies reported energy and environmental impacts in terms of electricity use, heat energy requirements and air, water and land emissions associated with sawing, drying, boilers, and planing operations.

### Overview of the Inland Northwest softwood lumber industry

Softwood lumber is typically used for framing and finishing residential structures, and it is nominally 1 or 2 inches (actual 19 or 38 mm (0.75 or 1.5 inches)) thick, 4 to 12 inches (actual 89 to 286 mm (3.5 to 11.25 inches)) wide, and 8 to 20 feet (2.44 to 6.10 m ) long. This study focused upon production practices in the Inland Northwest Region of the U.S. which includes eastern Washington, eastern Oregon, Idaho and western Montana (Figure 1). Softwood lumber production often consists of debarking logs, sawing logs into lumber, drying green lumber in dry kilns, planing dried or green lumber, grading planed lumber, and packaging graded lumber for shipment. Softwood lumber species in the region include grand fir (Abies grandis), Douglas-fir (Pseudotsuga menziesii), western larch (Larix occidentalis), western redcedar (Thuja plicata), lodgepole pine (Pinus contorta), ponderosa pine (Pinus ponderosa), and western hemlock (Tsuga heterophylla). Total annual softwood lumber production for the Inland Northwest region in 2005 was 3 billion board feet (4,866,000 cubic meters (m3) (WWPA 2006). This production represents 8% of the total U.S. softwood lumber production. Four lumber manufacturing plants from within the region provided data for this study.

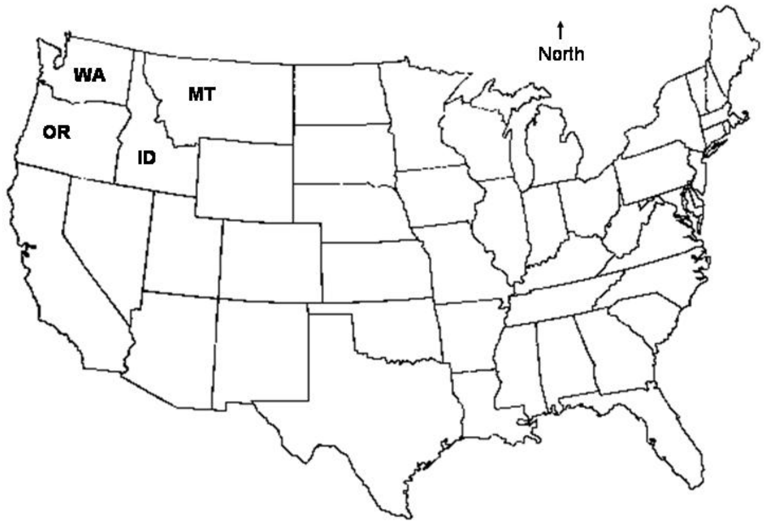


**Figure 1: Inland Northwest softwood lumber production region representing eastern Washington (WA), eastern Oregon (OR), Idaho (ID), and western Montana (MT).**

To conduct the survey of lumber manufacturers, four plants were identified based on their production capability and representativeness of the industry. All four plants provided data in terms of softwood lumber and co-products production, raw materials, electricity, fuel use, and emissions to air, land and water. The combined annual production of the four plants was 466 million board feet[1] (755,852 $m^3$ – actual solid wood)[2] in 2005/2006 or about 16 percent of the total production within the Inland Northwest Region.

This report documents a gate-to-gate life cycle inventory (LCI) of the manufacturing of softwood lumber from log resources of the Inland Northwest region. The scope of this report represents production of softwood lumber in the Inland Northwest region (Idaho, eastern Washington, eastern Oregon, and western Montana). Included in the system boundary are those activities associated with the production of softwood lumber, production, delivery and combustion of fuels, production and delivery of electricity, and all associated emissions. Excluded from the system boundary are the growing trees and harvesting and transportation of logs to the softwood lumber production facility. The output of this report will be data analyzed in a cradle-to-grave life cycle analysis (LCA) of structural building materials by CORRIM which will incorporate tree growth, management, harvesting and transportation to the production facilities as well as transportation of the finished products to construction sites.

This report considers those impacts associated solely with the manufacture of softwood lumber in the Inland Northwest Region, documenting all inputs and outputs and their impacts. Survey information covered operations of the mills throughout one full year, including summer and winter operations. While primary data was collected through surveys, secondary data was obtained from available databases (EIA 2007; FAL 2001; PRé Consultants 2008). Critical external reviews of this LCI process were conducted to ensure compliance with CORRIM guidelines and ISO 14044 standards (replaces ISO14040, 14041, 14042, and 14043) (CORRIM 2001; ISO 2006).

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[1] Board foot (BF) -The basic unit of measurement for lumber. One board foot is equal to a 1-inch board 12 inches in

[2] Conversion from board feet (BF) to $m^3$ (cubic meters) is based upon the actual size of nominal 2-inch thick and 6-

## Methodology

### Unit process approach

Lumber manufacturing was segmented into four unit processes that included log yard, sawmill (green lumber production), dry kilns (including wood and natural gas boilers), and planer (Figure 2). The rationale for this approach was that a multi-unit model would be most useful in analyzing ways to improve process efficiency, optimize operations, and reduce environmental impacts. Furthermore, data in this format provides benchmarks to document process improvements. In addition, this approach allows a sub-unit process developed for one product to be used for modeling other products. A multi-unit-process-type model also provides a realistic assignment of environmental burdens. The inputs to lumber manufacturing (gate-to gate) included logs with bark, energy (electricity and fuels), and water. Outputs included planed-dried lumber, co-products (bark, chips, sawdust, and planer shavings), and emissions to air, land, and water. A complete list of material inputs and outputs can be found in Table 1.

Sawmill boilers are fired with co-product bark and wood waste. As such, the bark and other wood waste in the form of "hogged fuel" for heat generation are considered within the system boundary for the LCI analysis. Excluded from the study were the harvesting and growth of the trees. Figure 2 provides an overview of the entire system boundary for modeling the lumber process.

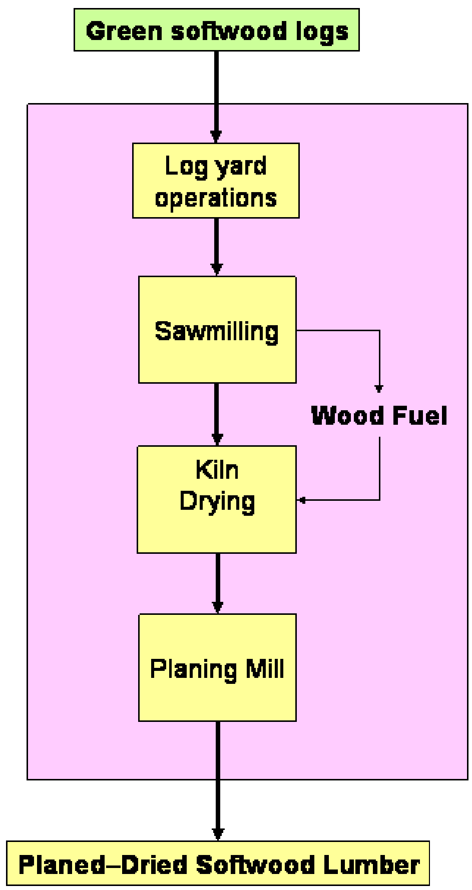


**Figure 2: Unit process approach to the modeling of the Inland Northwest softwood lumber manufacturing process**

**Table 1: Listing of input materials, products, and co-products for producing lumber.**

| Input Materials | Co-products Produced | Products |
|---|---|---|
| Softwood logs with bark | Bark | Planed-dried lumber |
| | Chips, green | |
| | Chips, dry | |
| | Sawdust, green | |
| | Planer shaving, dry | |
| | Wood fiber, green | |
| | Wood fuel (bark and wood) | |

***Description of Sub-unit processes:***

1. 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 (Figure 2). Inputs included logs with bark, fuel and lubricants, electricity, and water. Outputs included logs with bark, dust, hydrocarbons, bark, and rock.
2. 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 included logs with bark, fuel and lubricants, and electricity. Outputs included rough-green lumber, pulp chips, green sawdust, and bark.
3. 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. Inputs included rough-green lumber, steam, electricity, and fuel and lubricants. Outputs included rough-dry lumber and air emissions. The boiler processes included boiling water to produce steam for the dry kilns. Inputs included hogged fuel (bark and wood), natural gas, water, and water treatment chemicals. Outputs included steam, air emissions, and ash. During winter, logs are not thawed prior to sawing. Rather, frozen logs are sawn with special teeth, so there is no boiler heat required to thaw the logs.
4. The planer process included unstacking rough-dry lumber, planing rough-dry lumber, grading planed lumber, sorting graded lumber, packaging graded lumber, and loading graded lumber for shipment. Inputs included rough-dry lumber, fuel and lubricants, lumber wrap and strapping, and electricity. Outputs included planed-dried lumber, planer shavings, sawdust, and chips.

## Reference unit

The reference unit is 1 cubic meter (m3) which defines the volume comprised of 1,000 board feet of planed dried softwood lumber (= product). This follows CORRIM's Phase I LCI studies on softwood lumber production (Milota 2004, Milota et al. 2004). The board foot (BF) is a basic unit of measurement for lumber. One board foot of 2x6 lumber is two lineal feet. The conversion factor for one thousand board feet (MBF) was equal to 1.622 m3. A more specific functional unit was not developed because it requires the use of the lumber to be defined in a particular situation over its full life cycle. For example, the functional unit of framing lumber could be expressed in terms of an area of wall that is supported for a particular situation.

## System boundaries

The system boundary encompasses the product manufacturing processes including material (logs), electricity and fuels required to produce one cubic meter ($m^3$) of finished product. Transportation distances were reported in surveys and only referenced. The cumulative system boundary (gate-to-gate) includes all upstream flows of energy, fuel, and raw material production (Figure 3). The on-site system boundary included only those burdens generated on-site at the manufacturing facility. The on-site system boundary does not include the production and transportation of electricity and fuels (Figure 3). Fuel combustion emissions and sawmill manufacturing emissions (including dryer and boiler) are included. Log input to sawmills contains both wood and the accompanying bark. Green lumber is defined as lumber that has not yet been processed through the dry kiln. Green finished lumber, or S-Green, was not considered a product within the system boundaries and data was scaled to reflect appropriate allocations to planed-dried lumber.

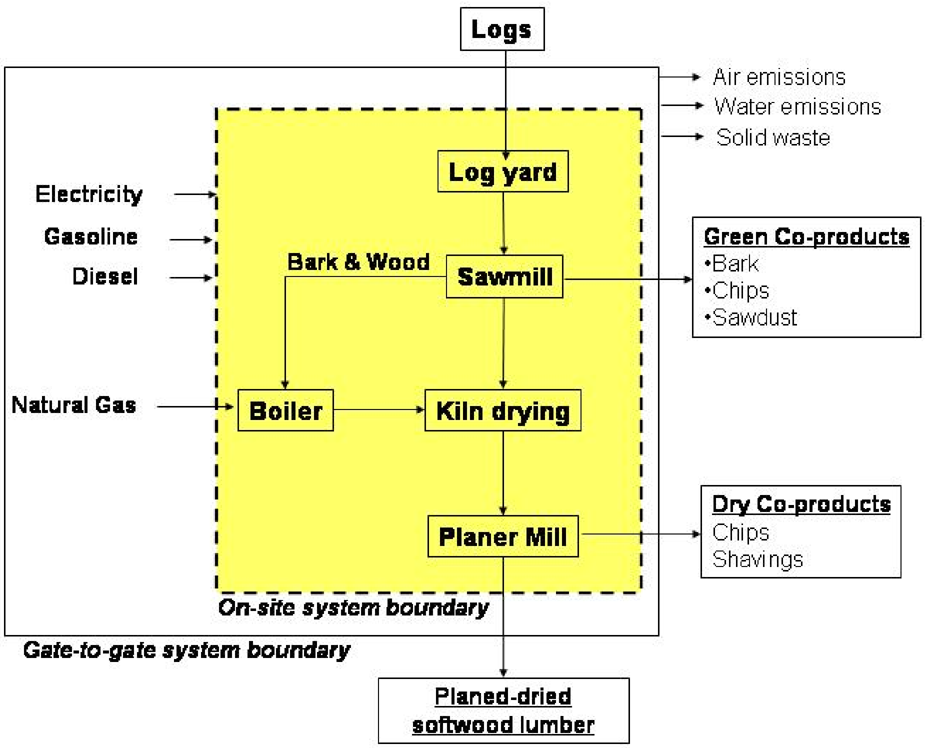


**Figure 3: System boundary and sub-unit processes used to model the lumber manufacturing process**

### Material flows

The materials considered in the LCI analysis include those listed in Table 1. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis. Three different log scales (Scribner Scaling C short and East Side Scale and weight-based) used by the four mills gave log inputs in either thousand board feet or tons. As part of the CORRIM protocol for ensuring data quality, an overall "wood balance" is required to fall within 5% from material input to material output. Wood-only log mass was calculated based on the previous assumption of 1.622 cubic meters per MBF and an average dry density (wood-only) of 436 kg/m$^3$.

### Transportation

Delivery of the input materials was by truck. Environmental burdens for transporting logs to the lumber manufacturing facilities were not included in this LCI. However, the average one-way haul distance was 129 km (80 miles). Environmental burdens for hauling logs to the manufacturing facility and back hauling empty trucks to the woods is included in CORRIM cradle-to-gate analysis of building materials.

### Density

The CORRIM SimaPro models for products using logs from the forest resources models are required to, 1. Enter log input volumes based on green volumes and, 2. Enter product outputs based on oven dry mass and volumes. This means that both green and dry (12%) specific gravities must be determined for the species mix of each product. Tables 2a and 2b below, list the wood species mix, specific gravities, percent reported in surveys, densities in both English and SI units, and the weighted average densities for input into the SimaPro model for both green and 12% specific gravities. Log volume inputs were determined with wood-only log volume data in Scribner scale with conversion to a volume (cubic feet or cubic meters) of wood by the appropriate conversion factor as given by Briggs (1994). A final conversion was then made from volume to mass (pound (lb)) by multiplying by the average weighted densities of the various wood species as determined by their percentage of the total in the survey and the densities for these species as provided in the Wood Handbook (1999). According to CORRIM guidelines, wood volume (logs) inputs where adjusted to reflect green volume inputs from the Inland Forest Resource model based on the weighed average specific gravity of 0.41 listed in Table 2a. For output products and co-products, CORRIM guidelines required all products to be on an oven dry mass and volume basis. Therefore, a weighted average specific gravity of 0.44 (density = 436 $kg/m^3$ (27 $lb/ft^3$)) was used (Table 2b).

