CORRIM: Phase II Final Report

Module D

Life-Cycle Inventory of Softwood Lumber Manufacturing in the Northeastern and North Central United States

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Conversion Table

1 megajoule = 0.278 kilowatt-hour
1 megajoule = 948.8 Btu
1 kilowatt = 3,412 Btu per hour
1 kilogram = 2.205 pounds
1 meter = 3.281 feet
1 millimeter = 0.0394 inches
1 meter squared = 10.76 feet squared
1 meter cubed = 35.31 feet cubed (264.2 gallons)
1 meter cubed = 423.8 actual board feet (0.4238 actual MBF)
1 liter = 0.2642 gallons
1 kilometer = 0.621 miles
1 metric ton (1,000 kilogram) = 1.10 tons (2,205 pounds)

Executive Summary

The goal of this study was to gain an understanding of the environmental impact for softwood lumber production through a gate-to-gate life-cycle inventory (LCI) of softwood sawmills in the northeastern and north central United States (NE/NC). Primary mill data were collected per Consortium on Research for Renewable Industrial Material (CORRIM) Research Guidelines (CORRIM 2001). Life-cycle analysis is beyond the scope of the study.

A mill questionnaire was used to survey six softwood sawmills across the NE/NC region. Total annual softwood lumber production for this region, in both 2006 and 2007, was 4.37 million m^3 (2.1 billion board feet[1]) (USCB 2008). Annual production for the six sawmills surveyed during 2006 and 2007 was greater than 531 thousand m^3 (256 million board feet (bf)) of rough green lumber, roughly 12% of the total softwood lumber production of this region for this two-year period. Most of the rough green softwood lumber is kiln dried and planed (surfaced) on-site prior to shipping, unlike hardwood lumber. The mill questionnaire separated softwood lumber manufacturing into three main unit processes: sawing, drying, and planing. The energy generation process, including boiler operations, was considered an auxiliary process. Mill data were weight-averaged on a per unit basis of 1.0 m^3 of planed dry lumber to find material flows and energy use. Material flow and energy use data were entered into modeling software (SimaPro 7, PRé Consultants, Amersfoort, The Netherlands) to determine environmental impact.

A mass conversion of 42.1% was found from producing planed (surfaced) dry lumber from a softwood log. Process energy consumption of 355 MJ of electricity (grid and on-site) and 2,728 MJ/m^3 from on-site fuels[2] were determined for the manufacturing of planed dry softwood lumber from incoming logs. Of the total electricity, grid electricity and on-site (cogeneration) electricity provided 304 and 51 MJ, respectively. Of the total value from burning on-site fuels per cubic meter of planed dry lumber, 2,016 MJ inputted into drying, 488 MJ inputted into on-site electrical generation, and 224 MJ inputted into plant heat. Cogeneration electrical efficiency was lower than expected at an estimated 10.5%. Burning green wood residues on-site generated most of the energy. Some important weight-averaged mill features are a log diameter of 0.239 m (9.4 in.), production kiln capacity of 1.42 thousand m^3 (600 thousand bf (MBF)), and mill volume of 110 thousand m^3 (52.9 million bf[1]) for the six mills surveyed. Also, pulp chips are the greatest proportion of wood residue produced. The wood species examined were eastern white pine (roughly half), red and jack pine, spruce, and balsam fir. Emission data produced through modeling estimated total biomass (biogenic) and fossil (anthropogenic) carbon dioxide production of 187 and 65.1 kg/m^3, respectively, considering all impacts.

The following conclusions are based on the life-cycle inventory:

- Sawing consumes the greatest proportion of electricity in the manufacturing of softwood lumber. Thus, installing optimization equipment would lower electrical consumption by reducing sawing errors. Accurately sized lumber through proper target sizing and lumber size quality control, along with curve sawing technology, proper saw design, and use of thinner kerf saws, improves lumber recovery. These features also reduce electrical consumption and the volume of green wood residue produced.
- Drying consumes the greatest proportion of fuel. In this LCI study, wood fuel accounts for 87% of thermal energy used. Upgrading or overhauling existing old and inefficient dry kiln facilities would lower overall energy consumption.

[1] One nominal board foot equals 1 by 12 by 12 in. (25 by 300 by 300 mm); 2.08 actual m^3 per nominal thousand board feet conversion.

[2] The value for on-site energy was based on higher heating values. No efficiencies assumed. All on-site energy was allocated to the planed dry lumber.

- Increasing on-site wood fuel consumption would reduce fossil greenhouse gases but increase other gases, especially particulate emissions.
- The region selected for production affects the environmental impact of this product because coal represents the greatest proportion of off-site material used for electrical power generation in the NE/NC region. Hydroelectric and natural gas are the top two sources of power in the Pacific Northwest; coal and uranium produce most of the power in the Southeast, similar to the situation in the NE/NC region.
- Increasing the level of air drying lumber prior to kiln drying, especially for species where color is not a problem, would reduce the energy required for the drying process. Therefore, improving air drying methods would lower energy use while maintaining lumber quality and reducing the environmental impact of producing softwood lumber.

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1.0 Introduction

Softwood lumber from species in the northeastern and north central United States (NE/NC) is used primarily for framing lumber and for moulding, depending on the species processed. Total annual U.S. softwood lumber production in 2006 was 89.0 million m^3 (37.7 billion board feet (bf)). Most softwood lumber is consumed domestically, but an estimated 2.06 million m^3 (873 million bf) was exported in 2006. Also, 53.3 million m^3 (22.6 billion bf) was imported in 2006 (USCB 2008). Domestic softwood lumber production occurs mostly in the Pacific Northwest (PNW) and the eastern United States. A smaller percentage of softwood lumber production occurs in the NE/NC region than in the Pacific Northwest (PNW) and Southeast (SE). Total annual softwood lumber production for this region, in both 2006 and 2007, was 4.37 million m^3 (2.1 billion bf). Most softwood lumber is used in residential construction, including new construction and repair and remodeling of existing buildings.

Economic costs, energy consumption, and environmental impact of manufacturing residential building products are playing an increasingly important role in the building industry because of increased public awareness of environmental issues. In 2003, the residential building industry used 87.6 million m^3 (37.1 billion bf) of softwood lumber in the United States (Spelter et al. 2007). One major reason for this huge consumption in production of residential building is an increase in average building size. The average-size single-family residential home increased from 193 m^2 (2,075 ft^2) in 1991 to 234 m^2 (2,521 ft^2) in 2007, a 25% increase. Another factor is the doubling in number of single-family residential buildings constructed from 1991 to 2005; this is less of a factor recently because of a large drop in single-family residential construction seasonally adjusted annual rate, from a high of 1.64 million in 2005 to 0.668 million in December 2008 (USCB 2009).

Green building is expected to play an increasing role in the residential building industry. “Green building” is defined as the practice of improving energy efficiency for materials, construction, and operation while reducing the overall environmental impact of building. Two percent ($7.4 billion) of new residential starts in 2005 were classified as “green buildings,” and this minimum market share is expected to increase to 5% ($19 billion) by 2010 (MHC 2006, Murray 2008). Developing a sound policy for building practices, especially for green building, must be a priority if the United States is to decrease its environmental burden on the world’s resources. However, scientific evidence is needed to evaluate claims for green building materials.

Accurate baseline life-cycle inventory (LCI) data are needed as a part of this broader scientific approach for determining building styles, type of construction materials, and product improvements with a focus on reducing environmental burdens. This LCI study provided useful data by examining the environmental impact of softwood lumber production in the NE/NC. In addition, these data can be interconnected into the scientific database managed by the National Renewable Energy Laboratory to complete a life-cycle analysis of softwood lumber-related wood products (NREL 2008).

LCI provides an accounting of the energy and waste associated with the creation of a product through use and disposal. In this study, the gate-to-gate LCI tracked softwood lumber production from softwood logs stored in the log yard to planed dry lumber. Life-cycle analysis (LCA) is a broader examination of the environmental and economic effects of a product at every stage of its existence, from harvesting to disposal and beyond. Such a cradle-to-grave assessment is beyond the scope of this study. In this LCI study, tracking the material flow of softwood lumber is needed for an accurate survey of the different unit processes.

Material flow is tracked from raw material—softwood logs—to planed (surfaced) dry lumber, the final product. Rough green (freshly cut) lumber sawn from softwood logs is typically dried in conventional dry kilns using wood and fossil fuels as heat sources. It is estimated that over 90% of all hardwood lumber

dried in the United States uses energy produced with wood residues from the milling processes (Denig et al. 2000). The percentage for softwood lumber is expected to be similar. The sawing process consumes the highest percentage of "electrical" energy. Prior to drying the lumber, the boards are stickered (separated by thin wood strips) and stacked to aid drying and prevent drying defects. The drying process consumes roughly 70% to 80% of the "total" energy required for producing softwood lumber (Comstock 1975). Total energy includes both electrical and thermal. The rough dry lumber is planed to required dimensions after drying is complete.

The goal of this study is to document the LCI of planed dry lumber production from softwood logs and determine material flow, energy use, and emissions for the softwood lumber manufacturing process on a per unit basis for the northeastern and north central United States (NE/NC) (Figure 1.1). Primary data were collected through questionnaires mailed to lumber mills; secondary data were collected from peer-reviewed literature per Consortium for Research on Renewable Industrial Material (CORRIM) guidelines (CORRIM 2001). Material and energy balances were calculated by use of a spreadsheet algorithm using data from primary and secondary data sources. Using these material and energy values, environmental impact was found by modeling the emissions through SimaPro 7 software (PRé Consultants, Amersfoort, The Netherlands) (PRé Consultants 2008a), which follows ISO 14040 protocols. SimaPro was used in previous CORRIM-initiated LCI projects: hardwood lumber (Bergman and Bowe 2008), softwood lumber (Milota et al. 2005), softwood plywood (Wilson and Sakimoto 2005), I-joist production (Wilson and Dancer 2005a), glue-laminated timbers (Puettmann and Wilson 2005), and laminated veneer lumber (Wilson and Dancer 2005b).

Figure 1.1 The shaded area was selected for life-cycle inventory of softwood lumber production in the NE/NC United States.

1.1 Annual Lumber Production

For the NE/NC region, annual softwood lumber production values for 2005 to 2007 are shown in Figure 1.2. Maine, Michigan, New Hampshire, Minnesota, and Wisconsin are the major softwood-lumber-producing states. Only 14 of 20 states in this region are represented because the other states did not report production for at least one of the three years investigated. The states that are omitted—Connecticut, Delaware, Illinois, Iowa, New Jersey, and Ohio—are estimated to produce a combined total annual softwood lumber volume of 30.7 thousand m^3 (13 million bf).

1.2 Mill Questionnaire

A mill questionnaire was developed from questionnaires used in other mill studies and adapted specifically to address the production of softwood lumber. A draft questionnaire was critically reviewed by a CORRIM representative. The questionnaire was split into two sections. Section 1 (Appendix A-1) of the questionnaire, entitled "Introduction and Questionnaire" and was sent to the mills; section 2 (Appendix A-2) was removed to keep the questionnaire simple. Section 2 had information describing the questionnaire but did not request primary mill data. By omitting section 2, we hoped to minimize confusion and increase the likelihood that mills would complete the questionnaire. Therefore, an edited version was mailed primarily to members of the Northeastern Lumber Manufacturer's Association (NeLMA). Mills from NeLMA were chosen because NeLMA members are representative of the softwood industry in the NE/NC region. The NeLMA president was supportive of the project and helpful in identifying participating mills. Six softwood lumber mills from four companies completed the questionnaire after several follow-up calls. Although the number of mills surveyed may be small (n = 6) compared with a "typical" mail survey, the level of detail and quantity of primary mill data for a CORRIM study is very high (Appendix A-1). Each mill contributed a substantial amount of time completing the questionnaire, ranging from 8 to 20 hours, with an average of 12 hours including the follow-up questions.

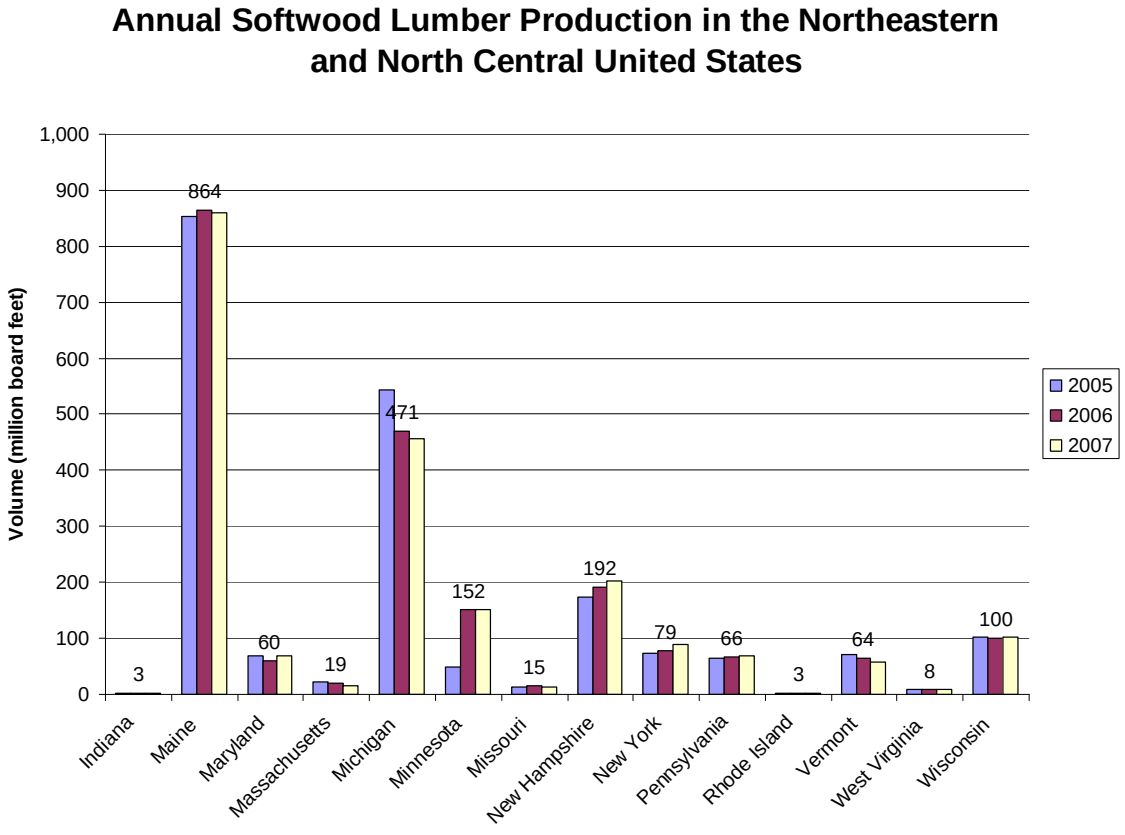

Figure 1.1 Annual softwood lumber production by State for the past 3 years (Source: USCB 2008.)

