CORRIM: Phase II Final Report

Module C

Life-Cycle Inventory of Hardwood Lumber Manufacturing in the Northeast and North Central United States

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Conversion Table

1 megajoule = 0.278 kilowatt-hour
1 gigajoule = 1,000 megajoule
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 foot
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 find the environmental impact of hardwood lumber production through a gate-to-gate Life-Cycle Inventory (LCI) on hardwood sawmills in the northeast and northcentral (NE/NC) United States. Primary mill data was collected per CORRIM Research Guidelines (CORRIM 2001). Life-cycle analysis is beyond the scope of the study.

A mill questionnaire surveyed twenty hardwoods sawmills across the NE/NC region. Total annual hardwood lumber production for this region in 2005 was 5.1 billion board feet (bf). Annual production for the twenty sawmills surveyed in 2005 was over 303 million bf of rough green lumber, about 6% of the total hardwood lumber production for this region. The mill questionnaire broke hardwood lumber manufacturing into four different unit processes: Sawing, Energy Generation, Drying, and Planing. The mill data was weight averaged on a per unit basis of 1.0 cubic meter of planed dry lumber to find material flows and energy use. The material flow and energy use data were entered into modeling software, SimaPro 7, to find the environmental impact.

A hardwood log to planed dry lumber volume conversion of 43.7% was found. Energy consumption of 608 MJ of electricity and 5,800 MJ of thermal energy per m^3 were determined for the manufacturing of planed dry hardwood lumber from incoming logs. Burning green wood residues on-site generate the most energy. Emission data produced through modeling estimated total biomass (biogenic) and fossil (anthropogenic) carbon dioxide production of 428 kg per m^3 and 139 kg per m^3, respectively, considering all impacts.

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

- Sawing consumes the highest proportion of electricity in the manufacturing of hardwood 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 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.

- 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 is the largest off-site material used for electrical power generation in the NE/NC region. Whereas, most power in the Pacific Northwest is produced from hydro and then natural gas while most of the power in the Southeast is produced from coal and uranium similar to 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 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 hardwood lumber.

- Once the competing non-wood substitutes have been inventoried, product selection for sustainable building could be used to compare vinyl to hardwood moulding or carpet systems to solid hardwood flooring.

Table of Contents **Page**

List of Figures **Page**

List of Tables **Page**

1.0 Introduction

Hardwood lumber is used primarily in wood flooring, pallets, furniture, cabinets, and moulding. The total annual hardwood production for the United States in 2005 was 10.6 billion board feet (USCB 2006a). Most hardwood lumber is consumed domestically, but there was an estimated 1.35 billion bf exported in 2005 (HMR 2006). Domestic hardwood lumber production occurs mostly in the eastern United States, with an annual production of 10.2 billion board feet[1] (bf) split equally between the northeastern and southeastern states. A small percentage of hardwood lumber production occurs on the West Coast.

Economic costs, energy use, and environmental impact of residential building products are playing an increasing large part due to increased awareness of the public on environmental issues. Two major reasons for the increase in residential building are the increase in average size and the number of U.S. new single-family residential housing units. The average-size single-family residential home has increased from 2,075 square feet in 1991 to 2,434 square feet in 2005 and completed single-family residential units have roughly increased 100% to 1.64 million units during this same period (USCB 2006b).

"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 the minimum market share is expected to increase to five percent ($19 billion) by 2010 (MHC 2006). 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.

Providing accurate baseline data for hardwood lumber production through a gate-to-gate Life-Cycle Inventory (LCI) are part of sustainable practices regarding building styles, construction materials, product improvements for energy consumption, and carbon sequestration policies. This LCI study will provide useful data to examine the environmental impact of hardwood lumber production. 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 hardwood lumber-related wood products (NREL 2007). Hardwood lumber is the raw material used in producing hardwood flooring and hardwood flooring is considered a building material unlike hardwood lumber.