**Table 2a: Average density of wood species used to calculate mass of wood from logs using green specific gravity**

| Wood Species[1/] | SG green [2/] | Percentage Use in Survey | Density | | Weighted Average Density | |
|---|---|---|---|---|---|---|
| | | | $kg/m^3$ | $lb/ft^3$ | $kg/m^3$ | $lb/ft^3$ |
| Ponderosa Pine | 0.38 | 4.37 | 380 | 23.72 | 16.61 | 1.04 |
| Lodgepole Pine | 0.38 | 9.62 | 380 | 23.72 | 36.56 | 2.28 |
| Douglas-fir [3/] | 0.45 | 11.23 | 450 | 28.09 | 50.54 | 3.15 |
| Larch | 0.48 | 0.6 | 480 | 29.96 | 2.88 | 0.18 |
| Doug-fir & Larch [4/] | 0.47 | 31.36 | 465 | 29.03 | 145.82 | 9.10 |
| Western Hemlock | 0.42 | 10.11 | 420 | 26.22 | 42.46 | 2.65 |
| White fir | 0.37 | 16.99 | 370 | 23.10 | 62.86 | 3.92 |
| ESLPAF [5/] | 0.34 | 7.05 | 340 | 21.22 | 23.97 | 1.50 |
| Inland Red Cedar | 0.31 | 8.67 | 310 | 19.35 | 26.88 | 1.68 |
| | | **100 %** | | | **409 $kg/m^3$** | **26 $lb/ft^3$** |

1 Wood species as reported in mill surveys

2 SG = Specific gravity = oven dry mass / volume at a specific moisture content. Wood specific gravity values from Table 4-3a Wood Handbook: Wood as an Engineering Material (FPL 1999). Average weighted specific gravity = 0.41 @ green (>30% MC).

3 Douglas-fir, Interior North

4 Assume 50:50 distribution

5 ESLPAF = Engelmann spruce, lodgepole pine, and alpine fir. Assume equal distribution

**Table 2b: Average density of wood species used to calculate mass of wood from logs using a 12% specific gravity**

| Wood Species[1] | SG 12% [2] | Percentage Use in Survey | Density | | Weighted Average Density | |
|---|---|---|---|---|---|---|
| | | | $kg/m^3$ | $lb/ft^3$ | $kg/m^3$ | $lb/ft^3$ |
| Ponderosa Pine | 0.4 | 4.37 | 400 | 24.97 | 17.48 | 1.09 |
| Lodgepole Pine | 0.41 | 9.62 | 410 | 25.59 | 39.44 | 2.46 |
| Douglas-fir [3] | 0.48 | 11.23 | 480 | 29.96 | 53.90 | 3.36 |
| Larch | 0.52 | 0.6 | 520 | 32.46 | 3.12 | 0.19 |
| Doug-fir & Larch [4] | 0.5 | 31.36 | 500 | 31.21 | 156.80 | 9.79 |
| Western Hemlock | 0.45 | 10.11 | 450 | 28.09 | 45.50 | 2.84 |
| White fir | 0.39 | 16.99 | 390 | 24.34 | 66.26 | 4.14 |
| ESLPAF [5] | 0.36 | 7.05 | 360 | 22.47 | 25.38 | 1.58 |
| Western Red Cedar | 0.32 | 8.67 | 320 | 19.98 | 27.74 | 1.73 |
| | | **100%** | | | **436 $kg/m^3$** | **27 $lb/ft^3$** |

1 Wood species as reported in mill surveys
2 SG = Specific gravity = oven dry mass / volume at a specific moisture content. Wood specific gravity values from Table 4-3a Wood Handbook: Wood as an Engineering Material (FPL 1999). Average weighted specific gravity = 0.44 @ 12%.
3 Douglas-fir, Interior North
4 Assume 50:50 distribution
5 ESLPAF = Engelmann spruce, lodgepole pine, and alpine fir. Assume equal distribution

## Assumptions

The study data collection, analysis, and assumptions followed protocols as defined in "Consortium for Research on Renewable Industrial Materials (CORRIM)--Research Guidelines for Life Cycle Inventories" dated April 18, 2001 and updated May 2008. Additional considerations include:

1 Primary data were collected via questionnaire in accordance with ISO protocol (ISO 2006) and CORRIM research guidelines. All data from the manufacturing-plant surveys were weighted based upon plant production. This produced a composite mill that was representative of the region. Missing values were not weight averaged for that particular process per ISO protocol to maintain good data quality. Primary data showed that the species represented were grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), western redcedar (*Thuja plicata*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and western hemlock (*Tsuga heterophylla*).

2 The LCI study covered one full year during the period 2006 and 2007 depending on when an operational (fiscal) year started at each softwood lumber company. The geographical area covered the Inland Northwest United States shown in Figure 1.

3 Data quality was high based upon comparisons to previous work (Milota et al. 2005) and based upon mass and heat balances.

4 Green and dry wood density and specific gravity values published in the Wood Handbook (1999) for the species mix reported and were applied to determine the mass basis conversion from board feet. Green and dry (12%) specific gravities were 0.41 and 0.44 respectively. Green and dry (12%) densities where 409 $kg/m^3$ and 436 $kg/m^3$ (27 $lb/ft^3$) respectively.

5 Log inputs were in either thousands of board feet Scribner scale or tons and were converted to $m^3$ and $ft^3$.

6 Lumber outputs were converted from thousands of board feet to cubic measure based upon the actual size of nominal 2x6 lumber (actual 38 x 140 mm (1.5 x 5.5 inches)).

7 Mass allocation procedure was based on CORRIM protocol. The sawmill process was divided into four unit processes. Therefore in the drying process, where much of the energy is consumed and the emissions are created, allowed the inputs and outputs for drying to be allocated directly to the dried lumber.

8 Higher heating values (HHV) were used to convert volume or mass basis of a fuel to its energy value. HHV represents the energy content of a fuel with the combustion products such as water vapor brought to 25ºC (77ºF) while the lower heating value (LHV) ignores the energy produced by the combustion of hydrogen in fuel. HHV is the preferred method in the United States.

9 Water applied on site for sprinkling conversion factor logs was both surface water and ground water. Two mills did not report water consumption and were not weight averaged. No water usage was reported for use in the boilers for steam generation.

10 SimaPro 7.1.6, a software package designed for analyzing the environmental impact of products during their entire life cycle, performed the life cycle analysis. Developed in the Netherlands by PRé Consultants B.V., SimaPro7 contains a US database for a number of materials, including paper products, fuels, and chemicals. Franklin Associates (FAL) provides an additional US database.

## Product Yields

The mass balance of the flow of wood and bark into and out of softwood lumber manufacturing facilities is shown in Table 3. The recovery efficiency for one cubic meter of the primary product (bone-dry softwood lumber) was 436 kg (1,559 lb/MBF) of lumber from 836 kg (2,990 lb/MBF) of bone-dry logs with bark or 52% (93% wood, 7% bark). Pulp chip production made up the largest segment of production with 221 kg (789 lb/MBF) or 27%, and sawdust was second with 52 kg (185 lb/MBF) or 6%.

**Table 3: Wood mass balance (weights on oven-dry basis) for lumber production in the Inland Northwest region.**

| **Inputs** [1] | **kg/m$^3$** | **lb/MBF** [2] |
|---|---|---|
| Round wood with bark (logs) | 836 | 2,990 |
| Wood only | 778.5 | 2,784 |
| Bark only | 57.6 | 206 |
| **Outputs** [1] | | |
| Lumber, planed dry | 436 | 1,559 |
| Pulp chips, green, sold | 216 | 774 |
| Pulp chips, dry, sold | 4 | 15 |
| Sawdust, green, sold | 52 | 185 |
| Shavings, dry, sold | 37 | 132 |
| Wood fiber, green, sold | 3 | 11 |
| Bark, sold | 29 | 102 |
| Wood fuel [3] | 60 | 215 |
| **Total Outputs** | **837** | **2,994** |

[1] Input and output totals do not match due to rounding.
[2] 1 MBF = 1.622 m$^3$
[3] Wood fuel (hogged fuel) is used on-site for heat generation in the boilers for wood drying
Values are per cubic meter of planed-dried softwood lumber (not allocated).

### Moisture content

Wood moisture contents are needed for computation of transportation weights and for determining the energy required to remove water from wood during drying. Average green moisture content (oven dry basis) of 60% was assumed for the species mix representing the Inland Northwest lumber production region. The average moisture content after kiln drying was reported in surveys to be approximately 15%. In accordance with CORRIM guidelines, wood fuel values were analyzed by SimaPro based on oven-dried weights with proper documentation of how this conversion was performed. All wood weights entered into SimaPro are on an oven-dry basis. Log volume weights entering the sawmill directly from the Forest Resources model were entered into SimaPro on a green volume basis calculated from the green specific gravity representing the Inland Northwest species mix. Wood fuel weights from industry surveys, following industry practice, were reported as green weight and assumed to be at 50% moisture content on a wet-weight basis.

## Manufacturing Energy Summary

### Sources of energy

Energy for the production of Inland Northwest softwood lumber comes from electricity, diesel, gasoline, natural gas and wood fuel (wood and bark) (Table 4). The electricity powers the debarker, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, saws, and dryer fans. Electricity was consumed in all processes. Wood fuel and natural gas provided energy for boilers that produced heat input for lumber drying. On-site forklifts, loaders and trucks consumed small amounts of gasoline and diesel fuel.

Cumulative energy is defined as the total fuel energy (production and combustion) allocated for the manufacture of one cubic meter of Inland Northwest softwood lumber. This includes the cradle-to-gate burdens associated with the production of all fuels (coal, crude oil, natural gas, wood, and uranium) for lumber production and electricity generation. Energy for harvesting operations to bring logs into the system is not included in this analysis, nor is the transportation needed to bring resources (excluding fuels) into and between system boundaries. Energy values have been determined with the HHV given in Table 5. Table 6 shows the cumulative energy requirements that are included in that boundary. Table 7 shows the large regional differences that exist among wood producers in energy consumption requirements to produce softwood lumber. The main differences are due to fuel source for drying wood and electricity grid fuel sources. For example, the southeast United States used nearly 100% biomass fuel for drying wood while the main source for fuel for electricity generation was coal (Milota et al. 2005).

On-site energy is defined as the energy combusted on-site for the lumber production and allocated to one cubic meter of softwood lumber. This is energy in the form of natural gas, diesel, gasoline, and wood fuel. Energy required to produce these fuels and deliver them to the lumber production site are excluded from this system boundary.

**Table 4: Electricity and Fuel inputs for the production of one cubic meter (m3) or 1000 board feet (MBF) of planed-dried softwood lumber from the Inland Northwest region. (allocated)**

| **Energy and Fuel Inputs** | | | | |
|---|---|---|---|---|
| **Materials** | **Unit** | **Per $m^3$** | **Unit** | **Per MBF**[1] |
| **Electrical Use** | | | | |
| Electricity | MJ[2] | 222 | kWh | 100 |
| **Fuel Use** | | | | |
| Hogged Fuel | kg | 55 | lb | 197 |
| Natural gas | $m^3$ | 25 | $ft^3$ | 1457 |
| Diesel | L | 1.89 | gal | 0.81 |
| Gasoline | L | 0.17 | gal | 0.07 |
| **Feedstock** | | | | |
| Lubricants and oils | L | 0.25 | gal | 0.11 |

[1] 1 MBF = 1.622 $m^3$
[2] 1 MJ = 1000 J

**Table 5: HHV for conversion of raw materials for fuel production into energy values**

| **Fuel Type** | **HHV (MJ/kg)** | **HHV (BTU/lb)** |
|---|---|---|
| Coal[1] | 26.2 | 11,260 |
| Crude Oil[1] | 45.5 | 19,578 |
| Diesel[1] | 44.0 | 18,932 |
| Gasoline[1] | 48.4 | 20,808 |
| Natural Gas[1] | 54.4 | 23,409 |
| Wood Fuel/Biomass[1,2] | 20.9 | 9,000 |
| Uranium[3] | 381,000 | 163,941,480 |

[1] As per CORRIM Guidelines
[2] Oven-dry basis
[3] Neil E. Todreas and Mujid S. Kazimi, Nuclear System I -Thermal Hydraulics Fundamentals, Taylor & Francis, Page 2, Table 1-1 (1993).

**Table 6: Cumulative energy (HHV)to produce of one cubic meter of planed-dried softwood lumber in the Inland Northwest regions.**

| | **Inland Northwest Lumber** | | |
|---|---|---|---|
| **Fuel**[1] | **kg/$m^3$** | **MJ/$m^3$** | **BTU/MBF** [2] |
| Natural Gas | 25.7 | 1,396 | 2,145,443 |
| Wood Fuel/Wood Waste | 55.0 | 1,151 | 1,768,932 |
| Hydro Power | 0 | 158 | 243,446 |
| Crude Oil | 4.7 | 215 | 330,827 |
| Coal | 3.3 | 85 | 131,393 |
| Uranium | 0.00003 | 97 | 149,642 |
| Other Energy | 0 | 6 | 8,569 |
| **Total** | | **3,108** | **4,778,253** |

[1] based on HHV values
[2] 1 MBF = 1.622 $m^3$
Includes fuel used for electricity production. Values are higher heating values (allocated).

**Table 7: Cumulative energy (HHV) to produce one cubic meter of planed-dried softwood lumber produced in the Inland Northwest region compared to that of softwood lumber produced in the Pacific Northwest and Southeast.**

| | CORRIM Phase I | | CORRIM Phase II |
|---|---|---|---|
| **Fuel[1]** | **Pacific Northwest** | **Southeast** | **Inland Northwest** |
| | | MJ/$m^3$ | |
| Natural Gas | 1,344 | 232 | 1,396 |
| Wood Fuel/Wood Waste | 1,592 | 3,023 | 1,151 |
| Hydro Power | 200 | 4 | 159 |
| Crude Oil | 91 | 97 | 112 |
| Coal | 95 | 411 | 84 |
| Uranium | 39 | 170 | 10 |
| Other Energy | 3 | 8 | 6 |
| Total | 3,364 | 3,945 | 2,911 |

[1] based on HHV values
Includes fuel used for electricity production (allocated) .