Material flow was given in oven-dried (OD) weight per cubic meter of planed dry lumber. As in previous CORRIM reports (Milota et al. 2004), data from the mill questionnaire were weight-averaged using

$$\overline{P}_{\text{weighted}} = \frac{\sum_{i=1}^{n} P_i x_i}{\sum_{i=1}^{n} x_i}$$

where $\overline{P}_{\text{weighted}}$ is the weighted average of the values reported by the mills, P_i is the reported mill value, and x_i is the fraction of the mill's value to total production for that specific value.

2.0 Unit Process Approach

2.1 Softwood Lumber Manufacturing and the Three Main Unit Processes

There are three main unit processes in producing softwood lumber—sawing, drying, and planing (Figure 2.1)—with energy generation as an auxiliary process. Production starts with softwood logs that are typically trucked to the sawmill and stored on the log yard until sawn. Logs may be stored dry or wet, depending on species and season. In the sawing process, incoming softwood logs (the raw material) are sawn into mostly 25- and 50-mm- (1- and 2-in.-) thick rough green (freshly cut) lumber of random widths and mostly 2.44-m (8-ft) lengths. Dimension sizes are nominal. The sawing process uses the most electrical energy of all unit processes. Once the rough green lumber is scaled (to measure production volume) and stickered for drying, the lumber is typically dried to 11% to 19% moisture content on a dry basis (MC_{DB}) using mostly energy-intensive drying methods such as kiln drying, although some air drying does occur. After drying, the rough dry lumber is planed to the dimension required for the final product. The energy generation process provides electricity and heat, primarily produced on-site for these three processes. Co-products are both sold and used for energy generation. In this LCI study, when referring to logs, lumber, and other co-products, the term green was used in the context of freshly cut material that is roughly 50% MC.

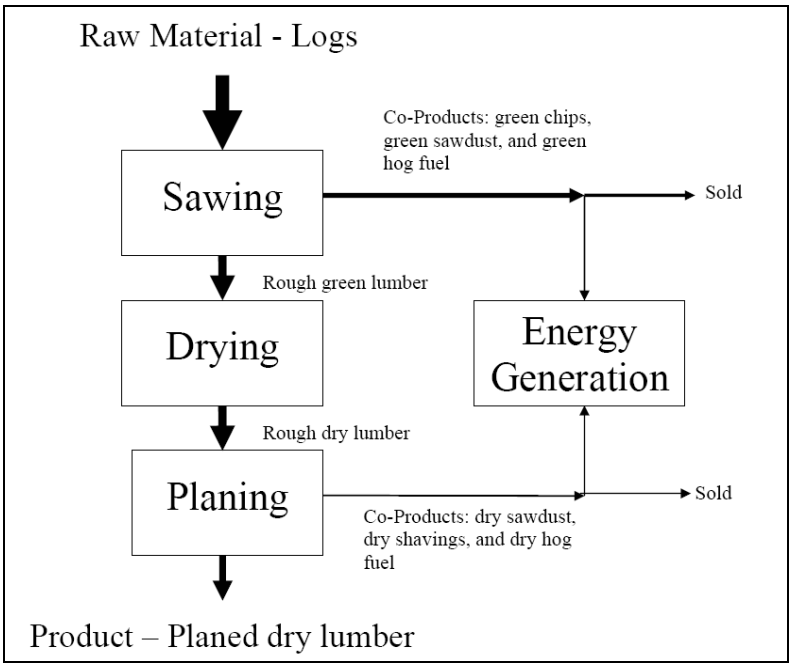

Figure 2.1 Material flow for the three unit processes of softwood lumber manufacturing.

2.1.1 Sawing.

This unit process begins with logs in the mill yard and includes the following operations:

- Sorting and storage of logs; storage wet or dry, depending on season and species
- In-yard transportation of logs from point of unloading to log deck storage
- In-yard transportation of logs from log deck storage to the sawmill infeed and debarker and log bucking saw
- Debarking of logs (by-product is bark) and merchandise long sawlogs into short sawlogs at bucking station (cutoff saw); produces some log trim ends
- Breakdown of logs (sawing) into rough green lumber and residues (bark, slabs, edgings, sawdust, and chips)
  - Slabs are sections of wood cut on circular or band head rigs from the outside portions of logs when opening up the log on each of four sides; slabs do not have square edges, and one face is waney (might have bark and is not flat).
  - Edgings are strips removed by a machine called an edger that produces a square-edged board from flitches (waney pieces of lumber).
  - Trim ends, slabs, and edging strips are processed at the chipper, producing clean (bark-free) pulp chips.
- Trimming, grading, and sorting
- Stacking, stickering, and in-yard transportation of rough lumber to kilns or planer facilities; may be dipped to prevent staining
- Sawfiling and maintenance of all sawmill equipment and yard transportation vehicles
- Treatment of process air, liquids, and solids

Outputs of this unit process are sawn rough green lumber and wood residues from the sawing process; bark, sawdust, slabs, edgings, and chips (hog fuel is a mixture of the wood residues produced). Most wood residues are sold, as a co-product; others, especially sawdust, are combusted as fuel, mostly to dry lumber. The remaining wood residues produce salable goods such as mulch (bark), pulp chips, feedstock for particle board plants.

2.1.2 Drying.

This unit process begins with rough green lumber and includes the following operations:

- Loading of stickered lumber into the following facilities, depending on species, season, and equipment
  - Air drying yards
  - Dry kilns
- Drying, equalizing, and conditioning of lumber within the kiln
- Maintenance of all kiln equipment and related yard transportation vehicles
- Treatment of process air, liquids, and solids
- Unloading and transportation of kiln-dried lumber to the planer mill

The output of this unit process is rough dry lumber, the majority transported by forklift to the planer mill. Drying generates most of the volatile organic compounds (VOCs) generated on-site and uses the most energy produced on-site from both wood and fossil fuel combustion. For the six mills surveyed, initial MC_{DB} was roughly 50% for rough green lumber and on average 16% for rough dry lumber. A lower than expected reported MC for rough green lumber was probably due to some air drying occurring prior to kiln drying. Different drying methods are used depending on species, lumber thickness, lumber grade, final

use, and available wood residue markets. A typical sawmill uses a kiln schedule when drying lumber to maintain high quality by preventing drying defects.

2.1.3 Planing.

This unit process begins with stickered, rough kiln-dried lumber and includes the following operations:

- Unstickering and/or unstacking of lumber
- Planing (surfacing) of lumber
- Trimming, grading, and sorting of lumber
- Stacking, strapping, and packaging of lumber
- Transportation of lumber within the planer mill and loading for shipping
- Maintenance of all planer equipment and associated yard transportation vehicles
- Treatment of process air, liquids, and solids

The output of this unit process is surfaced and packaged lumber, sorted by type, size, and grade as well as planer shavings, sawdust, and/or lumber trim ends. This process is the final stage of manufacturing. Some dry wood residue is burned on-site in the boilers for energy, whereas most is sold as co-products. Some planed lumber is only blanked or skip (hit or miss) planed. For instance, secondary manufacturers such as softwood moulding companies also plane a small portion of rough dry lumber. Furthermore, rough dry lumber is not precision end-trimmed.

2.1.4 Auxiliary energy generation.

This auxiliary process provides heat and in some cases electricity for use in other parts of the mill. A fuel such as wood or fuel oil is burned; green wood residue from the sawing process generates most of the thermal energy used at the plant. The thermal energy is typically in the form of steam that is used for the dry kilns and facility heating. A few mills operate cogeneration units. The second source of energy used on-site is off-site grid electricity. Also, emissions from grid electricity are released off-site. This process involves the following operations:

- Fuel handling
- Water added to the boiler (i.e., make-up water)
- Chemicals added at the boiler or to steam lines
- Distribution of steam
- Distribution of electricity
- Treatment of process air, liquids, and solids

Outputs of this auxiliary process are steam and hot water from boilers, combustion gases for drying, electricity from cogeneration units, and solid waste (wood ash), and air emissions (e.g., CO_2, CO) from combustion.

2.2 Functional Unit

Material flows, energy use, and emission data are standardized to a per unit volume basis for 1.0 m^3 of planed dry lumber, the final product of the softwood lumber manufacturing process. A typical conversion from cubic meters to thousand board feet (MBF) is 0.424 (2.36 m^3/MBF), which does not address differences between nominal and actual dimensions that are common in the lumber industry (USCB 2008). The value of 2.36 m^3/MBF is based on a board foot equaling 1 by 12 by 12 in. (25 by 300 by 300 mm). In this study, 1 m^3 of planed dry lumber equals 0.625 nominal MBF (1.60 m^3/MBF). The U.S. industry standard uses nominal dimensions, and commodity lumber is sold by variations of MBF. Rough green lumber and rough dry lumber are assumed to be 2.08 and 1.96 m^3/nominal MBF (FPL 1999a, Fonseca 2005, USDC 2005). Allocating all material and energy on a per unit basis of 1.0 m^3 planed dry

lumber standardizes the results to meet ISO protocols and can be used in other CORRIM studies, including LCA (ISO 2006a,b; CORRIM 2001).

2.3 System Boundaries

Boundary selection is important because the material and energy that cross this boundary must be accounted for (Figure 2.2) in the gate-to-gate life-cycle inventory. Two boundaries are defined by CORRIM (Wilson and Sakimoto 2005) and used to track the environmental impact of softwood lumber production. One is the total (cumulative) system boundary (solid line in Fig. 2.2), which includes both on-site and off-site emissions for all material and energy consumed. The site system boundary (dotted line in Fig 2.2) is the environmental impact for emissions developed just at the softwood sawmill (i.e., on-site) from the three unit processes. Examples of off-site emissions are grid electricity production, transportation of logs to the mill, and fuels produced off-site but used on-site.

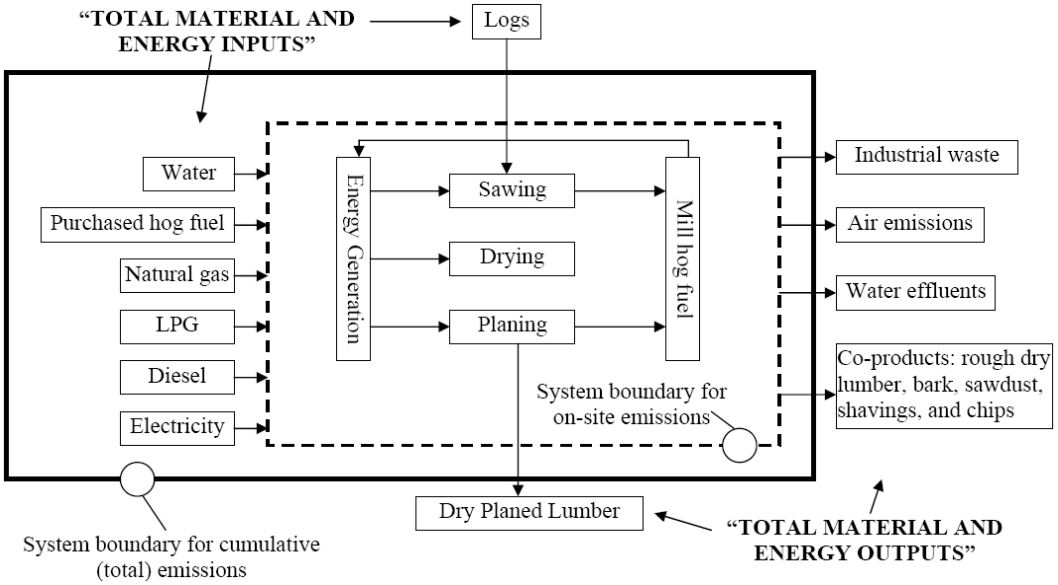

Figure 2.2 System boundaries for softwood lumber production.

2.4 Project Assumptions

One of two different methods of scaling logs are used by the mills: (1) International ¼ log rule, in which logs are stick scaled, and (2) weight scaling, in which the mass of logs is converted to log-scale board footage. The six mills surveyed gave log inputs in either MBF or tons, respectively. Common U.S. log rules estimate the green lumber board footage that might be sawn from a log, whereas lumber board foot tally provides the nominal green lumber volume produced from the log. Most other countries, including European countries, use a cubic log scale that measures the actual log volume (minus the bark).

In the NE/NC states that produce the most softwood lumber, the International ¼ rule is typically used. The accuracy of U.S. log rules varies with log diameter, taper, type of sawing method, type of products sawn, and sawing efficiencies. Due to inaccuracies of log rules, small-diameter logs typically recover more lumber for a given log than the log rule predicts in comparison with large-diameter logs. The volume difference between the log scale and board foot lumber tally is referred to as either overrun or underrun, depending on whether the lumber tally or the log scale is greater (if the lumber tally is greater, there is an overrun). In this study, a mill weight-averaged 26% overrun was estimated from scaling the incoming logs and the resultant rough green lumber tally. An average log conversion of 4.73 m^3/MBF was calculated based on a weight-averaged log diameter of 9.4 in. reported, with a range from 6.7 to 14 in., from the participating mills and assuming all lengths (Fonseca 2005). Also, a green log volume of 2.58 m^3 was calculated based on 931 OD kg of incoming wood volume on a per unit basis and a green specific gravity of 0.361.

Green and dry wood density and specific gravity values found in the *Wood Handbook* (FPL 1999a) for the five major wood species were used to determine the mass basis conversion from board feet. Weighted densities of 543 kg/m^3 (33.9 lb/ft^3) and 454 kg/m^3 (28.3 lb/ft^3) were used for green and kiln dry lumber, respectively. Also, a weight-averaged green density was calculated for verification using table 1.9 from the *Dry Kiln Operator's Manual* (Simpson 1991). Using initial lumber MC and species differentiation for lumber weight, a value of 585 kg/m^3 was interpolated.

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. Log mass was calculated based on the previous assumption of 4.73 m^3/MBF and an average green density of 543 kg/m^3. In this study, a 1% difference was calculated for the overall wood mass balance, falling within the CORRIM protocol. Additionally, a 2.3% difference was calculated before and after sawing and a 3.9% difference before and after planing.

Higher heating value (HHV) is 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), whereas lower heating value (LHV) ignores the energy produced by the combustion of hydrogen in fuel. HHV is the preferred method in the United States.

A standard check was conducted for energy use in the kiln drying of softwood lumber. This study considered energy used on-site that included drying lumber but also energy for plant heating and electrical co-generation. These sub-processes are typically not associated with values found in previous studies when calculating energy used in drying. Therefore, energy for plant heating and electrical co-generation were not included in the following energy checks:

1. Using initial MC_{DB} = 51%, final MC_{DB} = 16%, boiler efficiency of 66.7%, kiln efficiency of 50%, and 12.4 MJ of energy to remove 1% moisture from 1.0 m^3 rough green lumber (27,727 Btu for 1% moisture per MBF) based on literature values, a total of 2,120 MJ/m^3 (2.63 million Btu/MBF) planed dry lumber was calculated (Wengert 1980). An estimated value of 1,730 MJ/m^3 (1.83 million Btu/MBF) found from actual mill data resulted in a 15% difference between the literature and the actual values.