Life-Cycle Inventory 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 tracks hardwood lumber production from hardwood logs stored in the log yard to planed dry lumber leaving the planing process. 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.

Rough green lumber sawn from hardwood 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 is using wood residues from the milling processes (Denig *et al.* 2000). 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 hardwood lumber (Comstock 1975). Total energy is comprised of both electrical and thermal. The rough dry lumber is planed to required dimensions when drying is complete.

[1] A board foot measures 12 by 12 by 1 inch.

The goal of this study is to document the LCI of planed dry lumber production from hardwood logs and determine the material flow, energy use, and emissions for the hardwood lumber manufacturing process on a per unit basis for the northeastern and northcentral (NE/NC) United States (Figure 1.1). Primary data was collected through questionnaires mailed to lumber mills while secondary data was collected from peer-reviewed literature per Consortium for Research on Renewable Industrial Material (CORRIM) guidelines (CORRIM 2001). Material and energy balances were calculated through a spreadsheet from the primary and secondary data sources. Using these material and energy values, the environmental impact was found from modeling the emissions through software called SimaPro 7 (Pre' Consultants 2007), which follows ISO 14040 protocols. SimaPro was used in previous CORRIM-initiated LCI projects: 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).

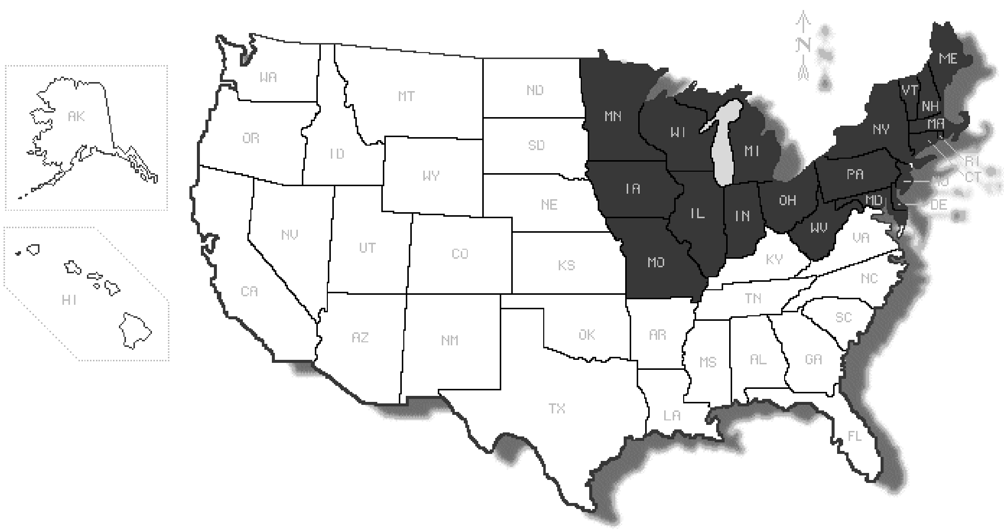

Figure 1.1. Dark area selected for Life-Cycle Inventory of hardwood lumber production in the United States

1.1 Annual Lumber Production

For the NE/NC region, annual hardwood lumber annual production for years 2003 to 2005 is shown in Figure 1.2. Pennsylvania, West Virginia, Missouri and Wisconsin are the major hardwood lumber producing states. Only fifteen of the twenty states in this region are shown because the other states did not report for at least one of the three years plotted. These states that are missing, Rhode Island, Connecticut, New Jersey, Delaware, and Iowa, are estimated to produce a combined total annual lumber volume of only 222 million board feet.