The ability of the softwood lumber industry to generate a major portion of its heat needs from the combustion of hogged fuel instead of natural gas provides a significant benefit. If an Inland Northwest plant producing 100 million board feet of solid wood (162,200 $m^3$) of softwood lumber annually replaced the hogged fuel with an equivalent quantity of natural gas, at $0.40 per therm (100,000 BTU), the plant would have an additional natural gas bill of $406,000. The electricity bills for the same annual production would be substantial at $0.0425 per kWh. The annual bill would be about $420,000. With the projected cost increases of both natural gas and electricity, means to become more energy efficient will receive more attention.

## Electricity Use Summary

Identification of the source of fuel for electricity generation for powering the manufacturing process is important in determining the type and amount of impact in the LCA. The proportional breakdown of electricity for the Inland Northwest region by fuel source is given in Table 8. The source of this data is the US Department of Energy (DOE) (EIA 2007). In 2005 the dominant form of electricity generation in the region was hydro, representing 71.5% of the total, followed by coal at 9.4% and natural gas at 9.0%. In the SimaPro (LCA software) impact analysis, no impacts are associated with hydro-generated electricity; however, combusting of coal can contribute significant impact values.

**Table 8: Electric power industry generation of electricity by primary energy sources and state for the Inland Northwest region as defined by the US Department of Energy (EIA 2005)**

| Percentage Share, 2005<br>Fuel Source | Idaho<br>% Share | Washington<br>% Share | Average<br>% Share |
|---|---|---|---|
| Coal | 0.88 | 10.30 | **9.4** |
| Petroleum | 0.00 | 0.06 | **0.1** |
| Natural Gas | 14.32 | 8.42 | **9.0** |
| Other Gases | 0.00 | 0.30 | **0.3** |
| Nuclear | 0.00 | 8.08 | **7.3** |
| Hydroelectric | 78.91 | 70.69 | **71.5** |
| Other Renewables | 5.33 | 2.08 | **2.4** |
| Other | 0.56 | 0.00 | **0.1** |
| Pumped Storage | 0.00 | 0.01 | **0.01** |
| **TOTAL** | 100.00 | 100.00 | **100** |

Considering the entire lumber production process allocated to one cubic meter of planed-dried softwood lumber, the planing of kiln-dried lumber required 45% of total electricity consumed, with sawmilling and lumber drying requiring 27% and 24%, respectively (Table 9). Cumulative process energy for electric power allocated to one cubic meter (436 kg) of planed-dried softwood lumber was 60 kWh/m$^3$ (97 kWh/MBF). This compares to the respective values published in Milota (2004) and Milota et al. (2004) of 51 kWh/m$^3$ and 93 kWh/m$^3$ for softwood lumber produced in the Pacific Northwest region and the Southeast United States.

**Table 9: Electricity distribution by sub-unit process for lumber production in the Inland Northwest region1. (not allocated)**

| Sub-unit Process | kWh | MJ | Allocation |
|---|---|---|---|
| Log yard | 3.12 | 11.22 | 4.09% |
| Sawmill | 20.77 | 74.76 | 27.24% |
| Drying | 18.26 | 65.72 | 23.95% |
| Planing | 34.09 | 122.74 | 44.72% |
| **Total** | **76.23** | **274.44** | **100%** |

[1] All values are given per 1.0 m$^3$ of lumber (436 kg of planed dried lumber)

## Fuel utilization as a heat source

Approximately 50% of the bark generated during debarking, as well as other wood waste sources from other unit processes, were consumed as wood fuel (hogged fuel) in the boiler for steam generation. Wood fuel weight from surveys, following industry practice, was given as green weight and assumed to be at 50% moisture content on a wet-weight basis. As such the total wood fuel burned, 110 kg/m$^3$ (392 lb/MBF) at 50% moisture content on a wet basis, is 55 kg/m$^3$/m$^3$ (196 lb/MBF) of oven-dry weight wood fuel. Hogged fuel at 55 kg/m$^3$ and natural gas at 25 m$^3$ (1,457 ft$^3$/MBF) were the fuel sources consumed in the boiler process. Hogged fuel and natural gas represented 54% and 46%, respectively, of the fuel consumed in the boiler processes. Tables 10a and 10b provide a breakdown of heat energy consumption for the boilers by fuel source in MJ/m$^3$ and BTU/ft$^3$, respectively.

**Table 10a: Inland Northwest lumber weighted data metric conversion of boiler inputs into heat energy for one cubic meter (m3) planed dried lumber production. (allocated)**

| Fuel Type | Value | Energy (MJ) | Fuel Source Breakdown |
|---|---|---|---|
| Wood fuel (kg)[1,2] | 55 | 1,148 | 54% |
| Natural gas ($m^3$)[3] | 25 | 975 | 46% |
| **Total** | | **2,124** | **100%** |

[1] Oven-dry weight;
[2] Weight of dry wood fuel multiplied by 20.92 MJ/kg with a 67% efficiency
[3] Volume of natural gas multiplied by 54.4 MJ/kg of natural gas, 80% efficiency—source ATHENA™ (1993). Density of natural gas = 0.7048 kg/$m^3$ (at conventional industry pressure in the US.)

**Table 10b: Inland Northwest lumber weighted data English conversion of boiler inputs into heat energy for 1000 board feet (MBF) planed-dried lumber production. (allocated)**

| Fuel Type | Value | Energy (BTU) | Fuel Source Breakdown |
|---|---|---|---|
| Hogged Fuel (lb)[1,2] | 196 | 1,765,537 | 54% |
| Natural gas ($ft^3$)[3] | 1,457 | 1,499,689 | 46% |
| **Total** | | **3,265,226** | **100%** |

[1] Oven-dry weight;
[2] Weight of dry hogged fuel multiplied by 9000 BTU/lb at a 67% efficiency
[3] Volume of natural gas multiplied by 0.044 lb/$ft^3$ (density) 23,409 BTU/lb, 80% efficiency—source ATHENA™ (1993)

Boiler data in the LCI was determined by calculating the energy equivalence of the two fuel sources of wood fuel and natural gas, then entering this data into the Franklin database processes for wood and natural gas boilers, respectively. The boiler module written for wood fuel used only Franklin Associates (FAL) data for wood boiler emissions. Table 11 does not include a transportation burden for the delivery of wood fuel to the plant. The natural gas-fired boiler emissions were based on the FAL database that included a transportation burden to the plant. For all fuel, whether wood fuel or natural gas, production and combustion emissions from the FAL database are included in the LCI results. Survey data was not reported or was very limited on boiler emissions from the four representative manufacturers in the Inland Northwest softwood production region. Future work should develop more complete information on biomass-fired boilers for CORRIM data that takes into account the specific wood products industry, geographic location, wood species, and fuel source, i.e. bark, or wood. To date, CORRIM has collected boiler data from manufacturers of softwood plywood, softwood lumber, and oriented strand board (OSB) (CORRIM 2003).

**Table 11: Exported wood boiler emissions (FAL) from the combustion of 55 kg or 196 lb of wood fuel required for the production of one cubic meter (m3) or 1,000 board feet (MBF) planed dried softwood lumber, respectively. (allocated)**

| Emissions to air | $kg/m^3$ | lb/MBF |
|---|---|---|
| Carbon dioxide, biogenic | 116 | 415 |
| Carbon monoxide | 0.7489 | 2.6780 |
| Nitrogen oxides | 0.0826 | 0.2952 |
| Potassium | 0.0430 | 0.1536 |
| Particulates, < 10 um | 0.0094 | 0.0336 |
| Organic substances, unspecified | 0.0092 | 0.0328 |
| Sulfur oxides | 0.0042 | 0.0151 |
| Phenol | 0.0022 | 0.0079 |
| Sodium | 0.0010 | 0.0034 |
| Manganese | 0.0005 | 0.0019 |
| Chlorine | 0.0004 | 0.0015 |
| Formaldehyde | 0.0003 | 0.0011 |
| Zinc | 0.0002 | 0.0008 |
| Iron | 0.0002 | 0.0008 |
| Barium | 0.0002 | 0.0008 |
| Benzene | 0.0002 | 0.0008 |
| Acetaldehyde | 0.0002 | 0.0008 |
| Naphthalene | 0.0001 | 0.0004 |
| Lead | 0.0001 | 0.0004 |

[1] 1 MBF = 1.622 $m^3$

## Drying emissions for Inland Northwest lumber production

Kiln-drying removed water from green lumber to reduce shrinkage of lumber during and after construction and to reduce transportation costs. Target moisture contents typically range from 12% to 19% on a dry weight basis. Dry-kiln temperatures are normally in the range of (60 to 116 degrees C (140 to 240 degrees F). The dry-kiln process emissions are shown in Table 12. These emissions from lumber drying escape from the dry kiln process through vents or leaks in the kilns. By far the leading emissions are VOC with 0.167 $kg/m^3$ (0.596 lb/MBF) of kiln-dried lumber.

**Table 12: Emissions for drying softwood lumber production in the inland northwest production region as reported in surveys. (allocated)**

| | Emissions from Dryer as Reported in Surveys | |
|---|---|---|
| Emissions to Air[1] | $kg/m^3$ | lb/MBF [2] |
| VOC | 0.167 | 0.596 |
| Methanol | 0.022 | 0.080 |
| Acetaldehyde | 0.002 | 0.007 |
| Formaldehyde | 0.002 | 0.006 |

[1] Air emission data as reported from surveys.
[2] 1 MBF = 1.622 $m^3$

## SimaPro model structure and input

SimaPro 7, developed in the Netherlands (Pré Consultants 2008) follows the ISO 14040 standards for environmental management and documentation. SimaPro has been the preferred software for CORRIM research and was employed by CORRIM Phase I Life-Cycle Inventory projects sponsored by CORRIM. SimaPro 7 incorporates a number of LCI databases that contain processes on materials, chemicals, fuels, energy, transportation and electricity. The Franklin LCI Database (FAL 2004) contains North America LCI production data and provided the database for energy, fuels, electricity, and transportation emissions. The Franklin database modeled provided the necessary environmental burdens (air, water, and land emissions) associated with production and combustion of the fuels and electricity.

A multi-unit process consisting of four sub-unit processes modeled softwood lumber production in SimaPro. A wood boiler process and a natural gas boiler process provided inputs for the sub-unit drying process (Figures 2 and 3). Fuel and electricity inputs for other processes were also provided by the Franklin database. Tables 13a-d list the SimaPro input sub-unit processes for: (1) log yard operation, (2) sawmilling (primary log breakdown, (3) kiln-drying (includes wood and natural gas boilers), and (4) planing of dried lumber. All data were obtained from the mill surveys collected for the production year 2005/2006, weighted based on lumber production per one cubic meter softwood lumber. Production emissions for input into the lumber model were reported in the four sawmill surveys. Allocation was made on a mass basis. Figure 4 shows an overview relationship among the input processes from the lumber production model. Lines represent flows within the model. Not all material inputs are shown. A contribution cutoff of 1.5% was used in this example.

**Table 13a: Log yard process inputs as entered into the SimaPro Model for the production of Inland Northwest softwood lumber. All input data are per cubic meter of kiln-dried, planed lumber (m3) and were collected from industry surveys. Data are a weighted average based on the 2005/2006 production year. (not allocated)**

| Products | Unit | Unit/$m^3$ [1] | Unit | Unit/MBF [4] | Allocation |
|---|---|---|---|---|---|
| Roundwood at mill, softwood, Inland Northwest, USA, U | kg | 778.54 | lb | 2,783.98 | 93.12% |
| Bark at mill, softwood, Inland Northwest, USA, U | kg | 57.54 | lb | 205.74 | 6.88% |
| | kg | 836.07 | lb | | |
| **Resources** | | | | | |
| Water, process, well, in ground | kg | 34.05 | lb | 121.74 | |
| **Materials/fuels** | | | | | |
| Residual fuel oil (RFO) FAL[2] | L | 0.02 | gal | 0.01 | |
| Residual fuel oil (RFO) FAL[3] | L | 0.05 | gal | 0.02 | |
| Diesel equipment (gal) | L | 2.30 | gal | 0.99 | |
| Gasoline equipment (gal) | L | 0.05 | gal | 0.02 | |
| **Electricity/heat** | | | | | |
| Electricity mix, Inland West, USA, U | kWh | 3.12 | kWh | 5.06 | |
| **Emissions to air** | | | | | |
| Particulates, unspecified | kg | 0.15 | lb | 0.53 | |
| Hydrocarbons, unspecified | kg | 0.0004 | lb | 0.0015 | |
| **Final waste flows** | | | | | |
| Log yard, wood waste to landfill, kg, softwood, Inland Northwest, USA | kg | 9.99 | lb | 35.71 | |
| Log yard, waste to landfill, $m^3$, Inland Northwest, USA | $m^3$ | 0.21 | ft3 | 12.00 | |

[1] all weights entered on oven-dry basis; [2] surrogate hydraulic oil; [3] surrogate for motor oil; [4] 1 MBF = 1.622 $m^3$

**Table 13b: Primary log breakdown (sawmilling) process inputs as entered into the SimaPro model for the production of Inland Northwest softwood lumber. All input data are per cubic meter of kiln-dried, planed lumber (m3) and were collected from industry surveys. Data are a weighted average based on the 2005/2006 production year. (not allocated)**

| Products | Unit | Unit/$m^3$ [1] | Unit | Unit/MBF [3] | Allocation |
|---|---|---|---|---|---|
| Sawn lumber, Softwood, Rough, Green, Inland Northwest, USA, U | kg | 476.31 | lb | 1,703.23 | 56.97% |
| Wood Chips, Softwood, Green, Inland Northwest, USA, U | kg | 216.06 | lb | 772.60 | 25.84% |
| Sawdust, Softwood, Green, Inland Northwest, USA, U | kg | 51.77 | lb | 185.11 | 6.19% |
| Bark at mill, Softwood, Green, Inland Northwest, USA, U | kg | 28.15 | lb | 100.67 | 3.37% |
| Wood fiber, Softwood, Green, Inland Northwest, USA, U | kg | 3.31 | lb | 11.84 | 0.40% |
| Wood fuel, Softwood, Green, Inland Northwest, USA, U | kg | 60.48 | lb | 216.27 | 7.23% |
| | kg | 836.08 | lb | 2,989.72 | 100% |
| **Materials/fuels** | | | | | |
| Roundwood at mill, softwood, Inland Northwest, USA, U | kg | 778.54 | lb | 2,783.98 | |
| Bark at mill, softwood, Inland Northwest, USA, U | kg | 57.54 | lb | 205.74 | |
| Gasoline equipment (gal) | L | 0.14 | gal | 0.06 | |
| Diesel equipment (gal) | L | 0.04 | gal | 0.02 | |
| Residual fuel oil (RFO) FAL[2] | L | 0.08 | gal | 0.03 | |
| **Electricity/heat** | | | | | |
| Electricity mix, Inland Northwest, USA, U | kWh | 20.77 | kWh | 33.68 | |