2. Energy use varied for the six mills drying lumber. Cogeneration and plant heating consumed 18% and 8% of the total process energy, respectively. Average technology was assumed with processes producing similar outputs in North America for modeling the environmental burden.

Primary data were collected through the questionnaire in accordance with ISO protocols and CORRIM research guidelines. Missing values were not weight-averaged for a particular process per ISO protocol to maintain data quality. Primary data indicated the species represented were eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa* ait.), jack pine (*Pinus banksiana*), eastern spruce (*Picea rubens*, *Picea marina*, and *Picea glauca*), and balsam fir (*Abies balsamea*). As shown in Table 2.1, these percentages varied notably from reported data, with both red and jack pine percentages lower and eastern white pine percentages higher compared with 2006 U.S. census figures (USCB 2008). This difference was probably due to surveying only six mills.

Table 2.1 Species softwood lumber production for the NE/NC United States compared with LCI survey data

		Lumber production (%)	
	Species	**U.S. Census Bureau[1]**	**LCI survey data (*n* = 6)**
1	Eastern white pine	34.9	45.6
2	Eastern spruce/balsam fir	32.0	31.8
3	Red and jack pine	33.1	22.6
	Total	**100**	**100**

[1] USCB (2008).

Logging transportation data assumed the same number of fully loaded trucks as empty trucks because logging trucks are usually built for hauling logs, not for hauling either lumber or wood residue. Each logging truck hauled roughly 5,500 bf softwood logs or 27.5 tons (5 tons logs per MBF lumber). One mill did not report logging transportation data and was not included. Logging trucks were assumed to be empty upon return to the logging site.

Purchased wood fuel transportation data was from three mills that burned 98% of the total purchased wood fuel trucked to the mills. Two mills did not use purchased wood fuel. The other mill that burned purchased wood fuel did not report transportation data and was omitted.

Water used on-site typically was ground water, typically wells, and primarily used for sprinkling logs and for make-up boiler water. Three mills did not report water consumption and were not weight-averaged.

All bark produced was assumed to be sold off-site as mulch. Bark was not given an allocation for an environmental burden in SimaPro, per CORRIM research guidelines (CORRIM 2001). Allocation refers to the distribution of environmental burden.

The LCI study covered one full year during the period 2006 and 2007 and depended on when an operational (fiscal) year started at each company. The geographical area covered the NE/NC region shown in Figure 1.1.

2.5 Modeling Software Selection

Modeling software was needed to generate air, water, and land emission data from the weight-averaged results of material flow and energy use and type for softwood lumber manufacturing in a systematic and transparent way. Because the LCI practitioner adhered to the basic four steps of life-cycle research—goal and scope definition, inventory analysis, impact analysis, and interpretation—the software also needed to follow the ISO 14040 protocols related to environmental management. SimaPro was the modeling software selected, and SimaPro training was completed in December 2004.

SimaPro 7 follows the ISO 14040 standards for environmental management and documentation. Other software programs for life-cycle analysis were considered, but SimaPro is the preferred software by CORRIM and was used in Phase I of the other life-cycle inventory projects sponsored by CORRIM. Phase I projects dealt mostly with forest resources and residential construction in the U.S. Pacific Northwest and Southeast. SimaPro 7 was developed in the Netherlands and has an installed Franklin Associate (FAL) database that uses North America production data. The FAL database tracked energy use and material flow in this study (FAL 2003a,b).

SimaPro allowed the use of the unit process approach in this LCI project that is more rigorous and transparent than the simple system process approach. This transparency allows the tracking of all

individual unit processes. SimaPro contains a database for a large number of processes such as boilers (energy generation), grid electricity, and transport fuels. The database is broken into three main sections: project data, library data, and general data. In this study, the project data section is where all new LCI data were entered. Library data were the sources for an individual project, and the Franklin Associate (FAL) database library was selected for this LCI. The last section (general data) contained common data such as substance data and unit conversion factors (PRé Consultants 2008b).

2.6 Material Properties

2.6.1 Lumber size production.

Primary mill data were provided based on rough green lumber dimensions as shown in Table 2.2. Over half the total surveyed production was from 1×6, 1×8, 2×4, and 2×6 lumber.

Table 2.2 Rough green lumber production

English units (in.)	SI units (mm)	Volume (MBF)	Volume[a] (m^3)	Proportion of total production (%)
1 × 4	25 × 100	17,196	35,698	6.7
1 × 6	25 × 150	29,204	60,625	11.4
1 × 8	25 × 200	30,477	63,267	11.9
1 × 10	25 × 250	12,509	25,968	4.9
2 × 4	50 × 100	37,744	78,354	14.8
2 × 6	50 × 150	36,390	75,543	14.3
2 × 8	50 × 200	13,538	28,104	5.3
2 × 10	50 × 250	5,369	11,146	2.1
4 × 4	100 × 100	23,049	47,848	9.0
4 × 6	100 × 150	5,220	10,836	2.0
6 × 6	150 × 150	6,960	14,448	2.7
1 × 12	25 × 300	25,824	53,609	10.1
1 × 5	25 × 125	4,022	8,348	1.6
1 × 7	25 × 175	248	514	0.1
5.5 × 5.5	138 × 138	2,320	4,816	0.9
5.5 × 7.5	138 × 188	1,740	3,612	0.7
5 × 5	125 × 125	1,160	2,408	0.5
5/4 × 8	31 × 200	734	1,524	0.3
3 × 4	75 × 100	89	185	0.0
2 × 3	50 × 75	1,573	3,265	0.6
TOTAL		**255,365**	**530,118**	**100**

[a] *Lumber conversion of 2.08 m^3/MBF rough green lumber.*

2.6.2 Wood species composition.

A number of commercial softwood species are sawn in the NE/NC region Often, several species within one species group are averaged together to find specific gravity and densities; eastern spruce has three such species: red, white, and black. Table 2.1 shows the breakdown of primary mill data compared with U.S. Census Bureau data for the 20 individual states reported as an aggregate for the entire NE/NC region.

2.6.3 Wood density and specific gravity.

Rough green lumber.

In Table 2.3, a weighted-averaged green specific gravity of 0.36 was calculated based on the species distribution percentages determined from primary mill data and each individual species' specific gravity

from secondary data found in *Softwoods of North America* (Alden 1997). Using initial MC_{DB} = 51% and a weighted-averaged green specific gravity of 0.36, a density of 543 kg/m^3 was estimated for rough green lumber using table 3-7a in the *Wood Handbook* (FPL 1999a).

Table 2.3 Physical data for species sawn in the NE/NC United States

			Specific gravity[a]	
	Species	**Distribution (%)**	**Green volume[b]**	**12% MC volume**
1	Eastern white pine	45.6%	0.34	0.35
2	Eastern spruce (mix)	26.7%	0.36	0.39
3	Balsam fir	5.1%	0.33	0.35
4	Red pine	20.6%	0.41	0.46
5	Jack pine	2.0%	0.40	0.43
Weighted average		100%	0.36	0.39

[a] *Moisture content is on dry basis.*
[b] *Freshly cut wood (no drying).*

Rough and planed dry lumber.
In Table 2.3, a weighted-averaged 12% MC specific gravity of 0.39 was calculated based on the species distribution percentages determined from primary mill data and each individual species' specific gravity from secondary data found in Softwoods of North America (Alden 1997). Using a final MC of 16% and a weighted-averaged 12% MC specific gravity of 0.39, a density of 454 kg/m3 was estimated for rough and planed dry lumber using table 3-7a in the Wood Handbook (FPL 1999a).

2.6.4 Wood fuel.

Types.
Distinguishing between different wood fuels is necessary when entering wood fuel values into SimaPro 7. SimaPro lists three types of wood fuels used in this project, distinguished primarily based on energy and material inputs required to process, emissions produced during combustion, and if the fuel is as found in nature (the forest):

- *Wood boiler fuel* is listed as a raw material; it is also found in nature and therefore has no processing or combustion values assigned to it.
- *Wood FAL* is listed as a process and is found in the Material/Wood section. The process data given are for the cradle-to-gate resource requirements and emissions for providing 1,000 lb of wood (4.5 million Btu in 1996) at 50% moisture content on a wet basis (MC_{WB}) to industrial boilers. "Note that these boilers operate at paper mills and generally burn waste wood/wood scraps, and nearly all of the pre-combustion burdens associated with getting this wood to the mill have been assigned to the wood inputs to paper production" (PRé Consultants 2008a).
- *Wood into industrial boilers* is listed as a process and is found in the Energy/Heat/Wood section. The process given is for the cradle-to-gate resource requirements and emissions for the combustion of 1,000 lb of wood (4.5 million Btu in 1996) at 50% MC_{WB} (100% MC_{DB}) in industrial boilers.

Wood fuel used at the surveyed mills is either produced on-site or purchased off-site. These required two new types of categories using both "Wood into industrial boiler" and "Wood FAL" processes. First, we created a new category for purchased wood fuel. In SimaPro 7, the default wood fuel input into the technosphere for the "Wood into industrial boiler" is "Wood FAL." A new category—"Wood FAL, Softwood, NE/NC, USA, U"—was created for this study as an input of purchased wood fuel. This first category accounts for the cradle-to-gate resource requirements and emissions to provide purchased wood fuel to the mill gate.

The following category is for wood fuel purchased off-site and then combusted on-site because both the required energy and any necessary material used to bring the wood fuel from nature (the forest) to the mill gate and the emissions released during this process must be accounted for. Also, the cradle-to-gate resource requirements to combust this material and emissions released during combustion has been already accounted for in the program. The second new category is "Wood into industrial boilers (purchased), Softwood, green and kiln dried, NE/NC, USA, U." The first new category ("Wood FAL, Softwood, NE/NC, USA, U") is an input to this second new category.

Wood fuel generated on-site needs only values assigned to it as cradle-to-gate resource requirements and as emissions related to the combustion of this material—not the wood fuel itself—because the softwood lumber LCI already accounts for cradle-to-gate resource requirements and emissions for transporting the wood fuel to the boiler through the incoming logs. This is the main difference between generated on-site and purchased wood fuel. The third new category is "Wood into industrial boilers (generated on-site), Softwood, green and kiln-dried, NE/NC, USA, U." Green and kiln-dried wood residue produced on-site and burned for fuel in this boiler uses the nomenclature "Wood Fuel, Softwood, green, NE/NC, USA, U" and "Wood Fuel, Softwood, kiln-dried, NE/NC, USA, U," respectively.

Moisture content

Wood FAL and Wood into industrial boilers are based on average U.S. technology in the late 1990s (FAL 2003a,b) and uses green wood at 50% MCWB. In accordance with CORRIM guidelines, wood fuel values were entered into SimaPro using OD weights with proper documentation of how this conversion was done for easier tracking. SimaPro emission data was given in SI units.

2.6.5 Wood residues.

Green residue

Four mills used water sprinklers and one mill used pond storage to keep logs from staining. Sprinkling usually affects only the MC of the bark, which can easily reach 60% to 70% and higher on a wet basis. Bark is not typically used as wood fuel for most mills and is less than 0.15% of total wood fuel consumed on-site. The MC of bark is also not monitored or reported because it is an end product that is typically mulched and sold by either the ton or cubic yard.

Physical properties and moisture content for green wood residues used in calculations are listed in Table 2.4. Green chips were the greatest proportion of green wood residue at 32.2% by weight of the total log.

Table 2.4 Physical properties of green wood residues

	Co-product MC (wet basis) (%)	Weight percent		Volume percent	
		Total log	Total log (minus bark)	Total log (minus bark)[1]	Total log (minus bark)[2]
Green chips	52.0	32.2	36.5	35.1	32.0
Green sawdust	51.8	8.1	9.3	7.2	12.4
Green bark	49.1	11.9	—	—	—
Green hog fuel	30.0	0.3	0.4	—	—
Green lumber	—	47.5	53.8	57.7	55.7
Total		100.0	100.0	100.0	100.0

[a] Fonseca (2005). (Table 6.1 Stud; added shavings to lumber and adjusted for 3% shrinkage.)

[b] Fonseca (2005). (Table 6.1 Board; added shavings to lumber and adjusted for 3% shrinkage.)

Dry (liln dry) residue.
The planing process produces two types of kiln dry residue: shavings and lumber trim ends used as hog fuel. Their MC and other physical properties are listed in Table 2.5. Dry hog fuel is a combination of kiln-dried wood residues not defined by the mill, such as cutoffs, cutbacks, edgings, and broken pieces. The term is used to prevent confusion with hogged material, which most assume is green.

Table 2.5 Physical properties of dry wood residues

	Co-product MC (wet basis) (%)	Weight percent
Dry shavings	13.5	18.9
Dry hog fuel (trim ends)	9.9	2.0
Planed (surfaced) dry lumber	15.8	79.1
Total		**100.0**

2.6.6 Lumber volume conversion factors.

The purpose of developing conversion factors is to derive material and energy use based on 1.0 m^3 of planed dry lumber because dimensions vary when the lumber is processed. The different sizes of material from the sawmill, dryer, and planer were estimated based on primary mill data regarding lumber thicknesses and verified by data from the *Wood Handbook* (FPL 1999a). A rough green lumber conversion factor was determined at 2.08 m^3/MBF. Actual board length was used in the calculation to determine exact volume, therefore trimming was a factor in the conversion for planed dry lumber. The ratios show that for 1.0 m^3 of planed dry lumber, 1.30 m^3 of rough green lumber and 1.23 m^3 of rough dry lumber were used. These numbers indicate that shrinkage from rough green lumber is a factor and that material loss from planing rough dry lumber is roughly 20%. Conversion factors of 1.96 and 1.60 m^3/MBF were also calculated for rough dry and planed dry lumber from lumber thickness primary mill data. A value of 1.64 m^3/MBF was also calculated based on lumber dimensions and distribution shown in Table 2.2.

For example, wood fuel consumption was based on the actual rough green lumber entering and rough dry lumber exiting the drying process. After the wood fuel values were found for drying based on the rough dry lumber produced on a board foot basis, the energy values were then converted to a per unit basis of planed dry lumber basis using values given above.

3.0 Product Yields

Mass and energy values, including emissions for softwood lumber production, were obtained by surveying six mills in the NE/NC United States that provided detailed data on mass flow and energy consumption and type. Survey data were modeled in SimaPro 7 to find non-wood raw material use and emission data. Inputted LCI data are provided in Appendix B.

All energy and material values were weight averaged from six mills across the NE/NC United States. For the six mills, 531 thousand m^3 (256 million bf^3) rough green lumber were produced on an annual basis for either 2006 or 2007. This value is roughly 12% of the total annual 2006 U.S. production from this region estimated at 4.37 million m^3 (2.1 billion bf^1) (USCB 2008). This 12% value exceeded the minimum CORRIM protocol guideline for data representation (CORRIM 2001). Also, 486 thousand m^3

[3] 2.08 m^3/MBF rough green lumber

(248 million bf[4]) and 365 thousand m^3 (229 million bf[5]) of rough dry lumber and planed dry lumber, respectively, were produced. Not all sawn lumber was planed prior to shipping.