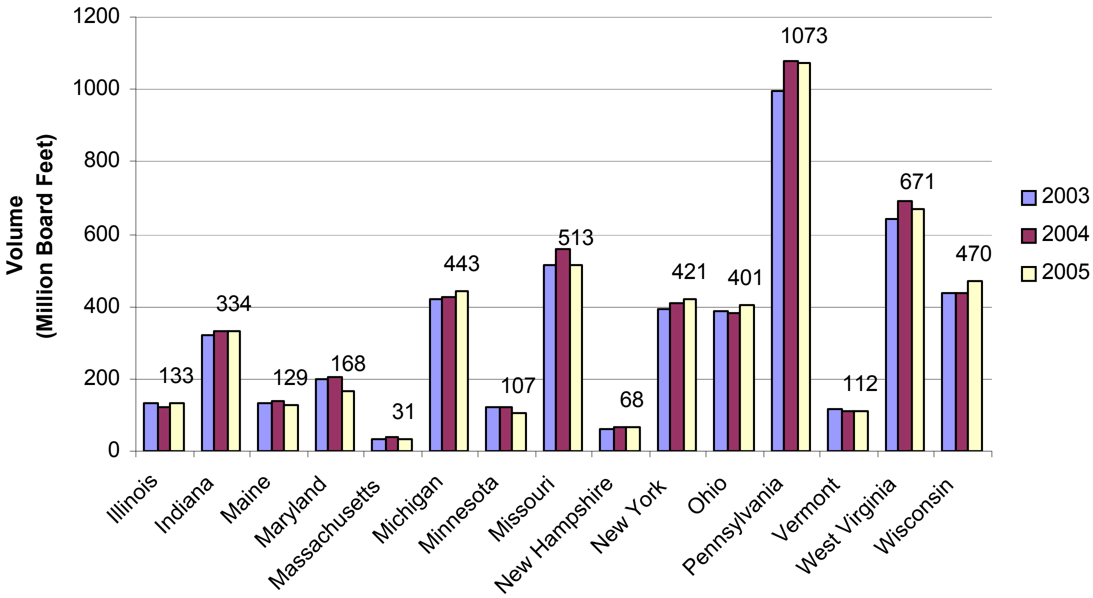

Figure 1.2. Annual hardwood lumber production by State for the last three years
Source: United States Census Bureau (2005)

1.2 Mill Questionnaire

A mill questionnaire was developed from questionnaires used in other mill studies and adapted specifically to address the production of hardwood lumber. A draft questionnaire was critically reviewed by a CORRIM representative and then sent to a hardwood lumber company as a pre-test. The pre-tested questionnaire was then split in two sections based on comments from the past Hardwood Manufacturing Association's (HMA) Executive Vice-President. Section 1 (Appendix A-1) of the questionnaire entitled "Introduction and Questionnaire" was given to 22 mills while section 2 (Appendix A-2) was removed to keep the questionnaire simple. Section 2 contained more information on describing the questionnaire but no request for primary mill data. We believed that keeping Section 2 would cause confusion and mill would choose not to complete the questionnaire. Also, Section 1 is the only section that requests primary mill data. Based on these comments, an edited version was mailed to board members of the HMA. Mills from the HMA were chosen because the HMA members produce mainly hardwood lumber and the LCI study was supported by the HMA Executive Vice-President and President. A total of 20 hardwood lumber mills from 17 companies completed the questionnaire after several follow-up calls for a total response rate of 90.9%. Although the number of mills surveys may be small (n=20) compared to a "typical" mail survey, the level of detail and amount of primary mill data for a CORRIM study is very high (Appendix A-1). Each mill contributes a substantial amount of time completing the questionnaire ranging from 6 to 24 hours with an average of 15 hours including follow-up questions.

Average annual production for the mills that completed the survey was 15.25 million bf with a range of 7,230 to 48,000 MBF. A large hardwood lumber mills is considered 10 million bf or more. In a similar study, a large production softwood lumber mill in the southeast typically was 75 million bf or more (Milota *et al* 2004). A major challenge in conducting the LCI study was the small relative size of hardwood sawmills to the NE/NC region's total production. Because of the mill size demographics, a high number of mills were required to respond, compared to other CORRIM studies. There are at least 1,500 mills of greater than 2.0 MMBF annual production in the NE/NC United States with most being hardwood mills (USCB 2002). It was important that the HMA supported the project so that enough production data could be obtained to meet the minimum CORRIM requirement of 5% of total production in the NE/NC region.