[1] all weights entered on oven-dry basis
[2] surrogate for motor oil and hydraulic oil, combined
[3] 1 MBF = 1.622 $m^3$

**Table 13c: Kiln drying process inputs as entered into the SimaPro model for the production of Inland Northwest softwood lumber. All input data are per cubic meter of kiln-dried, planed lumber (m3) and were collected from industry surveys. Data are a weighted average based on the 2005/2006 production year. (not allocated)**

| Products | Unit | Unit/m$^3$ [1] | Unit | Unit/MBF [3] | Allocation |
|---|---|---|---|---|---|
| Sawn lumber, Softwood, Rough, Kiln dried, Inland Northwest, USA, U | kg | 476.31 | lb | 1,703.23 | 100% |
| | | | | | |
| **Materials/fuels** | | | | | |
| Sawn lumber, Softwood, Rough, Green, Inland Northwest, USA, U | kg | 476.31 | lb | 1,703.23 | |
| Diesel equipment (gal) | L | 0.14 | gal | 0.06 | |
| Residual Fuel Oil (RFO) FAL[2] | L | 0.08 | gal | 0.04 | |
| | | | | | |
| **Electricity/heat** | | | | | |
| Wood into industrial boilers, softwood, Inland Northwest Lumber, USA, U | kg | 60.48 | lb | 216.27 | |
| Electricity mix, Inland Northwest, USA, U | kWh | 18.26 | kWh | 29.61 | |
| Nat. gas into industrial boilers, Inland Northwest lumber | $m^3$ | 28.00 | $ft^3$ | 1,603.67 | |
| | | | | | |
| **Emissions to air** | | | | | |
| VOC | kg | 0.18 | lb | 0.66 | |
| Formaldehyde | kg | 0.001 | lb | 0.003 | |
| Acetaldehyde | kg | 0.002 | lb | 0.008 | |
| Methanol | kg | 0.025 | lb | 0.088 | |

[1] all weights entered on oven-dry basis
[2] surrogate for motor oil and hydraulic oil, combined
[3] 1 MBF = 1.622 $m^3$

**Table 13d: Planing process inputs inputs as entered into the SimaPro model for the production of Inland Northwest softwood lumber. All input data are per cubic meter of kiln-dried, planed lumber (m3) and were collected from industry surveys. Data are a weighted average based on the 2005/2006 production year. (not allocated)**

| **Products** | **Unit** | **Unit/m³ [1]** | **Unit** | **Unit/MBF [3]** | **Allocation** |
|---|---|---|---|---|---|
| Sawn Lumber, Softwood, Planed, Kiln dried, Inland Northwest, USA, U | kg | 435.79 | lb | 1558.33 | 91% |
| Shavings, Softwood, Kiln Dried, Inland Northwest, USA, U | kg | 36.55 | lb | 130.69 | 8% |
| Wood Chips, Softwood, Kiln dried, Inland Northwest, USA, U | kg | 3.97 | lb | 14.21 | 1% |
| | kg | 476.31 | lb | 1703.23 | 100% |
| **Materials/fuels** | | | | | |
| Sawn lumber, Softwood, Rough, Kiln dried, Inland Northwest, USA, U | kg | 476.31 | lb | 1703.23 | |
| Gasoline equipment (gal) | L | 0.06 | gal | 0.03 | |
| Diesel equipment (gal) | L | 0.44 | gal | 0.19 | |
| Residual fuel oil (RFO) FAL[2] | L | 0.10 | gal | 0.04 | |
| **Electricity/heat** | | | | | |
| Electricity mix, Inland Northwest, USA, U | kWh | 34.09 | kWh | 55.30 | |

[1] all weights entered on oven-dry basis
[2] surrogate for motor oil and hydraulic oil, combined
[3] 1 MBF = 1.622 m³

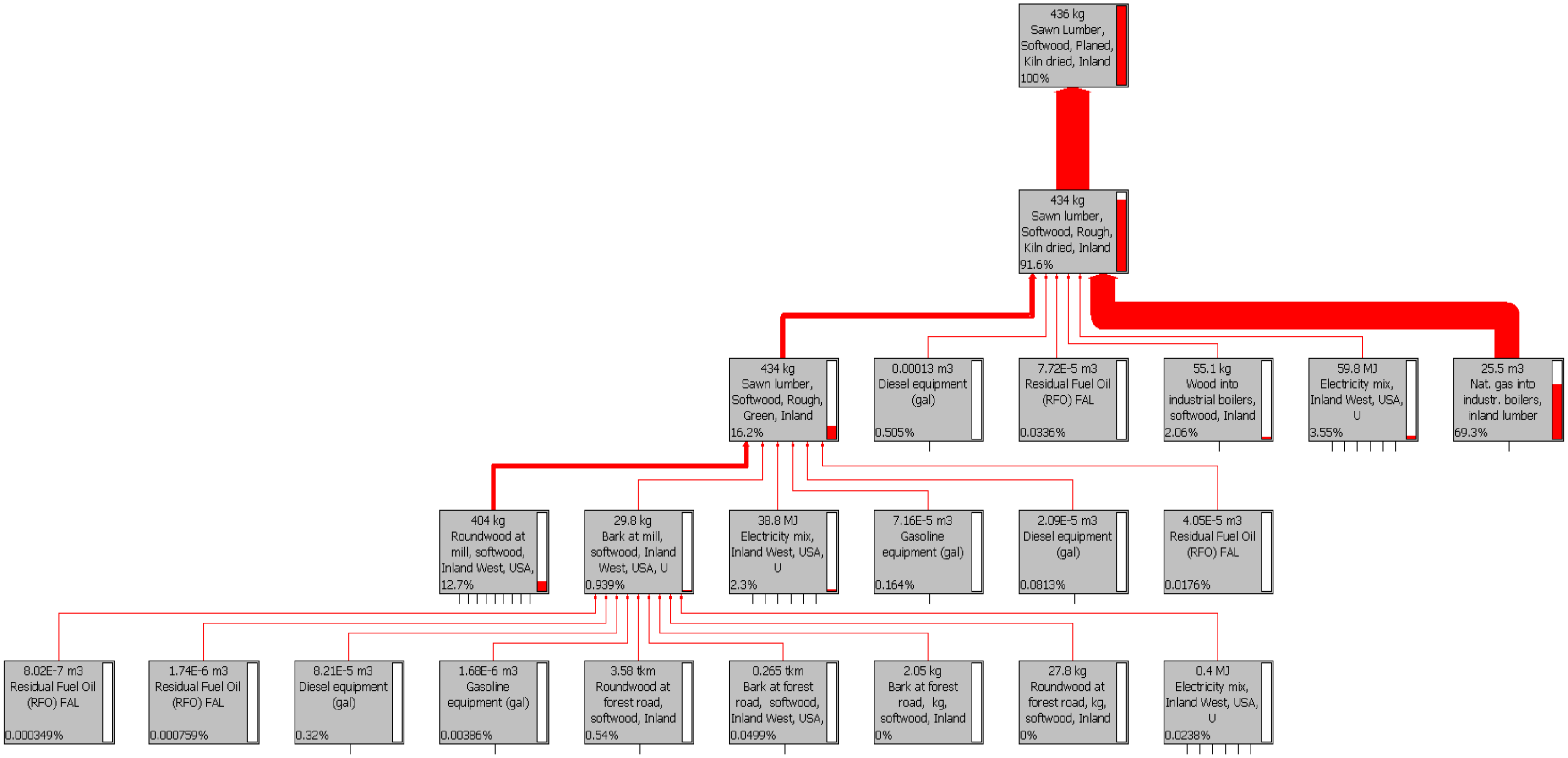


**Figure 4: A Process flow diagram on the relationship between sub-unit processes used to model softwood lumber from the Inland Northwest region. Processes were modeled in Simapro7.**

Notes: Lines represent requirements for main product. 436 kg of kiln-dried softwood lumber = one cubic meter of product. Not all input materials (processes) are shown. A 1.5% cut-off is used for this example.

## Life cycle inventory results

### Process related emissions

The total emissions from each sub-unit process were determined and are given in Tables 14a and 14b by sub-unit process: (1) Log yard activities, (2) sawmill (primary log breakdown), (3) kiln drying (includes biomass and natural gas boilers) and (4) planing mill. The values include the burdens in terms of emissions for the production of softwood lumber and of any electricity or fuel, in addition to that of the hogged fuel and natural gas.

**Table 14a: Process emissions (kg/m3) for the production of softwood lumber in the Inland Northwest region. Emissions are allocated per cubic meter of planed-dried softwood lumber.**

| | **Log Yard** | **Sawmill** | **Drying** | **Planing** | **Total[1]** |
|---|---|---|---|---|---|
| **Substance[2]** | **kg/m$^3$ planed-dried softwood lumber** | | | | |
| Carbon dioxide, biogenic | 0.0011 | 0.0021 | 115.5445 | 0.0029 | 115.5506 |
| Carbon dioxide, fossil | 2.5220 | 4.0834 | 58.5243 | 6.5769 | 71.7067 |
| Carbon monoxide | 0.0280 | 0.0414 | 0.8788 | 0.0368 | 0.9849 |
| Sulfur oxides | 0.0113 | 0.0208 | 0.8705 | 0.0541 | 0.9566 |
| Nitrogen oxides | 0.0713 | 0.0153 | 0.2861 | 0.0435 | 0.4160 |
| NMVOC[3] | 0.0140 | 0.0062 | 0.2286 | 0.0139 | 0.2628 |
| Methane | 0.0013 | 0.0050 | 0.1639 | 0.0128 | 0.1831 |
| VOC | 0.0000 | 0.0000 | 0.1669 | 0.0000 | 0.1669 |
| Particulates, < 10 um | 0.0050 | 0.0010 | 0.0149 | 0.0026 | 0.0234 |
| Methanol | 0.0000 | 0.0000 | 0.0224 | 0.0000 | 0.0224 |
| Formaldehyde | 0.0011 | 0.0001 | 0.0014 | 0.0003 | 0.0029 |
| Phenol | 0.0000 | 0.0000 | 0.0022 | 0.0000 | 0.0022 |
| Acetaldehyde | 0.0000 | 0.0000 | 0.0022 | 0.0000 | 0.0022 |
| **TOTAL** | **2.66** | **4.48** | **176.71** | **6.74** | **190.28** |

[1] Totals may vary from other LCI tables in this report due to rounding errors.
[2] Total emissions include emissions for the production and delivery of electricity and fuel production and combustion.
[3] NMVOC = non-methane volatile organic compounds, unspecified origin

**Table 14b: Process emissions (lb/MBF) for the production of softwood lumber in the Inland Northwest region. Emissions are allocated per cubic meter of planed-dried softwood lumber.**

| | Log Yard | Sawmill | Drying | Planing | Total[1] |
|---|---|---|---|---|---|
| **Substance[2]** | **lb/MBF [3] planed-dried softwood lumber** | | | | |
| Carbon dioxide, biogenic | 0.004 | 0 | 413 | 0 | 413 |
| Carbon dioxide, fossil | 9.019 | 15 | 209 | 24 | 256 |
| Carbon monoxide | 0.100 | 0.148 | 3.142 | 0.132 | 3.522 |
| Sulfur oxides | 0.040 | 0.074 | 3.113 | 0.193 | 3.421 |
| Nitrogen oxides | 0.255 | 0.055 | 1.023 | 0.156 | 1.488 |
| NMVOC[4] | 0.050 | 0.022 | 0.817 | 0.050 | 0.940 |
| Methane | 0.005 | 0.018 | 0.586 | 0.046 | 0.655 |
| VOC | 0.000 | 0.000 | 0.597 | 0.000 | 0.597 |
| Particulates, < 10 um | 0.018 | 0.003 | 0.053 | 0.009 | 0.084 |
| Methanol | 0.000 | 0.000 | 0.080 | 0.000 | 0.080 |
| Formaldehyde | 0.004 | 0.000 | 0.005 | 0.001 | 0.010 |
| Phenol | 0.000 | 0.000 | 0.008 | 0.000 | 0.008 |
| Acetaldehyde | 0.000 | 0.000 | 0.008 | 0.000 | 0.008 |
| **TOTAL** | **9.50** | **15.32** | **631.43** | **24.59** | **679.81** |

[1] Totals may vary from other LCI tables in this report due to rounding errors.

[2] Total emissions include emissions for the production and delivery of electricity and fuel production, delivery and combustion.

[3] 1 MBF = 1.622 $m^3$

[4] NMVOC = non-methane volatile organic compounds, unspecified origin

### Gate-to-gate life cycle inventory results

Four sub-unit processes were defined for the Inland Northwest Softwood Lumber process in SimaPro with the wood boiler process structured as an input process into the kiln-drying sub-process (Figure 3). Other processes taken from the Franklin database were also used for fuel and electricity inputs. Tables 15-21 list the cumulative input as entered into SimaPro for the four Inland Northwest softwood lumber production sub-unit processes. All data were obtained from the mill surveys collected for the production year 2005/2006. Values were weighted based on lumber production per one cubic meter ($m^3$) of planed-dried lumber. Production emissions for input into the softwood lumber model were reported in the sawmill surveys. Allocation was made on a mass basis.