Weight-average annual production for the softwood sawmills was 110 thousand m^3 (52.9 million bf[2]) with a range of 46.8 to 169 thousand m^3 (22.5 to 81.2 million bf). A large production hardwood lumber mill is considered 30.8 thousand m^3 (12 million bf[6]) or more (Bergman and Bowe 2008). Regarding mill participation, it was important that the NeLMA supported the project so that sufficient production data could be obtained to meet the minimum CORRIM requirement of 5% of total production in the NE/NC region.

Weight-averaged mill features were a log diameter of 239 mm (9.4 in.), with a range of 170 to 356 mm (6.7 to 14.0 in.) and production kiln capacity of 1.42 thousand m^3 (600 thousand bf[7]), with a range of 0.909 to 2.12 thousand m^3 (385 to 900 thousand bf). Also, pulp chips were the largest proportion of wood residue produced at 348 OD kg/m^3 planed dry lumber (Table 3.1). The species sawn were eastern white pine (roughly half), red and jack pine, spruce, and balsam fir.

For the mass balance, the LCI study examined the three main unit processes and the overall process to track material flow. Using a weight-averaged approach, 931 OD kg (2,050 OD lb) of incoming softwood logs with a density of 543 kg/m^3 (33.9 lb/ft^3) produced 1.0 m^3 (625 nominal bf) of planed dry lumber. Sawing produced 494 kg of rough green lumber; the drying process did not result in any loss of wood substance. Planing reduced the 494 OD kg of rough dry lumber to 392 OD kg of planed dry lumber, for roughly 20% reduction in mass. Boilers burned 68 OD kg of both green and dry wood fuel produced on-site (Table 3.1). Overall, an average log was reduced to 42.1% of its original mass in conversion to the final product of planed dry lumber. A percentage difference of 1% was calculated based on the overall mass balance that included intermediate products such as rough green and rough dry lumber. Appendix C-1 and C-2 provide flowcharts showing weight-averaged material flow including co-products (excluding intermediate products) and showing an overall wood balance including intermediate products.

Table 3.1 Weight-averaged wood mass balance for 1.0 m3 of planed dry lumber (values in ovendry kilograms)

	Sawing process		Boiler process input	Drying process		Planer process		All processes combined		
Material	**Input**	**Output**		**Input**	**Output**	**Input**	**Output**	**Input**	**Output**	**Diff**
Green logs	931							931	0	–931
Green chips		348						0	348	348
Green sawdust		84	42					42	84	42
Green bark[a]	127	127						127	127	0
Green hog fuel		3	3					3	3	0
Rough green lumber		496		496				496	496	0
Rough dry lumber					496	496		496	496	0
Planed dry lumber							392	0	392	392
Dry shavings			13				94	13	94	81
Dry mixings			10				19	10	10	0
Sum	**1,058**	**1,058**	**68**	**496**	**496**	**496**	**484**	**2,118**	**2,050**	**–68**

[a] Bark volume is not included in log scale.

[4] 1.96 m^3/MBF rough dry lumber
[5] 1.60 m^3/MBF planed dry lumber
[6] 2.57 m^3/MBF rough green hardwood lumber (Bergman and Bowe 2008)
[7] 2.36 m^3/MBF

Most mills in the United States use volumetric values such as board feet log scale to purchase and a lumber tally for selling and therefore need to track log breakdown to find mill efficiency. The lumber recovery factor (LRF) is one way to track the log breakdown. LRF quantifies productivity as the nominal board feet lumber tally recovered per cubic foot of log inputs. In the NE/NC region of the United States, 2.58 m^3 (91.1 ft^3) of softwood logs are sawn, dried, and planed into the final product of 1.0 m^3 (625 nominal bf) of planed dry lumber, for a total volume conversion of 38.8% of incoming logs (Table 3.2). A comparison value of 146 ft^3/MBF planed green lumber was also calculated, therefore the weight-averaged LRF was 6.9 bf. The difference for total volume and total mass conversion was due to lumber shrinkage during the drying process (Table 3.3).

Table 3.2 Volume conversion of incoming logs to 1.0 cubic meter of planed dry lumber

	Wood volume (actual dimensions)[a]		
	(m^3/m^3)	**(ft^3/MBF)[b]**	**(%)**
Raw wood material			
Incoming green log	2.58	146	100
Intermediate products			
Rough green lumber	1.30	73.6	50.4
Rough dried lumber	1.23	69.6	47.7
Final product			
Planed dried lumber	1.00	56.6	38.8

[a] All values provided in actual dimensions.
[b] 1.60 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber.

Table 3.3 Mass conversion of incoming logs to 1.0 m3 of planed dry lumber

	SI units		English units	
Material	In	Out	In	Out
Logs[a]	2.58 m^3		146 ft^3	
Green chips, sold		348 kg		1,228 lb
Green sawdust, sold		42.5 kg		150 lb
Green sawdust, fuel		41.6 kg		147 lb
Green hog fuel		2.8 kg		9.8 lb
Bark, mulch		127 kg		448 lb
Rough green lumber		1.30 m^3		1 MBF (2.08 m^3)
Rough dry lumber		1.23 m^3		1 MBF (1.96 m^3)
Dry shavings, sold		80.6 kg		284 lb
Dry shavings, fuel		12.8 kg		45 lb
Dry hog fuel		10.0 kg		35 lb
Planed dry lumber		1.0 m^3		1 MBF (1.60 m^3)

[a] Bark not included in green log volume.

4.0 Energy Consumption

4.1 Electrical Use

Softwood lumber production requires both electrical and thermal energy for processing logs into planed dry lumber. All the thermal energy is produced on-site, whereas most electricity is produced off-site from a regional power grid. Electrical energy is required by all three unit processes, whereas most of the

thermal energy is required for the drying process. All mills reported their electrical usage. Total electrical consumption was 355 MJ/m^3 (158 kWh/MBF) of planed dry lumber. Of this total 2,730 MJ of embodied energy consumed per cubic meter planed dry lumber, 2,020 MJ was for drying; 488 MJ for on-site electrical generation (co-generation); and 224 MJ for plant heat. This includes both off-site and on-site electrical sources (Table 4.1).

Table 4.1 Material and energy consumed on-site to produce 1.0 m3 of planed dry lumber (SimaPro input values)

	Quantity	
Fuel type	**(units/m^3)**	**(units/MBF[e])**
Fossil fuel[a]		
Fuel oil #1	0.04 L	0.02 gal
Fuel oil #2	8.91 L	3.76 gal
Electricity[b]		
Off-site generation	304 MJ	135 kWh
On-site generation	51 MJ	23 kWh
On-site transportation fuel[c]		
Off-road diesel	2.04 L	0.86 gal
Gasoline	0.038 L	0.016 gal
Renewable fuel[d]		
On-site wood Fuel	68.1 kg	240 lb
Purchased wood fuel	45.8 kg	161 lb
Water use		
Surface water	811 L	343 gal
Ground water	172 L	73 gal

[a] Energy values were determined using their higher heating values (HHV) in MJ/kg: 43.3 for fuel oil #1 and #2.
[b] Conversion unit for electricity is 3.6 MJ/kWh.
[c] Energy values were determined using their higher heating values (HHV) in MJ/kg: 45.5 for off-road diesel and 54.4 for gasoline.
[d] Values given in oven-dry weights (20.9 MJ/OD kg)
[e] 1.60 actual m^3 per 1.0 nominal MBF planed dry lumber.

4.2 Electrical Energy Composition for Unit Processes

For the unit processes, sawing, drying, and planing, the distribution of electrical energy consumption was 54.7%, 25.5%, and 19.8% of the total, respectively. Based on these percentages, the three unit processes use 194, 90.5, and 70.4 MJ/m^3, or 86.2, 40.2, and 31.3 kWh/MBF planed dry lumber, respectively. Wood-fuel cogeneration provides 14.3% of total electricity consumed.

4.3 Sources of Energy

4.3.1 Major sources

The process energy required for drying and other associated drying processes (including cogeneration) and facility heating is based on fuel consumption with the major source being wood fuel produced on-site from the sawing process. A portion of wood fuel produced on-site, 68.1 OD kg, and some purchased wood fuel, 45.8 OD kg, is combusted to generate heat for the mill per 1.0 m^3 planed dry lumber. Thermal energy produced on-site is the largest proportion of energy used on-site. Overall, wood fuel was 87% of total energy consumed on-site, with the other major contributor being fuel oil at 13%, mostly fuel oil #2. Grid electricity is a major factor in determining environmental impact, and this electricity was produced off-site (beyond the mill's boundary) for use on-site in the manufacturing process. Coal was the largest

fuel source for grid electricity—most grid electricity is generated from coal power plants in the NE/NC United States.

4.3.2 On-site transportation fuel

On-site transportation of wood stock is a major fuel consumer, with off-road diesel having the highest consumption. On-site transportation includes forklifts, front-end loaders, trucks, and other equipment used within the system boundary of the facility. Off-road diesel consumption is 2.04 L/m^3 of planed dry lumber and is consumed at roughly 60 times the rate of propane and gasoline combined, on average. Transportation fuel consumption for the unit processes is 60%, 20%, and 20% for sawing, drying, and planing, respectively. Corresponding values of the three unit processes for off-road diesel are 1.22, 0.41, and 0.41 L; for gasoline, 0.0228, 0.0076, and 0.0076 L, respectively.

4.3.3 Off-site electricity

The location of the softwood lumber facility affects the environmental impact because most electricity used is from the electric power industry. Average composition of (off-site) electrical generation was found for the NE/NC region by totaling the amount of different fuel sources for each of the 20 states given in thousand kilowatt hours and calculating the percentages (USDOE 2007). The most significant electric power contributor in the NE/NC region is coal, with 58.5% of total electrical utility power being provided by this fuel source. Other fuel sources are nuclear, natural gas, petroleum, hydro, and other renewables, which provide 24.9%, 11.0%, 1.2%, 2.5%, and 1.9%, respectively (Appendix D-1). These results compare well with 2005 data found by Bergman and Bowe (2008).

4.4 Water Consumption

Water use was mainly for sprinkling logs, dust control, and boiler make-up water. Water consumption was based on responses from three mills, with one mill using over 90% of total reported consumption mostly for sprinkling logs, and that is 100% recycled. Dust control is a problem for several mills having air yards surfaced with gravel ,especially during the dry season. Some mills are actively examining alternative methods. A surface and ground water consumption of 811 and 172 L/m^3 (343 and 73 gal/MBF) of planed dry lumber was calculated, respectively.

4.5 Transportation Distance

4.5.1 Logs

Logging transportation data were required to connect the forest resource LCI to the softwood lumber LCI. An average one-way haul distance for softwood log (including bark) transportation of 109 km (67.7 miles) with 100% empty backhaul was calculated from primary mill data. Mill average log MC was 49.1% wet basis (96.5% MC dry basis).

4.5.2 Purchased wood fuel

Most purchased wood fuel was brought to mills for heating the facilities during the winter months and for operating a cogeneration unit. A cogeneration unit provides both thermal and electrical energy for use on-site. An average one-way haul distance for purchased wood fuel transportation of 58.8 km (36.5 miles) with 100% empty backhaul was calculated from primary mill data. Mill average purchased wood fuel MC was 44.5% wet basis (80.2% MC dry basis)

5.0 Environmental Impact

SimaPro 7 modeled output factors during the manufacturing process with major consumption for raw materials, other than wood, for electrical generation. Major uses of raw material, other than logs processed into lumber, were purchased wood fuel (waste), coal, crude oil, and limestone, with allocated values of 32.7, 15.3, 8.52, and 4.93 kg, respectively. A wood volume of 1.23 m^3 entered the planing process to produce 1.0 m^3 planed dry lumber (Table 5.1). Limestone and most of the coal were used to produce off-site electricity, and oil was for both off-site electricity and thermal energy used on-site. Limestone is used to remove sulfur dioxide produced from burning coal. The region selected for production affects the environmental impact of softwood lumber production because coal is the primary off-site material used for electrical power production in the NE/NC, whereas most power in the Pacific Northwest is produced from hydro and natural gas.

Table 5.1 Raw materials consumed during production of planed (surfaced) dry lumber—cumulative, allocated gate-to-gate LCI values (SimaPro output values)

	Quantity[b]	
Raw material[a]	**(units/m^3)**	**(units/MBF)[c]**
Logs at mill gate[d]	1.23 m^3	69.2 ft^3
Water, well, in ground[e]	0.072 m^3	4.09 ft^3
Water, process and cooling, surface[e]	0.341 m^3	19.3 ft^3
Purchased wood waste	32.7 kg	115 lb
Coal, in ground[e]	15.3 kg	54.1 lb
Gas, natural, in ground[e]	2.08 kg	7.34 lb
Oil, crude, in ground[e]	8.52 kg	30.0 lb
Limestone, in ground[e]	4.93 kg	17.4 lb
Energy, from hydro power[f]	4.74 MJ	2.11 kWh
Energy, unspecified[f]	3.28 MJ	1.46 kWh
Uranium, in ground[e]	0.000425 kg	0.00151 lb

[a] Values are allocated and cumulative.
[b] Energy values were found using their higher heating values (HHV) in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.
[c] 1.60 m^3 per 1.0 nominal MBF.
[d] Amount of wood in lumber form entering the planing process; no shrinkage taken into account from drying process.
[e] Materials as they exist in nature and have neither emissions nor energy consumption associated with them.
[f] Conversion for units of electricity is 3.6 MJ/kWh.

Two different life-cycle inventory scenarios for manufacturing softwood lumber were evaluated based on the six mills surveyed: allocated cumulative and allocated on-site. The allocated accumulative scheme examined all emissions for electricity and thermal energy generation that were required to produce 1.0 m^3 of planed dry lumber starting with softwood logs at the mill gate. These emissions involve the cradle-to-gate resource requirements (production and delivery) of grid electricity, fossil fuels, and purchased wood fuel used in the boiler, and fossil fuels used in yard equipment such as forklifts. Also, emission data for on-site combustions of the two latter materials and wood fuel generated on-site were included. Transportation of logs (including bark) to the mill gate was not included in either scenario. The allocated on-site scheme only includes emissions from the combustion of all fuels used at the mill, therefore it did not involve the manufacturing and delivery of material and electricity consumed at the mill.