For the 20 mills across the NE/NC United States, 305 million BF rough green lumber was produced in 2005 out of a total production from this region of 5,100 million BF. This value is roughly 6% (USCB 2006a) of the total United States' annual 2005 production that exceeded the minimum CORRIM protocol guideline for data representation (ISO 1998). Also, 180 million BF and 130 million BF of rough dry lumber and planed dry lumber, respectively, were produced. Not all sawn lumber was dried or planed prior to shipping.

Material flow was given in oven-dried weight per cubic meter of planed dry lumber. Data from the mill questionnaire were weight-averaged through the following equation, as previous CORRIM reports have done (Milota *et al* 2004).

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

where $\overline{P}$ 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 Hardwood lumber manufacturing and the four main unit processes

Production of hardwood lumber starts with hardwood logs that are typically trucked to the sawmill and stored in the log yard until sawn. Logs may be stored wet or dry depending on specie and season. There are four main unit processes in producing hardwood lumber: sawing, drying, energy generation, and planing (Figure 2.1). In the sawing process, the hardwood logs are sawn into mostly 1 in. (25.4 mm) thick rough green lumber of random widths and mostly 8-foot (2.44 m) lengths. The sawing process uses the most electrical consumption 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 6-8% moisture content on a dry basis (MC_{DB}) using energy-intensive drying methods. Not all rough green lumber is dried. After drying, the rough dry lumber is planed to the required dimension. Not all rough dry lumber is planed. The energy generation process provides electricity and heat primarily produced on-site for the other three processes.

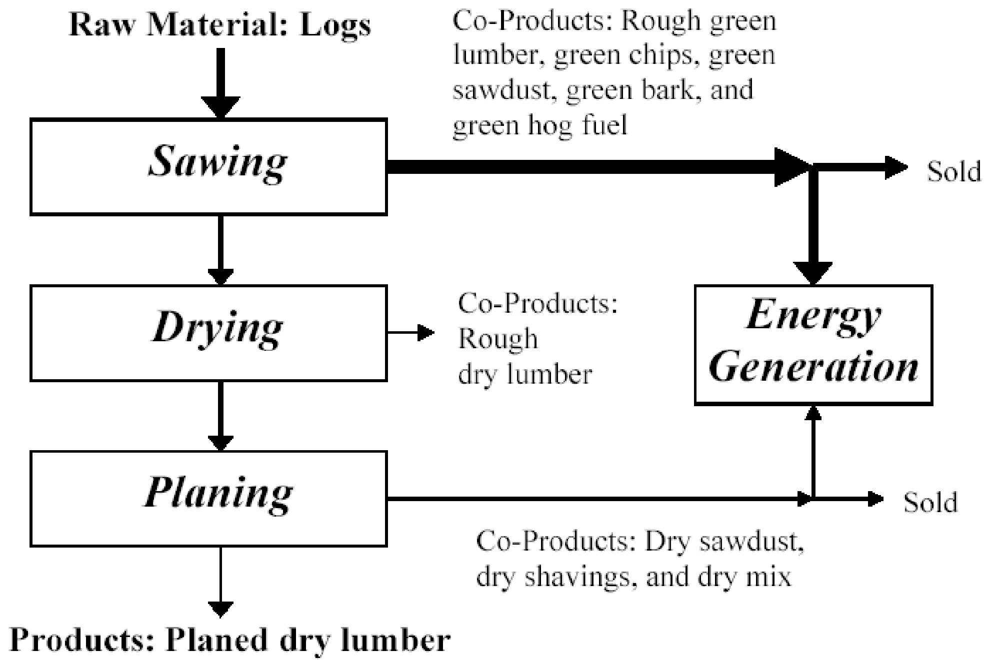

Figure 2.1. Description of the four unit processes for hardwood lumber manufacturing showing material flow.