**Table 15: Cumulative LCI inputs to produce 436 kg (1 cubic meter) or 1,000 board feet (MBF) of planed-dried softwood lumber in the Inland Northwest region. All data reported in surveys. (allocated)**

| Materials | Unit | Per $m^3$ | Unit | Per MBF [1] |
|---|---|---|---|---|
| Roundwood at mill | kg | 455 | lb | 1,627 |
| Bark | kg | 34 | lb | 120 |
| **Electrical Use** | | | | |
| Electricity | MJ | 215 | kWh | 97 |
| **Fuel Use** | | | | |
| Hogged fuel | kg | 55 | lb | 197 |
| Natural gas | $m^3$ | 25 | $ft^3$ | 1,457 |
| Diesel | L | 1.890 | gal | 0.810 |
| Gasoline | L | 0.169 | gal | 0.072 |
| Lubricants and oils | L | 0.253 | gal | 0.109 |
| **Water Use** | | | | 0.000 |
| Water, unspecified | L | 19.847 | gal | 8.504 |

1 1 MBF = 1.622 m3

**Table 16: Cumulative emissions to air (reduced list) allocated to one cubic meter (m3) or 1,000 board feet (MBF) of softwood lumber produced in the Inland Northwest region**

| Emissions to air | kg/$m^3$ | lb/MBF [1] |
|---|---|---|
| Carbon dioxide, biogenic | 116 | 413 |
| Carbon dioxide, fossil | 71 | 254 |
| Carbon monoxide | 0.9789 | 3.501 |
| Sulfur oxides | 0.9540 | 3.411 |
| Nitrogen oxides | 0.4083 | 1.460 |
| NMVOC | 0.2611 | 0.934 |
| Methane | 0.1825 | 0.653 |
| VOC | 0.1670 | 0.597 |
| Particulates, unspecified | 0.0961 | 0.344 |
| Particulates, < 10 um | 0.0229 | 0.082 |
| Methanol[3] | 0.0224 | 0.080 |
| Formaldehyde[3] | 0.0026 | 0.009 |
| Phenol[3] | 0.0022 | 0.008 |
| Acetaldehyde[3] | 0.0022 | 0.008 |
| **Total** | **190** | **679** |

1 1 MBF = 1.622 m3

2 NMVOC = non-methane volatile organic compounds, unspecified origin

3 HAP Total = 0.030 kg/m3, or 0.105 lb/MBF

Results include the production of electricity, fuels, and ancillary materials. Transportation of resources to sawmills and transportation of raw materials to the lumber production facility were omitted. (allocated)

**Table 17: Cumulative emissions to air allocated to one cubic meter (m3) or 1,000 board feet of softwood lumber produced in the Inland Northwest region.**

| Substance | $kg/m^3$ | lb/MBF |
|---|---|---|
| Carbon dioxide, biogenic | 116 | 415 |
| Carbon dioxide, fossil | 71 | 254 |
| Carbon monoxide | 0.9789 | 3.5006 |
| Sulfur oxides | 0.9540 | 3.4115 |
| Nitrogen oxides | 0.4083 | 1.4602 |
| NMVOC[2] | 0.2611 | 0.9336 |
| Methane | 0.1825 | 0.6527 |
| VOC | 0.1670 | 0.5972 |
| Particulates, unspecified | 0.0961 | 0.3435 |
| Potassium | 0.0430 | 0.1536 |
| Particulates, < 10 um | 0.0229 | 0.0819 |
| Methanol | 0.0224 | 0.0800 |
| Organic substances, unspecified | 0.0096 | 0.0344 |
| Phenol | 0.0022 | 0.0079 |
| Formaldehyde | 0.0026 | 0.0094 |
| Acetaldehyde | 0.0012 | 0.0042 |
| Sodium | 0.0010 | 0.0034 |
| Hydrogen chloride | 0.0006 | 0.0023 |
| Manganese | 0.0005 | 0.0019 |
| Chlorine | 0.0004 | 0.0015 |
| Aldehydes, unspecified | 0.0003 | 0.0011 |
| Hydrocarbons, unspecified | 0.0002 | 0.0008 |
| Barium | 0.0002 | 0.0008 |
| Iron | 0.0002 | 0.0008 |
| Zinc | 0.0002 | 0.0008 |
| Benzene | 0.0002 | 0.0008 |
| Naphthalene | 0.0001 | 0.0004 |
| Ammonia | 0.0001 | 0.0004 |
| Hydrogen fluoride | 0.0001 | 0.0004 |
| Lead | 0.0001 | 0.0004 |
| Dinitrogen monoxide | 0.0001 | 0.0004 |

1 1 MBF = 1.622 m3

2 NMVOC = non-methane volatile organic compounds, unspecified origin

Results include the production of electricity, fuels, and ancillary materials. Transportation of resources to sawmills and transportation of raw materials to the lumber production facility were omitted. (allocated)

**Table 18: Cumulative HAPS emissions allocated to one cubic meter (m3) or 1,000 board feet of softwood lumber produced in the Inland Northwest region.**

| HAPs Substance | $kg/m^3$ | lb/MBF |
|---|---|---|
| Methanol | 0.0224 | 0.0800 |
| Formaldehyde | 0.0027 | 0.0098 |
| Phenol | 0.0022 | 0.0079 |
| Acetaldehyde | 0.0022 | 0.0079 |
| Acrolein | 0.0000 | 0.0000 |
| TOTAL | 0.0295 | 0.1056 |

Results include the production of electricity, fuels, and ancillary materials. Transportation of resources to the sawmill and transportation of raw materials to the lumber production facility were omitted. (allocated)

[1] 1 MBF = 1.622 $m^3$

**Table 19: Airborne emissions for the production of one cubic meter of planed-dried lumber comparison between softwood lumber production produced in the Pacific Northwest, Southeast and Inland Northwest regions. (allocated)**

| | CORRIM Phase I[1] | | CORRIM Phase II |
|---|---|---|---|
| **Emissions to air** | **Pacific Northwest** | **Southeast** | **Inland Northwest** |
| | | $kg/m^3$ | |
| Carbon dioxide, biogenic | 160 | 304 | 116 |
| Carbon dioxide, fossil | 72 | 47 | 71 |
| Carbon monoxide | 1.2315 | 2.032 | 0.9789 |
| Sulfur oxides | 0.9852 | 0.431 | 0.9540 |
| Nitrogen oxides | 0.431 | 0.3695 | 0.4083 |
| Methane | 0.1878 | 0.0979 | 0.1825 |
| VOC | 0.0794 | 0.5222 | 0.1670 |
| Particulates, unspecified | 0.0333 | 0.0659 | 0.0961 |
| Particulates, < 10 um | 0.0017 | 0.0074 | 0.0229 |
| Methanol | 0.0006 | - | 0.0224 |
| Formaldehyde | 0.0014 | 0.0018 | 0.0026 |
| Phenol | 0.0031 | - | 0.0022 |
| Acetaldehyde | 0.0006 | - | 0.0012 |
| **Total** | **235** | **355** | **190** |

[1] Milota, M., C. West, and I. Hartley. 2005. Gate-to-gate life-cycle inventory of softwood lumber production. Wood and Fiber Science, 37 Corrim Special Issue, pp. 47 – 57.

**Table 20: Cumulative emissions to water allocated to one cubic meter (m3) or 1,000 board feet (MBF) planed-dried softwood lumber produced in the Inland Northwest region.**

| Emission | $kg/m^3$ | lb/MBF |
|---|---|---|
| Solved solids | 1.3597 | 4.8623 |
| Chloride | 0.0616 | 0.2204 |
| Sulfate | 0.0511 | 0.1826 |
| Suspended solids, unspecified | 0.0290 | 0.1036 |
| Oils, unspecified | 0.0238 | 0.0853 |
| COD, Chemical Oxygen Demand | 0.0190 | 0.0681 |
| Organic substances, unspecified | 0.0039 | 0.0140 |
| BOD5, Biological Oxygen Demand | 0.0013 | 0.0048 |
| Iron | 0.0005 | 0.0017 |
| Boron | 0.0003 | 0.0011 |
| Manganese | 0.0003 | 0.0009 |
| Sulfuric acid | 0.0001 | 0.0003 |
| Cadmium, ion | 0.0001 | 0.0002 |
| Chromium | 0.0001 | 0.0002 |
| Metallic ions, unspecified | 0.0001 | 0.0002 |
| Phosphate | 0.0000 | 0.0001 |
| Ammonia | 0.0000 | 0.0001 |
| Fluoride | 0.0000 | 0.0001 |
| Zinc, ion | 0.0000 | 0.0001 |

1 1 MBF = 1.622 m3
Results include the production of electricity, fuels, and ancillary materials. Transportation burdens of resources and raw materials to the lumber production facility were omitted. (allocated)

**Table 21: Cumulative emissions to water allocated to one cubic meter (m3) or 1,000 board feet (MBF) planed-dried softwood lumber produced in the Inland Northwest region.**

| Substance | Total $kg/m^3$ | Total lb/MBF |
|---|---|---|
| Waste, solid | 8.91 | 31.86 |
| Wood waste | 5.84 | 20.88 |
| | **Total $m^3/m^3$** | **Total $ft^3$/MBF** |
| Waste, rock and mud | 0.12 | 7.01 |

1 1 MBF = 1.622 m3
Results include the production of electricity, fuels, and ancillary materials. Transportation burdens of resources and raw materials to the lumber production facility were omitted. (allocated)

## On-site life cycle inventory results

It is also useful to examine those emissions attributed to the production of lumber only. Table 22 provides output data for site-generated emissions from manufacturing softwood lumber only. Not included are emissions contributed by the production and delivery of fuels and electricity. Table 23 provides a summary comparison of the site-generated emissions to the total emissions that include those from the production and delivery of fuels and electricity.

**Table 22: On-Site emissions for the production of one cubic meter (m3) or 1,000 board feet (MBF) of Inland Northwest softwood lumber.**

| Emissions to Air | kg/m3 | lb/MBF | Emissions to Air | kg/m3 | lb/MBF |
|---|---|---|---|---|---|
| Carbon dioxide, biogenic | 115 | 411 | Iron | 0.0002 | 0.0008 |
| Carbon dioxide, fossil | 54 | 193 | Zinc | 0.0002 | 0.0008 |
| Carbon monoxide | 0.8742 | 3.1261 | Benzene | 0.0002 | 0.0008 |
| Nitrogen oxides | 0.3174 | 1.1352 | Acetaldehyde | 0.0002 | 0.0008 |
| VOC | 0.1670 | 0.5972 | Naphthalene | 0.0001 | 0.0004 |
| Particulates, unspecified | 0.0866 | 0.3096 | Lead | 0.0001 | 0.0004 |
| Potassium | 0.0430 | 0.1536 | **Emissions to Land** | | |
| Sulfur oxides | 0.0420 | 0.1502 | Log yard, wood waste to landfill | 5.8347 | 20.8642 |
| Methanol | 0.0224 | 0.0800 | Waste, solid | 4.9534 | 17.7128 |
| Particulates, < 10 um | 0.0209 | 0.0747 | **Emissions to Water** | | |
| NMVOC[2] | 0.0150 | 0.0536 | Suspended solids, unspecified | 0.0204 | 0.0729 |
| Organic substances, unspecified | 0.0092 | 0.0328 | Solved solids | 0.0192 | 0.0687 |
| Phenol | 0.0022 | 0.0079 | COD, Chemical Oxygen Demand | 0.0098 | 0.0351 |
| Formaldehyde | 0.0020 | 0.0072 | BOD5, Biological Oxygen Demand | 0.0001 | 0.0004 |
| Acetaldehyde | 0.0020 | 0.0072 | | | |
| Methane | 0.0015 | 0.0053 | | | |
| Sodium | 0.0010 | 0.0034 | | | |
| Formaldehyde | 0.0006 | 0.0023 | | | |
| Manganese | 0.0005 | 0.0019 | | | |
| Chlorine | 0.0004 | 0.0015 | | | |
| Hydrocarbons, unspecified | 0.0002 | 0.0008 | | | |
| Barium | 0.0002 | 0.0008 | | | |

Data are from on-site production softwood lumber and the combustion of all fuels used on-site. Excludes impacts associated with fuel, electricity production and delivery. (allocated)

[1] 1 MBF = 1.622 $m^3$

[2] NMVOC = non-methane volatile organic compounds, unspecified origin

**Table 23: Comparison of total to on-site-generated emissions for one cubic meter (m3) or 1,000 board feet (MBF) softwood lumber production in the Inland Northwest region. (allocated)**

| | On-site | | Cumulative | | |
|---|---|---|---|---|---|
| Substance | **$kg/m^3$** | **lb/MBF** | **$kg/m^3$** | **lb/MBF** | **% difference** |
| Carbon dioxide, biogenic | 115 | 411 | 116 | 415 | 0.96% |
| Carbon dioxide, fossil | 54 | 192 | 71 | 254 | 24.61% |
| Carbon monoxide | 0.8741 | 3.1257 | 0.9786 | 3.4995 | 10.68% |
| Nitrogen oxides | 0.3178 | 1.1363 | 0.4086 | 1.4609 | 22.22% |
| Sulfur oxides | 0.0422 | 0.1510 | 0.9543 | 3.4126 | 95.58% |
| NMVOC[2] | 0.0148 | 0.0529 | 0.2608 | 0.9324 | 94.33% |
| Methane | 0.0011 | 0.0038 | 0.1826 | 0.6531 | 99.42% |

[1] 1 MBF = 1.622 $m^3$

[2] NMVOC = non-methane volatile organic compounds, unspecified origin

## Sensitivity analysis

A sensitivity analysis was conducted to examine the effects of using different fuel sources for heat generation. The analysis can be useful for understanding how various process parameters contribute to environmental output factors. For instance, in softwood lumber production, heat is needed to dry lumber from 100% moisture content to a moisture content around 15%. Heat generation consumes wood fuel (bark and wood) and/or natural gas. Changing the fuel source, also referred to as fuel switching, can have a dramatic effect on the type and quantity of emissions released into the environment. This sensitivity analysis was used to compare the effects of using all wood fuel — consisting of bark removed from the logs and wood waste from the primary log breakdown — or only natural gas as a fuel input. In the original model, based on survey data, fuel sources used for heat generation included both natural gas and wood fuel.

Currently hogged fuel and natural gas are the fuel sources relied on by the survey sawmills. The Inland Northwest softwood lumber manufacturing model from SimaPro modeled two additional fuel source scenarios against the base case model (survey data). The scenarios modeled were:

1. **Base Case** representing 46% natural gas and 54% wood fuel, with 100% of the hogged fuel self generated,
2. **Scenario 1**: 100% wood fuel generated on-site and
3. **Scenario 2:** 100% natural gas.

The original (Base Case) model, based on survey data, assumed 54% of the fuel in the form of wood fuel generated during the sawmilling process and 46% as natural gas. For scenario 2, some of the co-products were re-allocated to wood fuel. These co-products were wood fiber, sawdust, and some bark. In actuality, most softwood mills that dry lumber use only one or two types of fuel source. Milota's (2005) study on softwood production from the Pacific Northwest had similar fuel mixtures of natural gas and wood fuel with a small portion of diesel fuel. The Base Case model presented in the study was a weighted average fuel input from four softwood production manufacturers representing the Inland Northwest production region.

Three sensitivity scenarios were compared on the weighted averaged data. The first scenario compared LCI results from the Base Case to 100% wood fuel (100% self generated). The second scenario compared 100% natural gas for heat generation to the Base Case.