Table 5.2 shows the lower environmental impact of on-site compared to accumulative emissions for the six mills surveyed. Carbon dioxide and particulates are typically measured although other emissions are

frequently monitored from boilers to ensure regulatory compliance. Carbon dioxide (CO_2) emissions are separated by two fuel sources, biogenic (biomass-derived) and anthropogenic (fossil-fuel-derived). Biogenic CO_2 is carbon neutral because the CO_2 emitted is reabsorbed during the growth of the tree and released upon the decomposition or burning of the tree. Accumulative total emission values of 187 and 65.1 kg were reported from SimaPro for CO_2 (biogenic) and CO_2 (anthropogenic), respectively (Table 5.2). The percentage of biogenic CO_2 to total CO_2 increased from 74.1% to 88.1% from the total to on-site schemes. Volatile organic compound (VOC) gases produced from drying lumber generated the value of 0.652 kg regardless of scenario. An overall value of 0.752 kg/m^3 rough green lumber was calculated from literature (Rice and Erich 2006, Rice 2008).

Table 5.2 Life-cycle inventory results for total emissions on a per unit basis of planed dry lumber

	Allocated total		Allocated on-site	
Substance	(kg/m^3)	(lb/MBF)[a]	(kg/m^3)	(lb/MBF)[a]
Water emissions				
Biological oxygen demand (BOD)	2.35E-04	8.28E-04	—	—
Cl^-	5.74E-03	2.02E-02	1.09E-06	3.853E-06
Suspended solids	2.58E-02	9.10E-02	2.09E-04	7.37E-04
Oils	2.42E-03	8.52E-03	—	—
Dissolved solids	1.30E-01	4.59E-01	—	—
Chemical oxygen demand (COD)	2.25E-03	7.93E-03	—	—
Soil emissions				
Waste in inert landfill	0.22	0.77	0.22	0.78
Waste to recycling	0.018	0.062	0.018	0.062
Solid waste	15.2	53.4	8.00	28.2
Air emissions				
Acetaldehyde	2.67E-04	9.39E-04	2.67E-04	9.39E-04
Acrolein	5.48E-07	1.93E-06	—	—
Benzene	3.20E-04	1.13E-03	3.20E-04	1.13E-03
CO	1.27	4.47	1.24	4.36
CO_2 (biomass)	187	658	187	658
CO_2 (fossil)	65.1	230	25.1	88.6
CH_4	8.62E-02	3.04E-01	7.60E-05	2.68E-04
Formaldehyde	1.60E-03	5.63E-03	1.59E-03	5.62E-03
Mercury	1.28E-06	4.50E-06	3.35E-07	1.18E-06
Non-methane, volatile organic compounds (NMVOC)	4.02E-01	1.42E+00	2.19E-01	7.71E-01
NOx	7.98E-02	2.81E-01	5.95E-03	2.10E-02
Particulate (PM10)	2.91E-02	1.03E-01	2.15E-02	7.57E-02
Particulate (unspecified)	4.01E-02	1.41E-01	—	—
Phenol	3.55E-03	1.25E-02	3.55E-03	1.25E-02
SOx	3.62E-01	1.28E+00	5.65E-02	1.99E-01
VOC	6.52E-01	2.30E+00	6.52E-01	2.30E+00

[a] 1.60 m^3 per 1.0 nominal MBF planed dry lumber.

6.0 Carbon Balance

Carbon emissions are playing an increasingly important role in policy decision making in the United States and throughout the world. The impact of carbon was determined by estimating values of carbon found in wood and bark as described from previous studies, such as Skog and Nicholson (1998), using a mixture of softwood roundwood values for the NE/NC United States. We used a mixed softwood factor

of 197.8 kg/m^3 of wood material and a carbon content of 51.1% with an incoming log wood mass of 931 OD kg/m^3 planed dry lumber to calculate the carbon balance. Total carbon input and output of 543 and 549 kg/m^3 planed dry lumber were found (Table 6.1) resulting in a difference of 1.1%. Contribution to the carbon balance from air emissions are shown in Table 6.2.

Table 6.1 Tracking of wood-based carbon inputs and outputs

	Elemental carbon	
Substance[a]	(kg/m$^{3)}$	(lb/MBF)[b]
Input		
Logs	432	1,520
Bark	59	186
Wood Fuel	55	186
Sum carbon in	543	1,913
Output		
Planed dry lumber	182	640
Co-product[c]	308	1,087
Solid emissions	7	24
Air emissions	52	184
Sum carbon out	549	1,935

[a] Wood-related carbon and its emissions
[b] 1.60 m^3 per nominal MBF planed dry lumber
[c] Bark leaves the system as a co-product (mulch)

Table 6.2 Composition of wood-based air emissions related to carbon contribution

	Total[a]		**Carbon[a]**		
Substance	**(kg/m^3)**	**(lb/MBF)[b]**	**(%)[c]**	**(kg/m^3)**	**(lb/MBF)[b]**
Benzene	3.20E-04	1.13E-03	92.3	2.96E-04	1.04E-03
Carbon dioxide, biogenic	1.87E+02	6.58E+02	27.3	5.09E+01	1.79E+02
Carbon monoxide	1.27E+00	4.47E+00	42.9	5.43E-01	1.91E+00
Formaldehyde	1.60E-03	5.63E-03	40.0	6.39E-04	2.25E-03
Methane	8.62E-02	3.04E-01	75.0	6.46E-02	2.28E-01
Naphthalene	2.13E-04	7.52E-04	93.7	2.00E-04	7.04E-04
NMVOC, non-methane volatile organic compounds, unspecified origin	7.98E-02	2.81E-01	88.2	7.04E-02	2.48E-01
Organic substances, unspecified	1.52E-02	5.36E-02	50.0	7.60E-03	2.68E-02
Phenol	3.55E-03	1.25E-02	76.6	2.72E-03	9.60E-03
VOC, volatile organic compounds	6.52E-01	2.30E+00	88.2	5.75E-01	2.03E+00
Total	**189**	**665**	**27.6**	**52**	**184**

[a] All values per unit of planed dry lumber.
[b] 1.60 m^3 per 1.0 nominal MBF planed dry lumber.
[3] Percentage from Softwood Lumber LCI (Milota et al. 2004) and Softwood Plywood LCI (Wilson and Sakimoto 2004).

7.0 Sensitivity Analysis

A sensitivity analysis was completed to model the effects of using different quantities of fuel sources for thermal energy generation. Sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in softwood lumber manufacturing, heat is used in several sub-processes, consuming a combination of wood and fuel oil as fuel to generate

the heat. Changing fuel sources, also referred to as fuel switching, can have a significant effect on the type and quantity of emissions. This sensitivity analysis compared the effects of the "base" fuel mix to using (1) all on-site generated wood fuel (mostly green sawdust from the sawing process) and (2) using all fuel oil #2 as a fuel input.

7.1 Alternative Fuel Sources

The "base" fuel mix in this study included four fuel sources, with wood fuel and fuel oil #2 supplying the majority of the energy. Propane and fuel oil #1 contributed less than 0.1%. Based on survey data, the original model assumed 87.3% of the fuel used was in the form of wood fuel (59.8% produced on-site and the remainder purchased) and 12.7% as fuel oil #2. Most mills use only one or two types of fuel, whereas the original study resulted in a weight-averaged composite model incorporating different fuel sources taken from primary mill data for six mills. In this sensitivity analysis, two alternative fuel-use schemes were created for comparison to the "composite mill" or "base" scenario. One alternative assumed consumption of only on-site (generated) wood fuel used for all thermal energy by increasing the initial base value of 68.1 to 131 OD kg for this "100% on-site wood fuel" case to generate 2,730 MJ/m^3 (4.14 million Btu/MBF) of planed dry lumber. The second alternative fuel-use scheme, "100% fuel oil #2," had fuel oil #2 use increase from the base value of 8.95 to 70.4 L to provide all necessary heat for the facility.

7.2 Three Fuel Source Scenarios

This sensitivity analysis examined three scenarios for heat generation using the base fuel mix, 100% fuel oil #2, and 100% on-site (generated) wood fuel cases. The following three scenarios were modeled using SimaPro to find the differences in emissions: (1) comparing 100% fuel oil #2 case to the "base" softwood lumber fuel mix that used both fuel oil #2 and wood fuel, (2) comparing 100% on-site (generated) wood fuel to the "base" softwood lumber fuel mix that again had no fuel changes, and (3) comparing 100% fuel oil #2 to 100% on-site (generated) wood fuel cases.

7.3 Sensitivity Analysis Results

Table 7.1 presents the summary of the three fuel use scenarios, with a partial list of air emissions for the NE/NC region. In scenarios 1 and 2, a negative percentage difference number indicated that the alternative fuel source released fewer emissions than did the base model. A positive percentage difference means that the base or original model released fewer emissions. Scenario 1 indicated that less particulate (PM10), acetaldehyde, and biogenic CO_2, but more fossil CO_2, methane, non-methane VOC, and SOx, were produced when burning 100% fuel oil #2 than in the base fuel mix (original). Scenario 2 showed more biogenic CO_2, both types of particulate, acetaldehyde, benzene, naphthalene, and phenol, but less fossil CO_2, non-methane VOC, and SOx, were produced when burning 100% wood fuel than in the base fuel mix (original). In scenario 3, a negative number indicates that the all fuel oil #2 case released fewer emissions than the all on-site produced wood fuel case and a positive percentage number means that all on-site produced wood fuel model released fewer emissions. Scenario 3 highlighted the slight increase of fossil CO_2, non-methane VOC, and SOx produced along with less particulate (PM10) and biogenic CO_2 produced compared with scenario 1. For all three scenarios, the amount of VOC produced was similar regardless of the fuel used because most VOC originated in the actual drying of the softwood lumber.

Table 7.1 Sensitivity analysis for manufacturing softwood lumber in the NE/NC

	Fuel Distribution (kg per cubic meter planed dry lumber)			Difference (%)		
Substance	**100% fuel oil[a]**	**100% wood fuel[b]**	**Original (base)**	**Scenario 1— 100% fuel oil to original**	**Scenario 2— 100% wood fuel to original**	**Scenario 3— 100% fuel oil to 100% wood fuel**
Acetaldehyde	0.00E+00	3.24E-04	2.67E-04	–200.0	19.5	–200.0
Benzene	5.69E-07	3.89E-04	3.20E-04	–199.3	19.4	–199.4
CO_2 (biogenic)	5.29E-02	2.27E+02	1.87E+02	–199.9	19.5	–199.9
CO_2 (fossil)	1.98E+02	4.98E+01	6.51E+01	101.1	–26.6	119.6
CO	1.11E-01	1.52E+00	1.27E+00	–167.9	17.9	–172.8
Formaldehyde	9.35E-04	1.87E-03	1.60E-03	–52.3	15.7	–66.7
Methane	1.03E-01	9.37E-02	8.62E-02	17.4	8.3	9.1
Naphthalene	7.32E-08	2.59E-04	2.13E-04	–199.9	19.5	–199.9
NOx	4.04E-01	4.07E-01	4.02E-01	0.6	1.2	–0.6
Non-methane, VOC	3.51E-01	4.23E-02	7.98E-02	126.0	–61.4	157.0
Organic substances, unspecified	2.08E-03	1.82E-02	1.52E-02	–151.9	17.7	–159.0
Particulate (PM10)	2.13E-02	3.29E-02	2.91E-02	–31.2	12.0	–42.8
Particulate (unspecified)	4.62E-02	4.35E-02	4.01E-02	14.1	8.3	5.8
Phenol	1.96E-06	4.32E-03	3.55E-03	–199.8	19.5	–199.8
SOx	6.32E-01	3.56E-01	3.62E-01	54.2	–1.7	55.7
VOC	6.25E-01	6.88E-01	6.52E-01	–4.2	5.4	–9.7

[a] Fuel oil used was fuel oil #2.
[b] All wood fuel used was generated on-site.

8.0 Study Summary

A rigorous material and energy balance was completed on six softwood mills located in the northeastern and north central United States. The results indicate that total energy consumption varied significantly, depending on the species sawn, age of the boiler and dry kiln equipment, method of drying, and origin of electricity (on-site or grid). For softwood lumber, weight-averaged process energy of 2,728 MJ/m^3 of planed dry lumber (4.14 million Btu/MBF) was found with 2,016 MJ for drying, 488 MJ for on-site electrical generation (co-generation), and 224 MJ for plant heat. Total electrical energy consumption of 355 MJ/m^3 of planed dry lumber (158 kWh/MBF) was also determined, including on-site electrical generation. Process energy used varied considerably, depending on whether the mill ran a cogeneration unit. One mill that produced their own electrical power consumed over three times the amount of wood residue than mills that did not produce their electrical power per unit volume of lumber dried. The cogeneration unit converted 488 MJ of thermal energy into 51 MJ of electrical energy.

9.0 Discussion

Total energy consumption per cubic meter of planed (surfaced) dry softwood lumber was found to be comparable to published data (Armstrong and Brock 1989, Breiner et al. 1987, Comstock 1975). However, unlike previous studies, processes such as facility heating and cogeneration were examined because their energy use was significant. Wood has two significant advantages over non-wood

substitutes: wood is carbon neutral and carbon can be sequestered (captured and stored). Therefore, using wood as a fuel (energy resource) or in a finished wood product from softwood lumber (material resource) could be considered a sustainable practice. Other non-wood products typically do not have the benefits of a carbon-neutral product to use both as a fuel and a finished product. Also, decreasing energy consumption would be of great benefit to the mills both in terms of its financial benefits (cost reduction) and environmental burden benefits, especially in sawing and drying.

There are several approaches to lowering energy consumption, and the mills that incorporate these methods would ultimately have significantly lower energy use. Using improved sawing practices such as the best opening face program (Harpole and Hallock 1977), improved lumber sizing, thinner kerf saws, and curve sawing technology have increased lumber yields while lowering electricity consumption. Most large mills are using these technologies.

Another approach reduces thermal energy use. Several different drying methods including altered kiln schedules can be used depending on species, fuel costs, and wood residue use. Air drying lumber is one such method but has not been the preferred method of drying due to drying degrades and large quantity of drying stock required, although one mill did have an air yard. Drying degrade is a reduction in lumber quality caused by drying; greater control of the drying process typically reduces drying degrade. Maintaining a large lumber inventory for air drying reduces profits due to delays in recovery investments. Air drying lumber has the least control among the different drying methods, resulting in the highest level of degrade, although it provides the lowest energy use of all drying methods (FPL 1999b, Denig et al. 2000, Nebel et al. 2006).

10.0 Conclusions

Based on the life-cycle inventory results, the following conclusions are drawn:

- Sawing consumes the highest proportion of electricity in the manufacturing of softwood lumber. Thus, installing optimization equipment would lower electrical consumption by reducing sawing errors. Thinner kerf saws reduce electrical consumption and reduce volume of green wood residue produced

- Drying consumes the highest proportion of fuel. In this study, wood fuel accounts for 87% of thermal energy used. Lowering overall energy consumption by upgrading or overhauling existing older and inefficient dry kiln facilities is indicated. Installing progressive dry kilns commonly used in Scandinavian countries would also significantly reduce energy consumption

- Increasing on-site wood fuel consumption would reduce fossil greenhouse gases but increase other gases, especially particulate emissions. Particulate matter can be captured prior to release to the atmosphere using commercially available technology but not without increased costs.