2.1.1 Sawing

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

- sorting and storage of logs; storage either wet or dry depending on weather and specie
- in-yard transportation of logs from the point of unloading to the deck;
- in-yard transportation of logs from the storage deck to the mill infeed and debarker;
- debarking of the logs (by-product is bark);
- breakdown of logs into rough lumber, bark, slabs, edgings, sawdust, and chips;
    - slabs (flitches) are the sections of wood cut on a circular or band head rigs from the outside portions of logs when squaring the log for lumber; the slabs do not have square edges and one face is waney (has bark and is not flat)
    - edgings are strips removed by a machine called an edger that produces a square-edged board
- trimming, grading, and sorting
- stacking, stickering, and in-yard transportation of rough lumber to kilns or planar facilities; end-coating to aid drying and dipping to prevent staining may be done
- 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 sawn rough green lumber and wood residue from the sawing process; bark, sawdust, slabs, edgings, and chips (hog fuel is a mixture of the wood residues produced). Most wood residue is sold, as a co-product, while the other residues especially sawdust is combusted as fuel to mostly dry lumber. The remaining wood residues produce salable goods such as mulch, paper chips, feedstock for particle board plants, etc.

2.1.2 Drying

This unit process begins with rough green lumber and includes:

loading of stickered lumber into the following facilities depending on specie and equipment
pre-dryer
air yards
dry kiln
walnut steamer
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 rough dry lumber; the majority to the planer mill. Drying generates most of the volatile organic compounds (VOC) generated on-site and uses the most energy produced on-site from wood and fossil fuel combustion. Initial $\%MC_{db}$ (moisture content on a dry basis) is roughly 80% for rough green lumber and 7% for rough dry lumber. Different drying methods are used depending on species, lumber thickness, lumber grade, and available wood residue markets.

2.1.3 Energy generation

This unit process provides heat and in some cases electricity for use in other parts of the mill. A fuel such as wood or natural gas is burned; green wood residue from the sawing process generates most of the thermal energy used at the plant. The second source of energy used on-site is off-site grid electricity.

fuel handling;
water added to the boiler (i.e. make-up water);
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 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 and CO) from combustion.

2.1.4 Planing

This unit process begins with 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, dry pulp chips, and/or lumber trim ends. This process is the final stage of manufacturing. Some dry wood residue is combusted on-site in the boilers for energy while most is sold as co-products. Some planed lumber is only skip (hit or miss) planed from 25.4 mm (1 in.) to 23.8 mm (0.9375 in.) instead of the standard 20.6 mm (0.8125 in.) for 4/4 hardwood lumber. Secondary manufacturers, like hardwood flooring companies, also plane a significant portion of rough dry lumber. Furthermore, rough dry lumber is not precision end trimmed.

2.2 Functional Unit

Material flows, energy use, and emission data are standardized to a per unit volume basis for planed dry lumber of 1.0 cubic meter (m^3), i.e., the final product of the hardwood lumber manufacturing process. A typical conversion from cubic meters to actual MBF is 0.424 (2.36 cubic meters per MBF) that does not address the differences between nominal and actual dimensions which are common in the lumber industry. In this hardwood LCI study, one cubic meter of planed dry lumber equals 0.568 nominal thousand board feet. The United States industry standard uses nominal dimensions and commodity lumber is sold by variations of a thousand board feet (MBF). In this study, the assumed dimensions used to convert board feet to cubic meters are the nominal dimensions of 1 by 6 in. (25.4 by 152 mm) with actual planed dimensions of 0.8125 by 5.5 in. (20.6 by 140 mm) for an 8-ft (2.44-m) board. Rough green lumber and rough dry lumber are assumed to be 1.0625 by 5.6875 in. (27.0 mm by 144 mm) and 1.0 by 5.625 in. (25.4 by 143 mm), respectively, and board length is 8.17 ft (2.49 m) prior to planing (FPL 1999). 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 1998; ISO 2005; CORRIM 2001).