**Sensitivity analysis results**

Table 24 is a summary of the three scenarios consisting of a reduced list of air emissions for softwood lumber production from the Inland Northwest production region. A negative percentage difference number indicates that the fuel source contributes fewer emissions than the Base Case (survey data) softwood lumber model. A positive percentage difference means that the Base case contributes lower emissions. Emissions decreased by use of 100% wood fuel from the Base case are methane, non methane VOC, sulfur oxides and nitrous oxides. When 100 % natural gas was substituted from the Base Case, there was a decrease in carbon monoxide, formaldehyde, particulates, and phenol. Fuel resource requirements changed dramatically between the two scenarios from the Base Case in the demand for wood or natural gas resources for 100% wood fuel and 100% natural gas heat generation respectively. Table 25 illustrates fuel requirements for the three scenarios when other energy sources are used.

**Table 24. Sensitivity analysis for the Inland Northwest softwood lumber production region.**

| | Base Case | Scenario 1 | Scenario 2 | % Difference from Base Case | |
|---|---|---|---|---|---|
| | 54% Wood fuel<br>46% Nat. gas | 100% Wood fuel | 100% natural gas | Scenario 1 | Scenario 2 |
| Emissions to air | $kg/m^3$ | kg/m3 | kg/m3 | % change | % Change |
| Acetaldehyde | 0.0022 | 0.0023 | 0.0024 | 6% | 10% |
| Carbon dioxide, biogenic | 115.5961 | 230.1042 | 0.0288 | 99% | -100% |
| Carbon dioxide, fossil | 71.1357 | 16.5792 | 123.8649 | -77% | 74% |
| Carbon monoxide | 0.9789 | 1.6078 | 0.3385 | 64% | -65% |
| Formaldehyde | 0.0026 | 0.0031 | 0.0022 | 16% | -16% |
| Methane | 0.1825 | 0.0260 | 0.3352 | -86% | 84% |
| Methanol | 0.0224 | 0.0224 | 0.0224 | No change | No change |
| Nitrogen oxides | 0.4083 | 0.3344 | 0.4879 | -18% | 19% |
| NMVOC[1] | 0.2611 | 0.0409 | 0.4746 | -84% | 82% |
| Particulates, < 10 um | 0.0229 | 0.0283 | 0.0166 | 24% | -27% |
| Particulates, unspecified | 0.0961 | 0.0081 | 0.0108 | -92% | -89% |
| Phenol | 0.0022 | 0.0044 | 0.0000 | 98% | -100% |
| Sulfur oxides | 0.9540 | 0.1243 | 1.7643 | -87% | 85% |
| VOC | 0.1670 | 0.1670 | 0.1670 | No change | No Change |

[1] NMVOC = = non-methane volatile organic compounds, unspecified origin

**Carbon Dioxide ($CO_2$)**

$CO_2$ fossil and biomass emissions are treated differently in LCI analyses because wood fuel is a biomass fuel, and natural gas, a fossil fuel. $CO_2$ biomass is treated separately because it can be taken back up in biomass through photosynthesis and is assumed to have a neutral impact on the environment, while $CO_2$ fossil emissions cannot be readily replenished as natural gas.

**Methane ($CH_4$)**

Methane emissions increased by 85% when natural gas was used compared to the Base Case model. The all self-produced wood fuel scenario reduced the methane emission by 85% from the Base Case.

**Nitrogen Oxides ($NO_X$)**

$NO_X$ emissions were decreased by 20% when the fuel source was 100% wood fuel, while these emissions increased by 19% when all natural gas was used

**Sulfur Oxides ($SO_X$)**

Sulfur oxide emissions decreased by 87% when 100% wood fuel was used from the Base Case, and increased 85% when 100% natural gas was used for heat energy

**VOC and NMVOC**

There is no difference in VOC emissions between various fuel sources for heat generation, although, non methane VOC is heavily influenced by natural gas combustion and increased by 82% in scenario 2 over the Base Case. Hogged fuel use does not contribute any non-methane VOC.

**HAP's (including acetaldehyde, formaldehyde, methanol, and phenol)**

Using natural gas as a heat source decreased HAP emissions, with the exception of methanol that was not influenced by fuel inputs.

**Carbon Monoxide (CO)**

Combustion of natural gas decreases CO emissions. When hogged fuel was used, CO emissions increased compared to Base Case model and were 64% higher than when using natural gas.

**Particulates**

Particulate emissions were affected by fuel switching. There was an increase of 27% for wood fuel combustion over the Base Case.

**Table 25: Sensitivity analysis for the Inland Northwest softwood lumber production region when alternate sources are used to generate heat energy.**

| | Base Case | Scenario 1 | Scenario 2 | % Difference from Base Case | |
|---|---|---|---|---|---|
| | 54% Wood fuel 46% Nat. gas | 100% Wood fuel | 100% Natural gas | Scenario 1 | Scenario 2 |
| **Fuel** | **MJ/m³** | **MJ/m³** | **MJ/m³** | **% change** | **% Change** |
| Natural gas | 1,396 | 103 | 2,647 | -93% | 90% |
| Wood fuel | 1,151 | 2,306 | 0 | 100% | -100% |
| Hydro power | 158 | 163 | 155 | 3% | -2% |
| Crude oil | 111 | 105 | 117 | -5% | 5% |
| Coal | 86 | 81 | 88 | -6% | 3% |
| Uranium | 10 | 10 | 10 | 1% | 3% |
| Other energy | 5 | 6 | 5 | 8% | 3% |

## Carbon Balance

The element, carbon, was tracked "gate-to-gate" in the study of softwood lumber production. To track carbon, a checklist was devised to balance the carbon inputs versus outputs to determine if there was any carbon missing and to also follow carbon in the LCI of lumber, to see which product or emission carbon is assigned. This analysis followed carbon from the inputs of material, electricity and fuels to its production of softwood lumber as a product, also its co-products and emissions into the environment. An average carbon ratio of 0.5037 was used for wood and bark was based on CORRIM Protocols for conducting Wood Product LCI's and Birdsey (1994). Other carbon ratios in substances other than wood were either taken from the Merck Index (1989) or were calculated by using atomic masses of each element from the chemical formula.

### Carbon balance results

Table 26 includes a list of inputs and outputs associated with softwood lumber production. Values are based on an LCI of softwood lumber from the Inland Northwest production region only and thus the input of materials, electricity, and fuels are allocated to one cubic meter of planed, kiln-dried softwood lumber, which is 52% by weight of the total outputs of materials. As a result, the inputs were also allocated so that 52% of the inputs by mass are used. Note that the result is that the carbon balance has a difference to the LCI of -8.5%%.

The sum of carbon output from the production of one cubic meter of softwood lumber was 457 kg. Of this, 45% was in final product, with 36% in co-products and 6% from wood fuel. The other 13% was in the form of air emissions with $CO_2$ biomass contributing 94% of that. Carbon dioxide (biomass) emissions were a result of the combustion of wood in the boiler to dry wood.

**Table 26: Carbon content balance including carbon containing emissions and materials for the production of one cubic meter (m3) softwood lumber from the Inland Northwest production region.**

| OUTPUTS | kg/m3 | Carbon (kg/m3) | Carbon ratio in material |
|---|---|---|---|
| **Emissions to Air** | | | |
| acetaldehyde | 0.002 | 0.001 | 0.540 |
| benzene | 0.000 | 0.000 | 0.923 |
| CO | 0.979 | 0.420 | 0.429 |
| CO2 (non-fossil) | 116.126 | 31.668 | 0.273 |
| ethanol | 0.000 | 0.000 | 0.522 |
| formaldehyde | 0.003 | 0.001 | 0.400 |
| hydrocarbons | 0.000 | 0.000 | 1.000 |
| methane | 0.183 | 0.137 | 0.750 |
| methanol | 0.022 | 0.008 | 0.375 |
| naphthalene | 0.000 | 0.000 | 0.937 |
| NMVOC | 0.261 | 0.261 | 1.000 |
| organic substances | 0.010 | 0.005 | 0.500 |
| particulates | 0.096 | 0.047 | 0.491 |
| particulates (PM10) | 0.023 | 0.011 | 0.491 |
| phenol | 0.002 | 0.002 | 0.766 |
| VOC | 0.167 | 0.167 | 1.000 |
| **Emission to Land** | | | |
| wood waste | 6 | 3 | 0.504 |
| ***Emissions Subtotal*** | ***124*** | ***36*** | |
| **Materials (Products and Co-Products)** | | | |
| Planed Kiln-dried Softwood Lumber | 436 | 220 | 0.504 |
| Wood Chips | 221 | 111 | 0.504 |
| Sawdust | 52 | 26 | 0.504 |
| Bark at mill | 29 | 14 | 0.504 |
| Wood fuel | 60 | 30 | 0.504 |
| Wood fiber | 3 | 2 | 0.504 |
| Shavings | 37 | 19 | 0.504 |
| ***Material Subtotal*** | ***837*** | ***422*** | |
| **TOTAL OUTPUTS** | **961** | **457** | |
| **INPUTS** | | | |
| Roundwood at mill, softwood, Inland Northwest, USA, U | 837 | 422 | |
| **TOTAL INPUTS** | **837** | **422** | |
| **Difference Percent** | | **-8.50%** | |

## Discussion

Total energy consumption per cubic meter of planed dry softwood lumber was found to be lower than previously published data for softwood production from the Pacific Northwest and the Southeast regions of the U.S. (Milota et al 2005). However these differences could be due in the Southeast region to higher energy requirements for sawing and drying southern pines due to their higher densities and moisture contents. For the Pacific Northwest region, a second survey was submitted to softwood lumber manufacturers specifically requesting boiler data and this could have resulted in more precise results for that region. Therefore the data collected could be considered more representative of the region than just the boiler information from the manufacturers that provided lumber production data. The Inland region also introduces an operational issue in the winter when logs might be frozen. The sawmill will use special teeth for the saws to saw frozen logs, but there may be additional energy consumption in the drying process if the lumber is still frozen at that stage. The Inland survey data did not distinguish between summer and winter operations since the survey covered a full year of operations. If specific data had been collected only on the boilers in summer and in winter, differences between energy consumption related to season might have been determined. In the southeast differences are primarily due to the higher amount energy used to dry southern pine species and the higher moisture contents of the lumber at the start of drying compared to softwood wood species from the Northwest region. Energy consumption and type are one of the most important elements considered in most life cycle inventory studies. In the wood products industry, with the availability of self produced wood fuel, there are significant reductions in carbon dioxide ($CO_2$ fossil) emitted. This can be seen in section 6.0 "Sensitivity Analysis" of this study. In addition if manufacturers can decrease their overall energy consumption. Lower energy needs will have a great benefit to the industry both in terms economic and environmental burden benefits.

## Conclusions

Based on the Life-Cycle Inventory results, the following conclusions are drawn:

- The data collected on Inland Northwest softwood lumber production represents 16% of the Inland Northwest Region's total softwood lumber production for the production year 2005/2006.
- The level of detail in energy and raw material use and product and co-product produced are what can be expected for the softwood lumber industry.
- The planing process consumes the highest proportion of electricity in the manufacturing of softwood lumber.
- In the Inland Northwest region, hydro power remains the largest contributor to electricity production. While this has remained the case, the contribution of hydro power has decreased over the years with natural gas use increasing. It is important to keep in mind the differences in environmental impacts based on fuel source for electricity production. Currently the SimaPro model with Franklin's incorporated database for electricity generation does not include environmental impacts associated with electricity generated from hydro power.
- The drying process emitted the greatest amounts of emissions to air, this is due to the boiler used for heat generation
- Drying consumes the highest proportion of fuel. In this LCI study, wood fuel accounts for 54% of thermal energy used with natural gas making up the remaining 46% energy needs. Since this study used boiler data only from the mills participating in the production survey, it is suggested that an

Inland Northwest Softwood Lumber Boiler study be conducted on a wider range of lumber producers.

- Total heat energy requirement of 2,944 MJ/$m^3$ of planed-dried softwood lumber – allocated, cumulative gate-to-gate.
- Survey reported data on process air emissions differ between lumber manufacturers; differences are a function, in part, of government regulations that apply to each facility depending upon use and type of kilns and or boilers.
- Increasing on-site wood fuel consumption would reduce fossil greenhouse gases but increase other gases and especially particulate emissions and HAPS. Therefore, more stringent emission control devices should be installed
  - Caution is required when using wood product LCI/LCA studies for comparison to alternative materials. It is important to understand the system boundaries of each study and functional unit (reference unit) is used. The LCI results presented in this study are based on the functional unit of cubic meter of finished planed-dried softwood lumber.

## References


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# Appendix I

## List of Terms

**Table A1.1: List of terms**

| | |
|---|---|
| Board foot | One board foot is equal to a 1-inch thick board, 12 inches in width, and 1 foot in length (1” x 12” x 1 ft). |
| BTU | British thermal unit |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| $CO_2$ (biomass) | Carbon dioxide emitted from the combustion wood or biomass |
| $CO_2$ (fossil) | Carbon dioxide emitted from the combustion on fossil fuels |
| CORRIM | The Consortium for Research on Renewable Industrial Materials |
| cuft | Cubic feet |
| cuin | Cubic inches |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| gal | US gallon |
| Wood fuel | Wood waste (shavings, trimmings, bark, planer shavings etc.) used to fire boiler or furnaces, often at the mill or plant at which the fuel was processed. |
| kg | Kilogram |
| $in^2$ | Inches squared |
| $kg/m^3$ | Kilogram per cubic meter |
| kWh | Kilowatt hour |
| L | Liter |
| lb | US pound |
| $lb/ft^3$ | Pound per cubic foot (density), US |
| LCA | Life-cycle assessment |
| LCI | Life-cycle inventory |
| LCIA | Life-cycle impact assessment |
| M | 1,000 |
| $m^3$ | Cubic meters |
| MBF | 1000 board feet |
| MCF | 1000 cubic feet |
| MJ | Mega joules |
| mm | Millimeters |
| MMBF | Million board feet |
| NMVOC | Non methane volatile organic substances |
| $NO_x$ | Nitrogen oxides: NOx as $NO_2$ |
| Particulate matter | A general term used for a mixture of solid particles and liquid droplets found in the air. |
| PM10 | Particulate matter less than 10 microns in diameter |
| $SO_x$ | Sulfur oxides: $SO_x$ as $SO_2$ |
| VOC’s | Volatile organic compounds |