- The region selected for production affects the environmental impact of this product because coal represents the greatest proportion of off-site material used for electrical power generation in the NE/NC region. Most power in the Pacific Northwest is produced from hydro and then natural gas, whereas most power in the Southeast is produced from coal and uranium just as in the NE/NC region.

- Increasing the level of air drying lumber and percentage of air drying prior to kiln drying, especially for species where color is not a problem, would lower the amount of energy required for the drying process. Therefore, improving air drying methods would lower energy use while maintaining lumber quality and reducing the environmental impact of softwood lumber.

Caution is required when using wood product LCI studies and the final LCA for comparison to non-wood products. It may be more important to know exactly how much material is needed for the same use instead of basing comparisons on a volume or mass basis. An example would be how much softwood flooring would be needed compared to a carpet system with a sub-floor. Floors and carpets are measured in square feet and yards, respectively, in the United States. This study gives results based on a cubic meter; therefore, thickness of material is a critical dimension for consideration.

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Appendix A-1. Primary Mill Data Questionnaire: Introduction And Questionnaire.

Softwood Sawmill Analysis Project

Thank you for giving me the opportunity to work with you on a project involving the long-term viability and profitability of the U.S. wood products industry. Results from this project will be a good marketing tool for the U.S. softwood industry particularly the green building industry. A growing demand for building projects that use environmentally friendly and energy-efficient materials has spurred a green movement in the construction industry. An estimated $10 billion of "green buildings" are in the process of construction this year in the United States.

This research will test the theory that using wood in more applications that substitute for non-renewable products can substantially improve environmental performance, thus increasing the marketability of forest products. As you know, wood offers unique opportunities to store carbon in the forest, products, and substitution (avoided fossil fuel intensive products) while also supporting other ecological services such as clean water, clean air, habitat, and recreation.

Based on the Forest Service Northeastern Region, my final report will describe a gate-to-gate analysis of softwood sawmills. The information collected will show the comparison of wood to non-wood materials on an energy, economic, and environmental basis. Regarding the questionnaire, our primary focus is on overall mill information because this data is vital for precise and accurate results. Details harder to report will be requested later so I encourage you to call with specific questions.

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. **Strict confidentiality** will be maintained for all the companies that supply the data for this project. Please complete the following questionnaire by **October 5, 2007**.

Company Name: _____

Mill Address: _____

_____

Contact Person: _____

Position/Title: _____

Telephone: _____ **Fax:** _____

Questions should be directed to:

Rick Bergman – Wood Drying Researcher
University of Wisconsin - Wood Products Program
120 Russell Labs
1630 Linden Dr
Madison, WI 53706
Phone (608) 231-9477 / FAX (608) 231-9303
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This report is part of a larger initiative sponsored by Consortium for Research on Renewable Industrial Materials (CORRIM) to provide a database of information for quantifying the environmental impacts and economic costs of wood building materials through the stages of planting, growing, manufacturing, construction, operational use, and demolition.

Softwood Sawmill Analysis

We have divided the mill into four unit processes. This division is like drawing a boundary around a part of the process. We want to find out everything that crosses the boundary. We would like to get information on total inputs and outputs from the mill first and then for each unit process where possible; please contact Rick Bergman @ (608) 231-9477 with any questions or concerns.
This questionnaire is divided into six parts.

- Part I deals with a basic description of the mill and its operations.
- Part II requests information on primary mill's total inputs and outputs for each of the following processes
    - Section A - Sawing (logyard and sawmill)
    - Section B - Drying
    - Section C - Planing (planing and packaging of lumber)
    - Section D - Energy generation

Within each of the last four parts, the questionnaire contains series of tables organized as follows:

Inputs
- Materials
- Energy (fuels and electricity)
- Water

Outputs,
- Products
- Air emissions
- Liquid emissions
- Solid waste

Emissions control equipment

Please complete the tables by either hand written or typing responses in the spaces provided. Provide as much detail as possible. Please contact Rick Bergman @ (608) 231-9477 if you have questions.

Space is provided throughout the questionnaire for any additional comments, clarifications or observations you might care to add.

Units are generally specified, but if you have other units that 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 hazardous air pollutants (HAPs) if the quantities of individual compounds are not known.

Thank you for the time and effort to fill in the blanks. Not all mills have everything on the list and it should be easier than it looks to complete.

PART I – Operation Overview

Reporting Year:	Starting Month:	Ending Month:

General Mill Information

1. Mill type (please check all that apply):
- ❑ Green lumber mill
- ❑ Dry lumber mill
- ❑ Cant / tie mill
- ❑ Pallet mill
- ❑ Other (specify)_____

2. Average log diameter _____ inches
Rough Green Lumber Production _____thousand board feet (MBF)
Average lumber dimension _____ (please provide estimate if able)
Percentage of 2 by 4s _____%
Percent kiln dried _____ % (Starting %MC _____ / Ending %MC _____)

3. Which of the following does this mill have (check each one that applies)?

- ❑ log storage
  - ○ dry deck
  - ○ sprinkled deck
  - ○ pond
  - ○ other: _____
- ❑ log handling
  - ○ log sorter/merchandizer
  - ○ debarker
- ❑ sawmill
  - ○ head rig(s): how many:_____
  - ○ band saw: how many:_____
  - ○ circular saw: how many:_____
  - ○ resaws: how many:_____
  - ○ edgers: how many:_____
  - ○ edger optimizer
  - ○ trimmer optimizer
  - ○ trimmer
  - ○ sorter, # bins:_____
  - ○ sticker stacker
- ❑ dryers and kilns
  - ○ predryer: Capacity_____
  - ○ conventional steam: Capacity_____
  - ○ high temperature steam: Capacity_____
  - ○ direct-fired: Capacity_____
  - ○ dehumidification: Capacity_____
  - ○ transfer car system: Capacity_____
  - ○ air drying yard: Capacity_____
- ❑ boiler
  - ○ wood-fired boiler
  - ○ gas-fired boiler (natural or propane)
  - ○ oil-fired boiler
  - ○ cogeneration facility (electricity)
  - ○ bag house
- ❑ planers
  - ○ planer
  - ○ in-line moisture meter
  - ○ grading station
  - ○ trimmer
  - ○ end paint/seal
- ❑ other mill equipment

PART II – Total Material and Energy Inputs and Outputs

TOTAL LOG/LUMBER INPUTS (Annual Production)

- Logs: ***What type of log scaling is used?*** _____

1. Volume of incoming logs _____ thousand BF
2. Volume sorted & sold to outside firms _____ thousand BF
3. Volume of logs to sawmill (on-site) _____ thousand BF

- Rough Green Lumber

4. Volume from on-site sawmill _____ thousand BF
5. Volume purchased from outside firms _____ thousand BF
6. Volume sorted & sold to outside firms _____ thousand BF
7. Volume from predryers _____ thousand BF
8. Volume from airyard _____ thousand BF
9. Volume to dry kilns _____ thousand BF

- Rough Dry Lumber

10. Volume kiln-dried on-site _____ thousand BF
11. Volume purchased from outside firms _____ thousand BF
12. Volume sorted & sold to outside firms _____ thousand BF
13. Volume to planer _____ thousand BF

- Planed Dry Lumber

14. Volume from planer _____ thousand BF
15. Volume purchased from outside firms _____ thousand BF
16. Volume sorted and sold to outside firms _____ thousand BF
17. Volume used internally (on-site) _____ thousand BF

Please complete the following table showing the breakdown of the individual tree species and approximate sizes processed by your mill by species or the average log diameter. If less than 2% of total, use category labeled "Other".

Species	% of total log input into sawmill	Log Diameter* (in)
Total	100%	

*Please provide individual log diameters if known otherwise please state the average or range of logs processed at your facility in bottom row under Log Diameter

ANNUAL GREEN LUMBER PRODUCTION BY DIMENSION

Lumber Dimension (thickness x width)	Annual Production (MBF)	Percentage (%)
1"x 4"		
1"x 6"		
1"x 8"		
1" x 10"		
2" x 4"		
2" x 6"		
2" x 8"		
2" x 10"		
4" x 4"		
4" x 6"		
6" x 6"		
Other _____		
Other _____		
Other _____		
Total		100%

TOTAL (NON-TRANSPORTATION) FUEL USE

- Wood
  - On-site wood boiler fuel _____ @ _____ %MC tons
  - Purchased wood boiler fuel _____ @ _____ %MC tons

- Fossil Fuel
  - Natural Gas _____ thousand cubic feet (ft^3)
  - Fuel oil #1(kerosene) _____ gallons
  - Fuel oil #2 (heating oil) _____ gallons
  - Fuel oil #6 _____ gallons
  - Propane _____ gallons
  - Other _____
  - Electricity for entire facility _____ kilowatt-hours (kWh)
  - Electricity for the four processes 1. Sawing _____ (kWh or %) 2.Drying ____ (kWh or %) 3. Energy Generation _____ (kWh or %) 4. Planing _____ (kWh or %) (**Estimation is ok**)

TOTAL WATER USE

- 1. Ground water _____ gallons or ft^3 2. Surface water _____gallons or ft^3

TOTAL TRANSPORTATION FUEL USE ON-SITE[2]

Type	Units
On-road diesel	Gallons
Off-road diesel	Gallons
Fuel Oil #6	Gallons
Propane	Gallons
Gasoline	Gallons
Other	

[2]Include all sources of energy such as fuels for yard equipment, forklifts, and carriers

TOTAL WOOD CO-PRODUCT/BY-PRODUCT OUTPUT

For each co-product and by-product, please indicate the percentages of total production for the reporting period that are sold (shipped) to other users, used internally (either as fuel or other uses), landfill, or inventoried for future use. Select whatever category best fits your mill's situation. If zero, enter a dash (-). Please state units if other than tons like cubic yards.

Co-products and By-Products	Moisture Content (wet basis)	Sold (Shipped)	Used Internally (as fuel)	Used Internally (other uses)	Landfilled	Inventory	Total
	(%)	tons	tons	tons	tons	tons	tons
Chips, green							
Sawdust, green							
Bark, green							
Edging strips, green							
Sawdust, dry							
Shavings, dry							
Hogged material							
Other							

TOTAL INDUSTRIAL (SOLID) WASTE **(material requiring disposal outside of mill)**

Type	Tons/Pounds	Percent Landfilled
Fly Ash		
Bottom ash		
General refuse		
Recycled material		

TOTAL AIR EMISSIONS (Provide stack test if available)

Type	Amount (pounds)
Particulate	
PM10	
HAPs	
Others (SO_2, ROG[1], etc.)	

[1]Reactive Organic Gases (also referred to as Volatile Organic Compounds)

TRANSPORTATION – LOGGING TRUCKS

Mileage logging trucks travel annually

_____ total hauling distance (miles)
_____ % One-way
_____ % Empty backhaul
_____ % Contracting
_____ average round-trip (miles)

ENERGY GENERATION - BOILER FUEL USE

1. If present, please indicate the actual (not rated) production output of every process boiler:

Boiler	Size (BTU/hr, HP, or lbs/hr of steam[3])	Fuel type	Amount of Fuel (units)
#1			
#2			
#3			

[3]If known, list boiler steam pressure

2. If any wood boiler fuel used on-site is ***purchased from off-site sources***, please indicate the amounts by type in the spaces provided below. Otherwise ignore and go to next question. If zero, enter a dash (-). Please make sure you show the **units** of measure.

Boiler Fuel	**Quantity**	**Units** (enter %MC if known)
Shavings, dry		
Sawdust, dry		
Sawdust, green		
Bark, green		
Hogged fuel (mixed grindings)		
Chips, green		

3. If present, please indicate the cogeneration facility production output:

Electricity (kW or MW)	Process heat (BTU/hr)	Fuel type	% used or sold off site	
			electricity	process heat

EMISSIONS CONTROL EQUIPMENT (ECD)

Include emission control devices (ECD) if any for air emissions such as cyclones, baghouses, and electric static precipitators (ESPs)

For water emissions, explain how runoff or other water discharges from the boiler and logyard are controlled (i.e. handled) such as settling pond, city sewer, septic

	Boiler #1	Boiler #2	Boiler #3	Sawmill	Planermill	Logyard
Type of Device						
Equipment controlled						
Electrical Use[1], kWh						
Type of emissions controlled						

[1]Or state other units

Appendix A-2. Primary Mill Data Questionnaire: Explanation And Diagrams

PART A – SAWING

Reporting Year:	Starting Month:	Ending Month:

Description of Unit Process

This unit process begins with logs in the mill yard and includes:

- in-yard transportation of logs from the point of unloading to the deck;
- sorting and storage of logs;
- in-yard transportation of logs from the deck to the optimizer or debarker;
- cutting to length of logs or tree lengths;
- debarking of the logs;
- breakdown of logs into rough lumber, pulp chips, bark, slabs, edgings, and sawdust;
    - slab is the lumber cut on a circular or band head rigs from the outside portions of logs when squaring the log for lumber; does not have square edges
    - edgings are these pieces of board that passed through a machine called an edger that can make two or more lineal cuts simultaneously
- stacking, stickering, and in-yard transportation of rough lumber to kilns or planar facilities;
- sawfiling and maintenance of all sawmill equipment and yard transportation vehicles; and
- treatment of process air, liquids, and solids.

The outputs of this unit process are rough green lumber, chips, bark, slabs, edgings, and sawdust.

PART B – DRYING

Reporting Year:	Starting Month:	Ending Month:

Description of Unit Process

This unit process begins with rough green lumber and includes:

- loading of stickered lumber into a kiln facility;
- heat treatment, drying, equalizing and conditioning of lumber within the kiln;
- maintenance of all kiln equipment and related yard transportation vehicles;
- treatment of process air, liquids and solids; and
- unloading and transportation of kiln-dried lumber to the planar mill.

The output of this unit process is stickered, rough kiln-dry lumber delivered to the planar mill.

PART C – PLANING

Reporting Year:	Starting Month:	Ending Month:

Description of Unit Process

This unit process begins with either rough green lumber or stickered, rough kiln-dried lumber.

The operations associated with this unit process include:

- de-stickering and/or unstacking of lumber;
- planing (surfacing) of lumber;
- trimming, grading, and sorting of lumber;
- stacking, strapping, and packaging of lumber.
- transportation of lumber within the planer operation and loading for shipping
- maintenance of all planar equipment and associated yard transportation vehicles; and
- treatment of process air, liquids and solids.

The output of this unit process is surfaced and packaged lumber, sorted by type, size and grade as well as planar shavings, sawdust, pulp chips, and/or lumber trim ends.