## 1.1 UNIT CONVERSIONS

**Table A1.2: Unit conversion factors**

| | | |
|---|---|---|
| Board foot, actual dimensions 2 x 6 basis (1.5 x 5.5) | Bf = | 0.0573 $ft^3$ |
| Board foot, nominal dimensions | Bf = | 0.0833 $ft^3$ |
| Thousand board foot nominal 2 x 6 basis | MBF | 1.622 $m^3$ |
| British Thermal Unit | BTU = | 0.00106 MJ |
| Cubic feet | $ft^3$ = | 0.02832 $m^3$ |
| Gallon | gal (US) = | 3.785 L |
| Kilogram | kg = | 2.2046 lb |
| Kilometers | km = | 0.6214 mi |
| Kilo watt hour | kWh= | 3.6 MJ |
| 1000 board feet, actual | MBF = | 1.6222 $m^3$ |
| Megajoule | MJ = | 0.2778 kWh |
| Megajoule | MJ = | 947.82 BTU's |
| Pound (US) | lb = | 0.4536 kg |
| Pound per cubic feet | lb/$ft^3$ = | 16.02 kg/$m^3$ |
| Liter | L = | 0.2642 gal (US) |
| Cubic meter | $m^3$ = | 35.3147 $ft^3$ |
| Miles | mi = | 1.61 km |

**Table A1.3: Fuel densities and energy content conversions**

| Fuel | Unit | HHV BTU/Unit | Densities | | HHV BTU/lb | HHV MJ/kg |
|---|---|---|---|---|---|---|
| | | | | | | |
| Coal | lb | 11,260 | | | 11,260 | 26.17 |
| DFO | gal | 139,000 | 7.1 lb/gal | | 19,578 | 45.50 |
| LPG | gal | 95,500 | 4.11 lb/gal | | 23,236 | 54.00 |
| Natural gas | ft3 | 1,030 | 0.044 lb/ft3 | | 23,409 | 54.40 |
| RFO | gal | 150,000 | 8.03 lb/gal | | 18,680 | 43.41 |
| Wood | lb | 4,500 | | | 9,000 | 20.92 |
| Uranium | lb | | | | 163,941,480 | 381,000 |
| | | | | | | |
| | | **HHV** | | | **HHV** | **HHV** |
| | | **BTU/Unit** | **lb/gal** | **kg/m$^3$** | **BTU/lb** | **MJ/kg** |
| Gasoline | gal | 125,000 | 6.01 | 880 | 20,808.33 | 48.36 |
| Diesel | gal | 139,000 | 7.34 | 720 | 18,931.80 | 44.00 |

## Appendix II

### 1.2 INLAND NORTHWEST SOFTWOOD LUMBER MILL SURVEY

### LIFE CYCLE INVENTORY ANALYSIS OF THE INLAND SOFTWOOD DIMENSION LUMBER INDUSTRY

The information from this survey will be used by CORRIM II, a consortia of university, industry and government groups. CORRIM II is conducting a life-cycle assessment that will describe the environmental influences of building materials. The objective is to acquire a database and produce life-cycle models of the environmental performances of various building materials. *This will allow the comparison of the overall environmental benefits of wood versus steel or concrete building components.*

This CORRIM survey is designed specifically for Inland softwood lumber mills. **Questions will be focused on annual production, energy use and generation, material inputs, and environmental emissions. We realize that you may not have all the information requested, but the data you are able to provide will be appreciated.** We will maintain the confidentiality of the companies that supply data for this survey.

**Company Name:** ________________________________________

**Mill Address:** ________________________________________

________________________________________

**Mill ID code:** ________________________________________

**Contact Person:** ________________________________________

**Position/Title:** ________________________________________

**Telephone:** (____) _________________________________

**Fax:** (____)__________________________________

**Questions should be directed to:**

**Dr. Fran Wagner**
**Department of Forest Products**
**College of Natural Resources**
**University of Idaho**
**Moscow, ID 83844-1132**
**Phone: (208) 885-6700**
**Fax: (208) 885-6226**
**fwagner@uidaho.edu**

## LIFE CYCLE INVENTORY ANALYSIS OF THE

## INLAND SOFTWOOD DIMENSION LUMBER INDUSTRY

There are six main parts to this survey (the entire mill, log yard, green sawmill, boiler & electrical co-generation, kiln drying & direct heating system, and planer mill). ***Imagine drawing a boundary around each part. We want to find out everything that crosses the boundary of each part.*** If you have any questions please contact Fran Wagner.

Please complete complete all parts of the questionnaire in the spaces provided. Feel free to add additional comments, clarifications or observations anywhere on a relevant page.

Units are generally specified, but if you have other units which are easier to use, please cross off our units and add yours.

If you do not know the quantities at the level of detail requested, group by category. For example, provide a value for all HAPs if the quantities of individual compounds are not known.

***Thank you for the time and effort to fill in the blanks.***

## The Entire Sawmill (Gate to Gate)

### BASIC DESCRIPTION

1. What type of mill are you?
   - Dimension Mill
   - Stud Mill
   - Other (specify)_______________

2. What was your lumber production last year?

   _________________________MMBF

3. What was the starting month and ending month for the above reporting year?

   ________________to___________________

4. What percent of your lumber production was kiln dried?

   _____________%

5. What were your target moisture contents?

   _____________% to ____________%

6. What process centers exist at your mill? Please check all that apply.

***Please attach a schematic of the mill, if available.***

- Log protection center (___pond or ____water sprinkling)
- Log yard cranes
- Log sorter/merchandiser
- Debark(s) (specify)_________________________________________
- Headrig(s) (specify)_________________________________________
- Resaw(s)
- Edger(s)
- Trimmer
- Kiln(s)
  - Conventional Kiln(s) X_________
  - High Temperature Kiln(s) X_____
  - Dehumidification Drier(s) X_____
- Planer Mill
- Process Heat Boiler(s)
- Cogeneration Facility
- Bag House
- Emissions Control Equipment (specify)
- Other(s) _______________________________________

7. What is the rating of your boiler?

   ______________BTU/hr

8. What is your steam production rating?

______________lbs/hr

9. What is the distance between process areas?

| From | To | Distance | Units |
|---|---|---|---|
| Log Yard | Log Deck | | |
| Green Chain Sorter | Dry Kiln | | |
| Dry Kiln | Planer Mill | | |
| Planer Mill | Lumber Storage/Shipping | | |

## TRANSPORTATION INPUTS

1. How much material inputs were used for **all the carrier equipment** used in the transportation of wood materials throughout the entire mill?

| Material Inputs | Units | Quantity | Hours Used |
|---|---|---|---|
| Carrier Fuel | | | |
| Oil | | | |
| Grease | | | |
| Hydraulic Fluid | | | |
| Antifreeze | | | |
| Ether | | | |
| Other(s) | | | |
| | | | |

## ENERGY INPUTS

1. What energy was purchased from ***outside*** the entire mill?

| Energy Inputs | Quantity | Units |
|---|---|---|
| Heavy Fuel Oil | | |
| Medium Fuel Oil | | |
| Light Fuel Oil | | |
| Kerosene | | |
| Gasoline | | |
| Diesel Fuel | | |
| Propane | | |
| Natural gas | | |
| Coal | | |
| Hog Fuel | | |
| Planer Shavings | | |
| Sawdust | | |
| Bark | | |
| Other: | | |
| Steam from Boiler | | |
| Purchased Steam | | |
| Purchased electricity | | |
| Other(s) | | |
| | | |

## MANUFACTURING OUTPUTS

1. What was the average annual production level for the selected reporting year by lumber size?

| Lumber Size (Thickness X Width) | | MMBF/yr | OR | Per Shift Tally (MBF) |
|---|---|---|---|---|
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2. What was your co-product production that ***left*** **the mill** last year?

| Co-product | Volume Produced (tons/yr) | | Volume Produced | Alternate Units |
|---|---|---|---|---|
| Pulp Chips | | | | |
| Planer Shavings | | | | |
| Sawdust (Green) | | OR | | |
| Sawdust (Dry) | | | | |
| Bark | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

3. What happened to the co-products that ***left*** **the mill**?

| Co-Product | Sold | Land filled | Stockpiled | Total |
|---|---|---|---|---|
| Pulp Chips | | | | 100% |
| Planer Shavings | | | | 100% |
| Sawdust (Green) | | | | 100% |
| Sawdust (Dry) | | | | 100% |
| Bark | | | | 100% |
| | | | | 100% |

## ENTIRE MILL ENVIRONMENTAL OUTPUTS

1. What were the air emissions for the **entire mill** last year?

**Complete this section if and only if environmental outputs cannot be linked to a specific process center.** There is an air emission table for the log yard, boiler/co-gen and kiln drying processes. For example, VOC's are listed in the kiln air emission table.

| Air Emissions | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| $Cl_2$ | | | |
| CO | | | |
| $CO_2$ | | | |
| Dust/Particles | | | |
| $F_2$ | | | |
| $H_2SO_4$ | | | |
| HCL | | | |
| HF | | | |
| Hg | | | |
| Hydrocarbons* | | | |
| $N_2O$ | | | |
| $NH_3$ | | | |
| $NO_x$ | | | |
| Organics* | | | |
| Other Metals | | | |
| Pb | | | |
| SO | | | |
| Other(s) | | | |
| | | | |
| | | | |

*Please list compounds included in these categories

2. What were the water effluents for the **entire mill** last year?

**<u>Complete this section if and only if environmental outputs cannot be linked to a specific process center.</u>** There is a water effluents table for the log yard, boiler/co-gen and kiln drying processes.

| Water Effluent | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| $H^+$ | | | |
| BOD | | | |
| COD | | | |
| $CL^-$ | | | |
| $CN^-$ | | | |
| Detergents | | | |
| Oils & Greases | | | |
| Dissolved Organics* | | | |
| $F^-$ | | | |
| Fe Ions | | | |
| Hg | | | |
| Hydrocarbons | | | |
| $Na^+$ | | | |
| $NH_4^+$ | | | |
| $NO_3$ | | | |
| Organo-Chlorine* | | | |
| Other Metals | | | |
| Other N* | | | |
| Phenols | | | |
| Phosphates | | | |
| $SO_4$ | | | |
| Suspended Solids | | | |
| Other(s) | | | |
| | | | |
| | | | |

*Please list compounds included in these categories

3. What were the solid waste outputs **that *left* the mill** last year?

| Solid Waste | Quantity | Units | Transportation Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Wood Fiber | | | | |
| Ash | | | | |
| Inorganic Material e.g. sand | | | | |
| Domestic Waste | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

## 2 Log Yard

**LOG YARD INPUTS**

1. What scaling rule or methods was used to quantify inputs to your mill?

   ___________________________________

2. What was the total input to your mill, for the selected reporting year?

   _____________________bf/year
   Or _____________________$m^3$/yr
   Or _____________________$ft^3$/yr
   Or _____________________tons/year

3. What species did you process? What were the average dimensions?

| Species | % of total timber input | Average log length (Feet) | Average log diameter (Inches) | Average load | Average haul distance (Miles) |
|---|---|---|---|---|---|
| | | | | | |
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4. How did these logs get to the mill?

   - Rail (___________%)
   - Truck (___________%)
   - Other (describe)_______________(__________%)

5. Do you know how the timber was harvested?

   - Manual (chainsaw felling and skidder/cable yarder)
   - Mechanized logging (feller, forwarder, delimber)
   - Other (describe)__________________________

6. What were the non-energy material inputs to the **log yard**?

| Material Inputs | Quantity | Units | Transport Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Stain Prevention Chemicals | | | | |
| Hydraulic Oils | | | | |
| Greases | | | | |
| Motor Oil | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

7. What were the energy inputs to **log yard**?

| Energy Inputs | Quantity | Units |
|---|---|---|
| Heavy Fuel Oil | | |
| Medium Fuel Oil | | |
| Light Fuel Oil | | |
| Kerosene | | |
| Gasoline | | |
| Diesel Fuel | | |
| Propane | | |
| Natural gas | | |
| Coal | | |
| Biomass (hog fuel) | | |
| Steam from Boiler | | |
| Purchased Steam | | |
| Purchased electricity | | |
| Other(s) | | |
| | | |

8. How much water was consumed in the **log yard**?

| | Log Protection | |
|---|---|---|
| **Water Consumption** | **Quantity** | **Units** |
| Surface Water | | |
| Ground Water | | |
| Recycled Water | | |

## LOG YARD OUTPUTS

1. What were the air emissions in **log yard** last year?

| Air Emissions | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| $Cl_2$ | | | |
| CO | | | |
| $CO_2$ | | | |
| **Dust/Particles** | | | |
| $F_2$ | | | |
| $H_2SO_4$ | | | |
| HCL | | | |
| HF | | | |
| Hg | | | |
| Hydrocarbons* | | | |
| $N_2O$ | | | |
| $NH_3$ | | | |
| $NO_x$ | | | |
| Organics* | | | |
| Other Metals | | | |
| Pb | | | |
| SO | | | |
| Other(s) | | | |
| | | | |
| | | | |

*Please list compounds included in these categories

2. How much water effluents drained from the **log yard** last year?

| Water Effluents | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| $H^+$ | | | |
| **BOD** | | | |
| **COD** | | | |
| $CL^-$ | | | |
| $CN^-$ | | | |
| Detergents | | | |
| Oils & Greases | | | |
| **Dissolved Organics*** | | | |
| $F^-$ | | | |
| Fe Ions | | | |
| Hg | | | |
| Hydrocarbons | | | |
| $Na^+$ | | | |
| $NH_4^+$ | | | |
| $NO_3$ | | | |
| Organo-Chlorine* | | | |
| Other Metals | | | |
| Other N* | | | |
| **Phenols** | | | |
| Phosphates | | | |
| $SO_4$ | | | |
| **Suspended Solids** | | | |
| **Tanins & Lignins** | | | |
| **Other(s)** | | | |
| | | | |

*Please list compounds included in these categories

3. What were the solid waste outputs from the **log yard** last year?

| Solid Waste | Quantity | Units | Transportation Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Un-process-able logs | | | | |
| Inorganic Material e.g. sand | | | | |
| Domestic Waste | | | | |
| Other(s) | | | | |
| | | | | |

4. What happens to the un-process-able logs?

# 3 The Sawmill (green lumber processing center)

***This is a stand alone processing center <u>separate</u> from drying and planing process centers.***

**SAWMILL INPUTS**

1. What were the material inputs to the sawmill (as a process center)?

| Material Inputs | Quantity | Units | Transport Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Sawlogs | | | | |
| Stain Prevention Chemicals | | | | |
| Hydraulic Oils | | | | |
| Greases | | | | |
| Motor Oil | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

2. What were the energy inputs to the sawmill (as a process center)?

| Energy Inputs | Quantity | Units |
|---|---|---|
| Heavy Fuel Oil | | |
| Medium Fuel Oil | | |
| Light Fuel Oil | | |
| Kerosene | | |
| Gasoline | | |
| Diesel Fuel | | |
| Propane | | |
| Natural gas | | |
| Coal | | |
| Biomass (hog fuel) | | |
| Steam from Boiler | | |
| Purchased Steam | | |
| Purchased electricity | | |
| Other(s) | | |
| | | |