PART D – ENERGY GENERATION (BOILER)

Reporting Year:	Starting Month:	Ending Month:

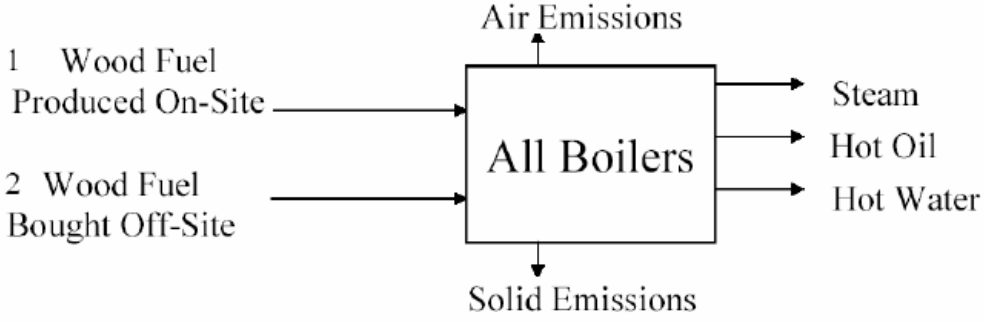
Description of Unit Process

This unit process provides heat and in some cases electricity for use in other parts of the mill or to be sold. A fuel such as wood or natural gas is burned.

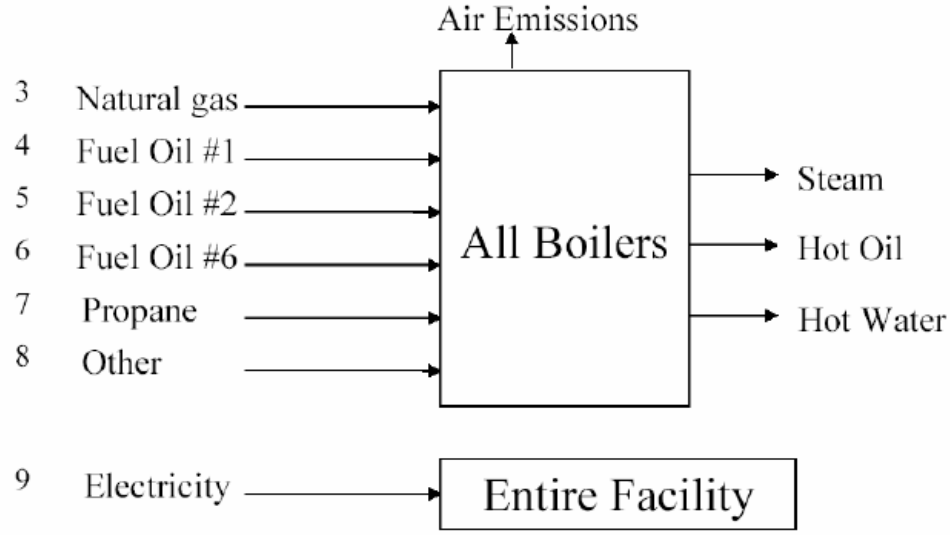
- fuel handling;
- water added to the boiler;
- chemicals added at the boiler or to steam lines;
- distribution of the steam;
- distribution of electricity; and
- the treatment of process air, liquids, and solids.
- The outputs of this unit process are process steam and electricity.

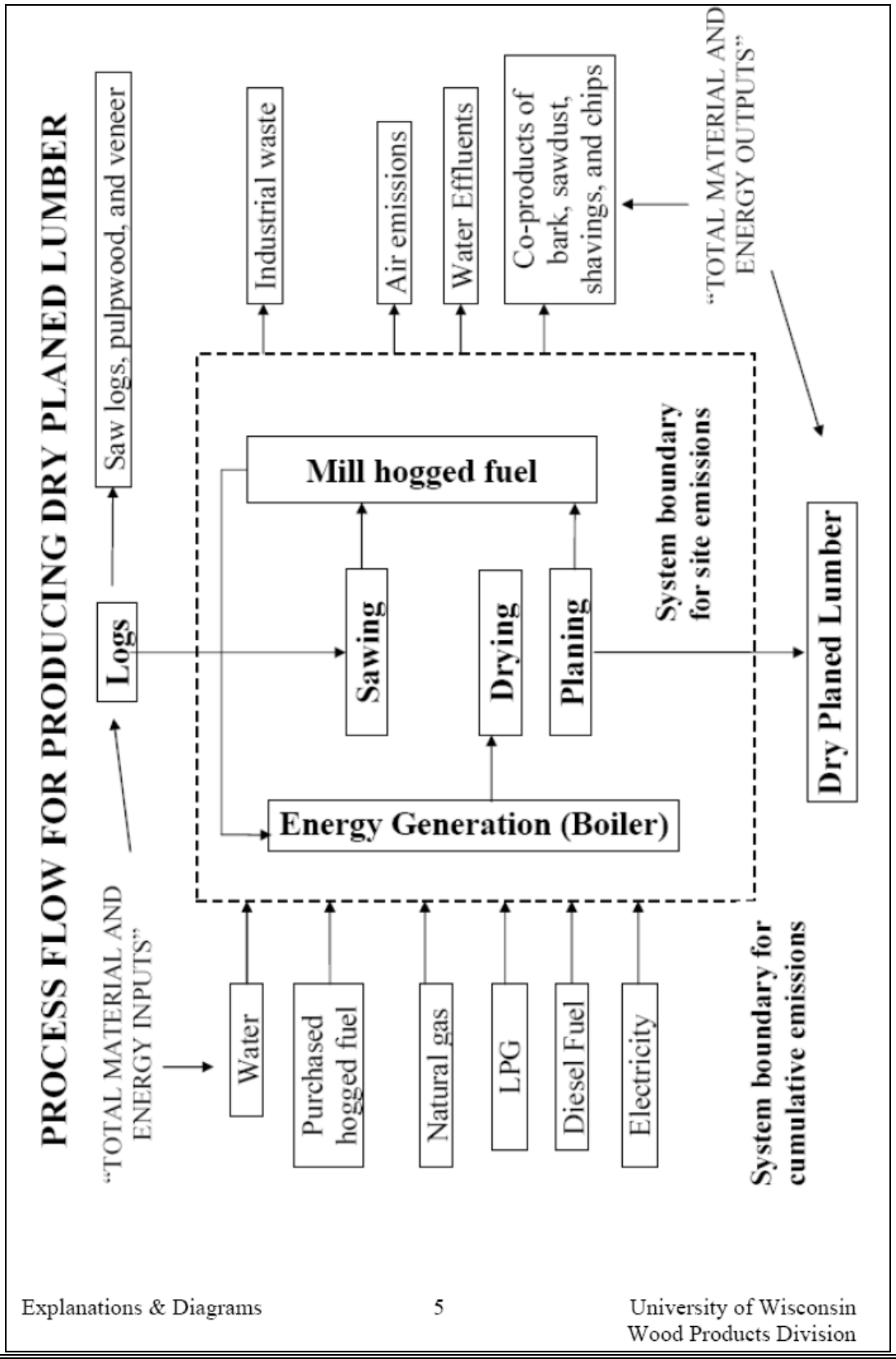
Energy Generation Block Diagram

Wood (Biomass) Fuel



Fossil Fuel




PROCESS FLOW FOR PRODUCING DRY PLANED LUMBER
"TOTAL MATERIAL AND ENERGY INPUTS"
Saw logs, pulpwood, and veneer
Industrial waste
Air emissions
Water Effluents
Co-products of bark, sawdust, shavings, and chips
"TOTAL MATERIAL AND ENERGY OUTPUTS"
Logs
Mill hogged fuel
Sawing
Drying
Planing
System boundary for site emissions
Dry Planed Lumber
Energy Generation (Boiler)
Water
Purchased hogged fuel
Natural gas
LPG
Diesel Fuel
Electricity
System boundary for cumulative emissions

Appendix B-1. LCI Inputs for Sawing Process

Sawing		
Products		
Sawn lumber, Softwood, green, rough, NE/NC, USA, U	496	kg
Wood Fuel, Softwood, green, NE/NC, USA, U	45.3	kg
Wood Chips, Softwood, green, NE/NC, USA, U	348	kg
Sawdust, Softwood, green, NE/NC, USA, U	41.6	kg
Bark, Softwood, green, NE/NC, USA, U	127	kg
Resources		
Water, well, in ground	172	l
Water, process and cooling, surface	811	l
Materials/fuels		
Gasoline equipment (gal)	0.0228	l
Diesel equipment (gal)	1.224	l
Roundwood at mill, kg, softwood, NE/NC, USA, U	931	kg
Bark at mill, kg, softwood, NE/NC, USA, U	127	kg
Electricity/heat		
Plant Heating, NE/NC Softwood Lumber Region	224	MJ
Grid Electricity, NE/NC Softwood Lumber Region	166	MJ
On-Site Electricity, NE/NC Softwood Lumber Region	27.9	MJ

Appendix B-2. LCI Inputs for Drying Process

Drying		
Products		
Sawn lumber, Softwood, rough, kiln dried, NE/NC, USA, U	496	kg
Materials/fuels		
Sawn lumber, Softwood, green, rough, NE/NC, USA, U	496	kg
Diesel equipment (gal)	0.408	l
Gasoline equipment (gal)	0.0076	l
Electricity/heat		
Drying, Franklin Boiler, NE/NC Softwood Lumber Region	2016	MJ
Grid Electricity, NE/NC Softwood Lumber Region	77.4	MJ
On-Site Electricity, NE/NC Softwood Lumber Region	13	MJ
Emissions to air		
VOC, volatile organic compounds	0.79	kg
Solid Waste		
Material for recycling	0.042	kg
Waste in inert landfill	0.524	kg

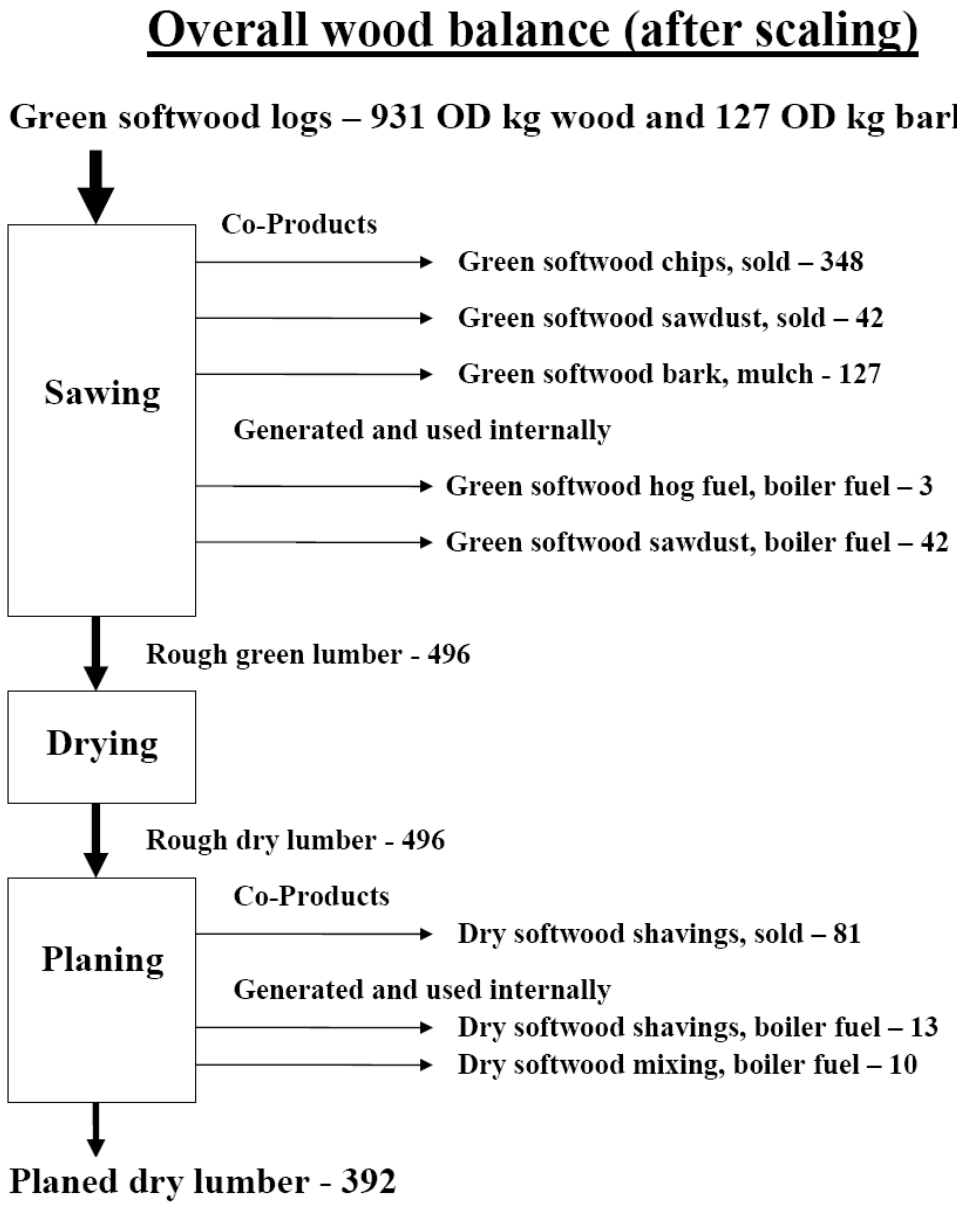
Appendix B-3. LCI Inputs for Planing Process

Planing		
Products		
Sawn lumber, Softwood, planed, kiln dried, NE/NC, USA, U	392	kg
Wood Fuel, Softwood, kiln dried, NE/NC, USA, U	22.9	kg
Shavings, Softwood, kiln dried, NE/NC, USA, U	80.6	kg
Materials/fuels		
Sawn lumber, Softwood, rough, kiln dried, NE/NC, USA, U	496	kg
Diesel equipment (gal)	0.408	l
Gasoline equipment (gal)	0.0076	l
Electricity/heat		
Grid Electricity, NE/NC Softwood Lumber Region	60.3	MJ
On-Site Electricity, NE/NC Softwood Lumber Region	10.1	MJ

Appendix B-4. LCI Inputs for Energy Generation (Franklin Boiler)

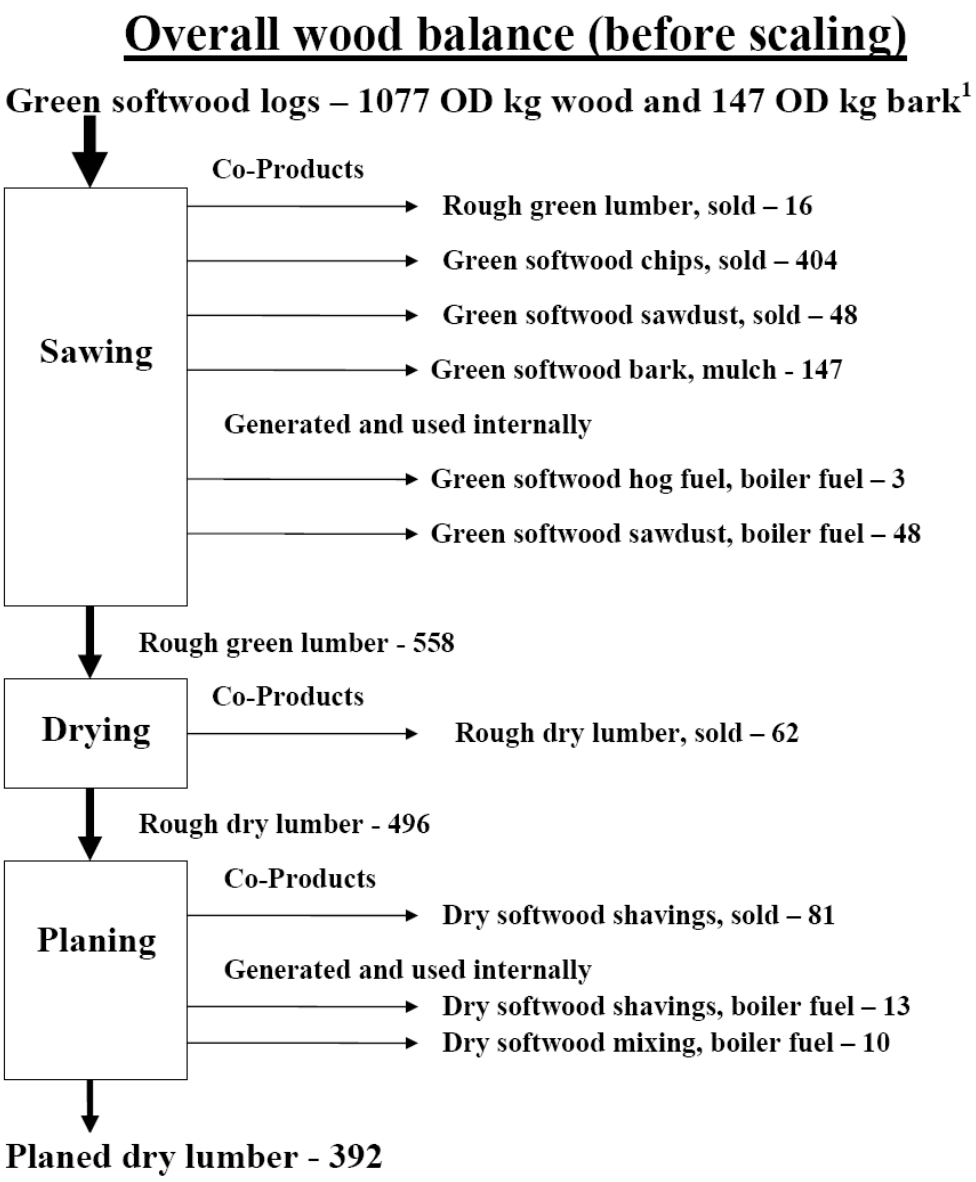
Energy Generation (Franklin Boiler)		
Products		
Drying, Franklin Boiler, NE/NC Softwood Lumber Region	2016	MJ
Plant Heating, Franklin Boiler, NE/NC Softwood Lumber Region	224	MJ
On-Site Electricity, NE/NC Softwood Lumber Region	51	MJ
Materials/fuels		
Wood into industrial boilers (purchased), Softwood, green and kiln dried NE/NC, USA, U	45.8	kg
DFO into industrial boilers	8.95	l
Electricity from DFO FAL, back-up generator	12	MJ
Wood into industrial boilers (generated on-site), Softwood, green and kiln-dried, NE/NC, USA, U	68.1	kg

Appendix C-1. Wood Material Balance Flowchart for the Production of 1.0 M3 of Planed Dry Lumber



[1] All wood and bark weights are oven dry kg.

Appendix C-2. Overall Wood Material Balance for The Production of 1.0 M3 of Planed Dry Lumber (Includes Rough Green and Dry Lumber Co-Products)



[1] All wood and bark weights are oven dry and in kg.

Appendix D-1. Total Electrical Power Industry by Source for the Northeastern and North Central United States for 2006 By State

CT	Coal	4.00.E+06
DE	Coal	4.97.E+06
IA	Coal	3.29.E+07
IL	Coal	9.16.E+07
IN	Coal	1.24.E+08
MA	Coal	1.11.E+07
MD	Coal	2.94.E+07
ME	Coal	3.22.E+05
MI	Coal	6.78.E+07
MN	Coal	3.31.E+07
MO	Coal	7.75.E+07
NH	Coal	3.89.E+06
NJ	Coal	1.09.E+07
NY	Coal	2.10.E+07
OH	Coal	1.33.E+08
PA	Coal	1.23.E+08
WI	Coal	3.89.E+07
WV	Coal	9.15.E+07
Subtotal		**8.98.E+08**

CT	Petroleum	1.29E+06
DE	Petroleum	1.32E+05
IA	Petroleum	1.98E+05
IL	Petroleum	1.34E+05
IN	Petroleum	1.64E+05
MA	Petroleum	2.36E+06
MD	Petroleum	5.82E+05
ME	Petroleum	5.85E+05
MI	Petroleum	3.96E+05
MN	Petroleum	4.91E+05
MO	Petroleum	6.04E+04
NH	Petroleum	4.38E+05
NJ	Petroleum	2.77E+05
NY	Petroleum	6.83E+06
OH	Petroleum	1.36E+06
PA	Petroleum	1.57E+06
RI	Petroleum	3.23E+04
VT	Petroleum	7.37E+03
WI	Petroleum	8.67E+05
WV	Petroleum	1.75E+05
Subtotal		**1.79E+07**

CT	Natural Gas	1.05.E+07
DE	Natural Gas	1.17.E+06
IA	Natural Gas	2.40.E+06
IL	Natural Gas	5.31.E+06
IN	Natural Gas	2.66.E+06
MA	Natural Gas	2.33.E+07
MD	Natural Gas	1.77.E+06
ME	Natural Gas	7.30.E+06
MI	Natural Gas	1.12.E+07
MN	Natural Gas	2.56.E+06
MO	Natural Gas	3.73.E+06
NH	Natural Gas	6.01.E+06
NJ	Natural Gas	1.56.E+07
NY	Natural Gas	4.21.E+07
OH	Natural Gas	2.38.E+06
PA	Natural Gas	1.35.E+07
RI	Natural Gas	5.78.E+06
VT	Natural Gas	1.88.E+03
WI	Natural Gas	5.36.E+06
WV	Natural Gas	3.58.E+05
Subtotal		**1.63E+08**

CT	Hydroelectric Conventional	5.44E+05
IA	Hydroelectric Conventional	9.09E+05
IL	Hydroelectric Conventional	1.73E+05
IN	Hydroelectric Conventional	4.90E+05
MA	Hydroelectric Conventional	1.51E+06
MD	Hydroelectric Conventional	2.10E+06
ME	Hydroelectric Conventional	4.28E+06
MI	Hydroelectric Conventional	1.52E+06
MN	Hydroelectric Conventional	5.72E+05
MO	Hydroelectric Conventional	1.99E+05
NH	Hydroelectric Conventional	1.53E+06
NJ	Hydroelectric Conventional	3.54E+04
NY	Hydroelectric Conventional	2.18E+07
OH	Hydroelectric Conventional	5.16E+05
PA	Hydroelectric Conventional	2.23E+06
RI	Hydroelectric Conventional	5.91E+03
VT	Hydroelectric Conventional	1.52E+06
WI	Hydroelectric Conventional	1.68E+06
WV	Hydroelectric Conventional	5.46E+05
Subtotal		**4.22E+07**

CT	Nuclear	1.66E+07
IA	Nuclear	5.10E+06
IL	Nuclear	9.42E+07
MA	Nuclear	5.83E+06
MD	Nuclear	1.38E+07
MI	Nuclear	2.91E+07
MN	Nuclear	1.32E+07
MO	Nuclear	1.01E+07
NH	Nuclear	9.40E+06
NJ	Nuclear	3.26E+07
NY	Nuclear	4.22E+07
OH	Nuclear	1.68E+07
PA	Nuclear	7.53E+07
VT	Nuclear	5.11E+06
WI	Nuclear	1.22E+07
Subtotal		**3.82E+08**

CT	Other Renewat	7.63E+05
DE	Other Renewat	4.17E+02
IA	Other Renewat	2.45E+06
IL	Other Renewat	8.49E+05
IN	Other Renewat	2.20E+05
MA	Other Renewat	1.28E+06
MD	Other Renewat	6.29E+05
ME	Other Renewat	3.97E+06
MI	Other Renewat	2.45E+06
MN	Other Renewat	3.06E+06
MO	Other Renewat	2.29E+04
NH	Other Renewat	7.46E+05
NJ	Other Renewat	9.17E+05
NY	Other Renewat	2.61E+06
OH	Other Renewat	3.99E+05
PA	Other Renewat	2.48E+06
RI	Other Renewat	1.49E+05
VT	Other Renewat	4.50E+05
WI	Other Renewat	1.35E+06
WV	Other Renewat	1.74E+05
Subtotal		**2.50E+07**

Total	**1.54.E+09**

CT	Other Gases	1.65E+03
DE	Other Gases	9.13E+05
IL	Other Gases	1.41E+05
IN	Other Gases	2.87E+06
MD	Other Gases	3.33E+05
ME	Other Gases	0.00E+00
MI	Other Gases	5.68E+05
MO	Other Gases	5.09E+03
NJ	Other Gases	1.30E+05
OH	Other Gases	3.60E+05
PA	Other Gases	5.07E+05
WV	Other Gases	5.28E+04
Subtotal		**5.89E+06**

CT	Pumped Storage	0.00E+00
MA	Pumped Storage	-5.79E+05
MI	Pumped Storage	-1.04E+06
MO	Pumped Storage	4.76E+04
NJ	Pumped Storage	-2.99E+05
NY	Pumped Storage	-7.56E+05
PA	Pumped Storage	-6.98E+05
Subtotal		**-3.32E+06**

CT	Other	7.39.E+05
IA	Other	1.04.E+04
IL	Other	3.84.E+04
IN	Other	4.38.E+05
MA	Other	-5.79.E+05
MD	Other	3.05.E+05
ME	Other	3.58.E+05
MI	Other	5.64.E+05
MN	Other	3.23.E+05
MO	Other	5.38.E+04
NH	Other	5.93.E+04
NJ	Other	5.71.E+05
NY	Other	9.77.E+05
PA	Other	7.22.E+05
WI	Other	1.10.E+05
WV	Other	6.48.E+03
Subtotal		**4.69E+06**

Addendum

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

Pascal Lesage, Sylvatica
Maureen Puettmann, WoodLife/CORRIM
April 25, 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 Softwood Lumber Manufacturing in the North Eastern and North Central United States", by R. Bergman and S. Bowe; 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 "NENC 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 external databases (e.g. Franklin, Ecoinvent) 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); and
- 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.

3. Changes to individual unit processes

3.1 "Logyard" processes

No changes beyond the general changes mentioned above were made.

3.2 Sawing

No changes beyond the general changes mentioned above were made.

3.3 Sawn Lumber, Hardwood, Rough, Kiln-dried, NE/NC, USA, U

The only change made by Sylvatica to this unit process beyond the general changes described above was to renormalize the unit process to $1m^3$ of rough dry lumber. The CORRIM unit process was initially normalized to 496 kg (OD basis) of kiln-dried rough softwood lumber which, assuming a specific gravity of kiln-dried softwood of 0.392, represents 1.265 m^3. All flows were therefore divided by 1.265.

3.4 Hardwood lumber planing

The only major modification Sylvatica made to this unit process beyond the general changes described above was to normalize it to 1 m3 of planed, kiln-dried sawn hardwood lumber.

3.5 Boiler, Northeastern Hardwood Lumber

This unit process allows the averaging of different fuel sources (wood, diesel) and different outputs (heat and, to a much lesser extent, electricity) for the boilers used by the NE/NC softwood lumber mills. The following changes were initially by Sylvatica beyond the general changes described above:

- The two heat flows (heat for drying and heat for facility heating) were combined into one general "heat" flow. Note that the portion used for facility heating is not used by any process, and hence are not accounted for in the gate-to-gate LCI. This is true even if the "heat for drying" and "heat for facility heating" flows remain separate. This is an error that was not resolved (in the NE/NC hardwood lumber module, this heat was attributed to the sawmill unit process).
- The transport of wood fuel from other mills was removed and integrated in the "Wood into industrial boilers, NE-NC softwood lumber, purchased".
- The input flow of CO2 was removed, as CO2 uptake is now accounted for in the "wood fuel, unspecified" unit process (see below).
- The allocation factors were corrected (source of original error unknown).

3.6 Adapted Franklin data

Three processes associated with wood combustion found in the CORRIM SimaPro model are slightly adapted versions of Franklin (FAL 98) datasets. What is more, these are almost exactly the same processes found in the NE/NC hardwood lumber module. These processes and their adaptations is described below.

Important note: The original Franklin datasets give no indication on what the moisture content of the wood from the generic "Wood and wood wastes" process, wood subsequently used in the Franklin "Wood into industrial boiler" process that served as a basis for the wood combustion process in the CORRIM modules. 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 kg wood and wood waste to 500 kg) 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 CO^2 emitted from the combustion processes (1050 kg) hints that approximately 572 kg of wood (oven-dry basis) is combusted, not 500 kg. 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.

1. The CORRIM SimaPro model initially used a process called "Wood FAL, Softwood, NE/NC, USA, U" to account for cradle-to-gate impacts of purchased wood fuel. However, this process was found to be exactly the same as the unit process "Wood fuel, unspecified" unit process used in the NE\NC hardwood lumber model. The latter is itself based on a Franklin unit process called "Wood Precombustion (1000 lb), updated 2000". For inclusion in the U.S. LCI, the unit process "Wood FAL, Softwood, NE/NC, USA, U" was simply replaced with the unit process "Wood fuel, unspecified": see the NE/NC Hardwood Lumber Changes report for more information on this process.
2. For the combustion of purchased wood in a boiler, a unit process was created by CORRIM called "Wood into industrial boilers (purchased), Softwood, green and kiln dried NE/NC, USA, U". This unit process is an adapted version of the Franklin unit process "Wood into industrial boilers", with the only difference being the basis (oven dried) for reporting the mass of wood flows. The only change that was made for inclusion in the U.S. LCI database was to add the transport of the purchased wood, transport which was initially included in the cogeneration process in the CORRIM SimaPro model. A transport amount of 106 kgkm/kg of purchased wood was determined based on a transport distance of 58.8 km and a moisture content of 80.2%.
3. For the combustion of wood fuel produced directly at the softwood lumber mills, a unit process was created by CORRIM called "Wood into industrial boilers (generated on-site), Softwood, green and kiln-dried, NE/NC, USA, U". Again, this unit process is an adapted version of the Franklin "Wood into industrial boilers", with the only differences being the basis for reporting the mass of wood flows and the change of wood fuel inputs to flows of wood fuel co-products from processes at the softwood lumber mill.

Important note: If ever data specific to softwood-burning boilers in the NE/NC 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 NE/NC softwood mills.