3. How much water was consumed in the **sawmill process center**?

| | Stain Prevention Dip Tank | |
|---|---|---|
| **Water Consumption** | **Quantity** | **Units** |
| Surface Water | | |
| Ground Water | | |
| Recycled Water | | |

## SAWMILL OUTPUTS

1. What were the product outputs of the sawmill (as a process center)?

   *(This does not include Drying or Planer outputs)*

| **Product Outputs** | **Quantity** | **Units** | **Transport Type** | **Avg. Delivery Distance** |
|---|---|---|---|---|
| Rough Lumber (Green) | | | | |
| Pulp chips (Green) | | | | |
| Sawdust (Green) | | | | |
| Bark (Green) | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

2. What were the solid waste outputs of the sawmill (as a process center)?

| **Solid Waste** | **Quantity** | **Units** | **Transportation Type** | **Avg. Delivery Distance** |
|---|---|---|---|---|
| Wood Fiber | | | | |
| Ash | | | | |
| Inorganic Material e.g. sand | | | | |
| Domestic Waste | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

# 4 Boiler & Electrical Co-Generation

**BOILER & ELECTRICAL CO-GEN INPUTS**

1. What were the material inputs to your boiler and/or co-generation process center?

| Material Inputs | Quantity | Outputs |
|---|---|---|
| Surface water | | |
| Groundwater | | |
| Natural Gas | | |
| Propane | | |
| Biomass (hog fuel) | | |
| Treatment Chemicals (specify) | | |
| | | |
| | | |
| | | |
| Other(s) | | |
| | | |
| | | |
| | | |
| | | |

**BOILER & ELECTRICAL CO-GEN OUTPUTS**

1. What were the product/energy outputs?

| Product & Energy Outputs | Quantity | Units |
|---|---|---|
| Self-generated process steam | | |
| Self-generated electricity | | |
| Other(s) | | |
| | | |
| | | |

2. What were the air emissions at the boiler/co-gen?

| Air Emissions | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| $Cl_2$ | | | |
| CO | | | |
| $CO_2$ | | | |
| Dust/Particles | | | |
| $F_2$ | | | |
| $H_2SO_4$ | | | |
| HCL | | | |
| HF | | | |
| Hg | | | |
| Hydrocarbons* | | | |
| $N_2O$ | | | |
| $NH_3$ | | | |
| $NO_x$ | | | |
| Organics* | | | |
| Other Metals | | | |
| Pb | | | |
| SO | | | |
| Other(s) | | | |
| | | | |
| | | | |

*Please list compounds included in these categories

3. What were the water effluents at the boiler/co-gen last year?

| Water Effluent | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| $H^+$ | | | |
| BOD | | | |
| COD | | | |
| $CL^-$ | | | |
| $CN^-$ | | | |
| Detergents | | | |
| Oils & Greases | | | |
| Dissolved Organics* | | | |
| $F^-$ | | | |
| Fe Ions | | | |
| Hg | | | |
| Hydrocarbons | | | |
| $Na^+$ | | | |
| $NH_4^+$ | | | |
| $NO_3$ | | | |
| Organo-Chlorine* | | | |
| Other Metals | | | |
| Other N* | | | |
| Phenols | | | |
| Phosphates | | | |
| $SO_4$ | | | |
| Suspended Solids | | | |
| Other(s) | | | |
| | | | |

*Please list compounds included in these categories

4. What were the solid waste outputs from the boiler/co-gen?

| Solid Waste | Quantity | Units | Transportation Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Wood Fiber | | | | |
| Ash | | | | |
| Inorganic Material e.g. sand | | | | |
| Domestic Waste | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

# 5 Kiln Drying & Direct Heating Systems

## KILN DRYING & DIRECT HEATING INPUTS

1. What were the energy inputs to the kiln drying process center?

| Energy Inputs | Quantity | Units |
|---|---|---|
| Heavy Fuel Oil | | |
| Medium Fuel Oil | | |
| Light Fuel Oil | | |
| Kerosene | | |
| Gasoline | | |
| Diesel Fuel | | |
| Propane | | |
| Natural gas | | |
| Coal | | |
| Biomass (hog fuel) | | |
| Steam from Boiler | | |
| Purchased Steam | | |
| Purchased electricity | | |
| Other(s) | | |
| | | |

2. What were the non-energy inputs to the kiln drying process center?

| Non-Energy Material Inputs | Quantity | Units | Transport Type | Avg. Load | Avg. Delivery Distance |
|---|---|---|---|---|---|
| Rough Green Lumber | | | | | |
| Stickers | | | | | |
| Hydraulic Oils | | | | | |
| Greases | | | | | |
| Motor Oil | | | | | |
| Other(s) | | | | | |
| | | | | | |
| | | | | | |

## KILN DRYING & DIRECT HEATING OUTPUTS

1. What were the product & energy outputs from the kiln drying process center?

| Product & Energy Outputs | Quantity | Units | Transport Type | Avg. Load | Avg. Delivery Distance |
|---|---|---|---|---|---|
| Kiln Dried Lumber | | | | | |
| Other(s) | | | | | |
| | | | | | |
| | | | | | |

2. What were the air emissions from the drying process?

| Air Emissions | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| Total VOC | | | |
| By parts: | | | |
| α-pinene | | | |
| β-pinene | | | |
| Δ-3 carene | | | |
| Limonene | | | |
| Formaldehyde | | | |
| Acetaldehyde | | | |
| | | | |
| Other(s) | | | |
| | | | |
| | | | |

3. What were the air emissions if ***direct heating*** the kiln(s)?

**Skip this question if you are using the boiler to heat the kiln(s).**

| Air Emissions | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| Cl2 | | | |
| CO | | | |
| CO2 | | | |
| Dust/Particles | | | |
| F2 | | | |
| H2SO4 | | | |
| HCL | | | |
| HF | | | |
| Hg | | | |
| Hydrocarbons* | | | |
| N2O | | | |
| NH3 | | | |
| NOx | | | |
| Organics* | | | |
| Other Metals | | | |
| Pb | | | |
| SO | | | |
| Other(s) | | | |
| | | | |

*Please list compounds included in these categories

4. What were the water effluents from the kiln drying process center?

| Water Effluent | Quantity | Units | Describe Sampling Procedure (Attach additional sheets if necessary) |
|---|---|---|---|
| H+ | | | |
| BOD | | | |
| COD | | | |
| CL- | | | |
| CN- | | | |
| Detergents | | | |
| Oils & Greases | | | |
| Dissolved Organics* | | | |
| F- | | | |
| Fe Ions | | | |
| Hg | | | |
| Hydrocarbons | | | |
| Na+ | | | |
| NH4+ | | | |
| NO3 | | | |
| Organo-Chlorine* | | | |
| Other Metals | | | |
| Other N* | | | |
| Phenols | | | |
| Phosphates | | | |
| SO4 | | | |
| Suspended Solids | | | |
| Other(s) | | | |
| | | | |
| | | | |

*Please list compounds included in these categories

5. What were the solid waste outputs from the kiln drying/direct heating process center?

| Solid Waste | Quantity | Units | Transportation Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Wood Fiber | | | | |
| Ash | | | | |
| Inorganic Material e.g. sand | | | | |
| Domestic Waste | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

# 6 PLANER MILL (including packaging of lumber)

**PLANER MILL INPUTS**

1. What were the non-energy material inputs to planer mill (as a process center)?

| Material Inputs | Quantity | Units | Transport Type | Avg. Delivery Distance |
|---|---|---|---|---|
| Rough Green Lumber | | | | |
| Rough Dry Lumber | | | | |
| Stickers | | | | |
| Hydraulic Oils | | | | |
| Greases | | | | |
| Motor Oil | | | | |
| End Paint | | | | |
| Polyethylene Plastic | | | | |
| Lumber Wrap | | | | |
| Steel Strapping | | | | |
| Liner Board | | | | |
| Other(s) | | | | |
| | | | | |
| | | | | |

2. What were the energy inputs to the planer (as a process center)?

| Energy Inputs | Quantity | Units |
|---|---|---|
| Heavy Fuel Oil | | |
| Medium Fuel Oil | | |
| Light Fuel Oil | | |
| Kerosene | | |
| Gasoline | | |
| Diesel Fuel | | |
| Propane | | |
| Natural gas | | |
| Coal | | |
| Biomass (hog fuel) | | |
| Steam from Boiler | | |
| Purchased Steam | | |
| Purchased electricity | | |
| Other(s) | | |
| | | |

**PLANER MILL OUTPUTS**

1. What were the product & energy outputs from the planer mill?

| Product & Energy Outputs | Quantity | Units | Transport Type | Avg. Load | Avg. Delivery Distance |
|---|---|---|---|---|---|
| Planed Dry Lumber | | | | | |
| Planed Green Lumber | | | | | |
| Planer Shavings | | | | | |
| Pulp chips | | | | | |
| Sawdust | | | | | |
| Other(s) | | | | | |
| | | | | | |
| | | | | | |

# Addendum

## Changes to Original CORRIM Model for Importation in U.S. LCI
## – Inland West Softwood Lumber Module –

Pascal Lesage, Sylvatica
Maureen Puettmann, WoodLife/CORRIM
April 21 2009

### 1. Objective and procedure

Sylvatica was contracted, through the Athena Institute, to transfer the CORRIM Phase II LCI data to the U.S. LCI database format for inclusion in the said database. Although a formal, in-depth review and validation of the data was not part of Sylvatica's mandate, some quality control work was done (e.g. mass balances, consistency checks). Note that this work does not guarantee that the data will necessarily pass, as is, a formal revision by NREL.

CORRIM supplied two sources of information:

- The report "Life Cycle Inventory of Inland Northwest Softwood Lumber Manufacturing", by Francis G. Wagner, Maureen E. Puettmann and Leonard R. Johnson; and
- A CORRIM SimaPro module, produced by Maureen Puettmann, WoodLife, LCA Consultant.

This report documents the changes made to the data as found in the original CORRIM SimaPro module. It is accompanied by (1) a spreadsheet file named "Inland West Softwood Lumber changes.xls", which documents all changes to individual flows, (2) a new version of the SimaPro module, where the proposed changes are implemented, and (3) a set of "Streamlined EcoSpold" files to be sent to NREL for inclusion in the U.S. LCI database.

Draft versions of this report, spreadsheet, revised SimaPro module and EcoSpold files were revised, commented and augmented by Maureen Puettmann: CORRIM therefore agrees to the changes that were made.

### 2. General changes

A number of changes concern all unit processes. These are:

- All flow names not fitting U.S. LCI database nomenclature were changed;
- Unit processes connecting to the FAL database were modified to use U.S. LCI data instead;
- Unit processes were all renormalized to produce "one unit" of product (rather than to represent the final amount needed to produce "one unit" of a downstream final product);
- All final waste flows were converted to waste management flows. Note that additional information on the management of these waste flows would improve the unit process quality; and

### 3. Changes to individual unit processes

#### 3.1 "Log Yard" processes

The CORRIM SimaPro model contained a set of processes grouped under the "log Yard" header. These processes were as follows:

1. "Bark at forest road, m3, softwood, Inland West, USA, U", and "Roundwood at forest road, m3, softwood, Inland West, USA, U": these processes were temporary processes serving as placeholders during modeling.
2. "Bark at forest road, softwood, Inland West, USA, U", and "Roundwood at forest road, softwood, Inland West, USA, U": these processes, both expressed as tkm, were basically only transportation processes, but contained no data on distance or weight transported. They simply, for each output tkm, linked to 1 tkm of a CORRIM custom transport process, which in turn simply referred to 1 tkm of the "Trailer diesel" unit process in the Franklin database.

3. “Bark at mill, softwood, Inland West, USA, U” and “Roundwood at mill, softwood, Inland West, USA, U”: these were actually two outputs from a single process which included the actual data on transportation of both bark and roundwood as well as various inputs and waste flows associated with the unloading and storing of the wood.

The two processes discussed in point (1) above were deleted as they are no longer needed: these outputs are produced from processes in the CORRIM Inland West Softwood Resources module. The two processes detailed in (2) above were also simply deleted, as they did not provide any additional information: they simply kinked, in a 1:1 ratio, to transport processes in a background database.

Beyond the types of changes made to all processes, the following changes were made to the main process described in (3):

- The inputs of custom transport processes were replaced with inputs of transport from the US LCI database.
- The input of bark from forest road is changed to a mass basis (since the output of the corresponding process in the Inland West Softwood Resources module is expressed on a mass basis). The volume (0.1407 m3) was converted to mass of 57.54 kg
- Non wood waste to landfilled changed from volume (m3) to kg using an estimated rock density of 2704 kg/m3. This is an assumption by CORRIM.

### 3.2 Sawmilling

No changes were made to this process beyond the general changes made to all processes.

### 3.3 Kiln drying

No changes were made to this process beyond the general changes made to all processes and renormalizing the output to a 1m3 basis (rather than a mass basis).

### 3.4 Planing

No changes were made to this process beyond the general changes made to all processes and renormalizing the output to a 1m3 basis (rather than a mass basis).

### 3.5 Adapted Franklin data: Wood in boiler

The Franklin dataset “Wood in industrial boilers” was adapted by CORRIM to represent an onsite boiler combusting fuel wood co-product used in the drying process. Other than renormalization, only two changes were made to this process:

1. The wood fuel input “Wood and wood waste” combusted in the original Franklin dataset was replaced with the Inland West softwood fuel produced in the sawmilling unit process;
2. The original Franklin dataset give no indication on what the moisture content of the generic “Wood and wood wastes” flow it combusts. Without further information, CORRIM assumes that oven-dry weight is half of the weight reported in the original Franklin data. This assumption was operationalized by halving the output in the Franklin dataset (from 1000 lb wood and wood waste to 500 lb) but keeping all other flow values unchanged. It should be noted that this assumption might underestimate the amount of wood actually consumed: the amount of CO2 emitted from the combustion processes (1050 lb) hints that approximately 572 lb of wood (oven-dry basis) is combusted, not 500 lb. Although this assumption was not changed in the U.S. LCI version of the processes, it was made clearer in the comments section that this was indeed an assumption; and
3. CO2 emissions were changed to account for the fact that these are biogenic CO2 emissions.

Note that, if ever data specific to softwood-burning boilers in the Inland West region become available to CORRIM, their inclusion in the U.S. LCI database would heighten the quality of these modules greatly, since the data borrowed from Franklin are probably not very representative of the technologies used by Inland West softwood mills.