2.3 System boundaries

Boundary selection is important because the material and energy that cross this boundary need to be accounted for (Figure 2.2) through the gate-to-gate Life-Cycle Inventory. There are two boundaries as defined by CORRIM (Wilson and Sakimoto 2005) used to track the environmental impact of hardwood lumber production. One is the total (cumulative) system boundary (solid line in Fig. 5) that includes both on-site and off-site emissions for all material and energy consumed. The site system boundary (dotted line in Fig 5) is the environmental impact for emissions developed just at the hardwood sawmill (i.e. on-site) from the four unit processes. Examples of off-site emissions are grid electricity production, transportation of logs and lumber to and from the mill, and fuels produced off-site but used on-site.

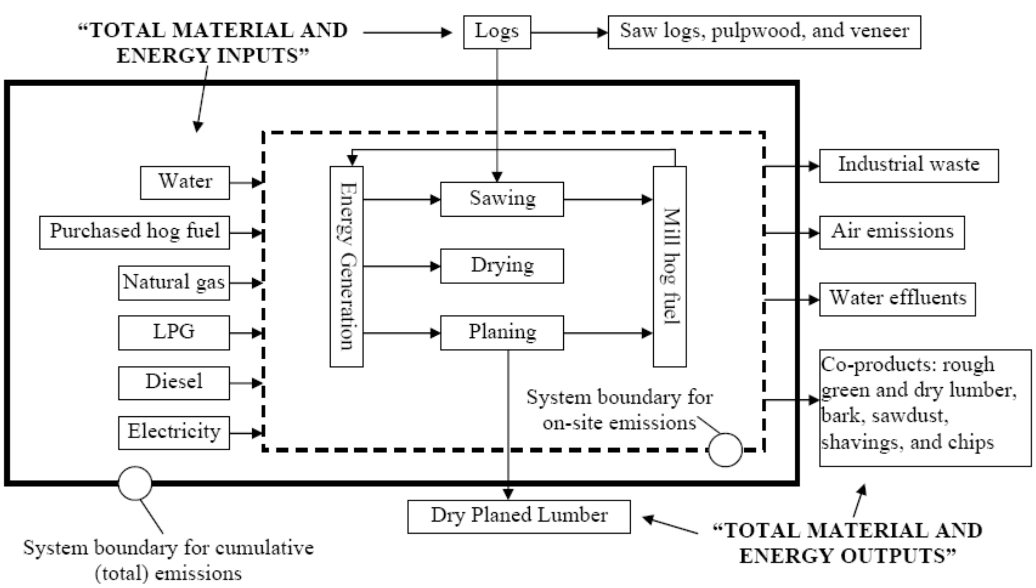

Figure 2.2. System boundaries for hardwood lumber production

2.4 Project Assumptions

Four different log scales (Scribner, Scribner Decimal C, Doyle, and International ¼) used by the 20 mills gave log inputs in thousand board feet (MBF). Common U.S. log scales estimate the green lumber output that might be sawn from a log, whereas lumber scales measures the actual green lumber volume produced from the log. Most other countries, including Europe, use a cubic log scale that measures the actual log volume (minus the bark). In the states that produce the most hardwood lumber, the Doyle scale is mostly used. The accuracy of U.S log scales varies with log diameter, type of sawing method, and sawing efficiencies. Small diameter logs typically produce more lumber for a given log scale volume than do largel diameter logs. The volume difference between the log and lumber scale is referred to as either overrun or underrun depending on whether the lumber scale or the log scale is higher. If the lumber scale is higher, there is an overrun. In this study, a 16% overrun was estimated. An average log conversion of 5.35 cubic meters per thousand board feet was used based on an average log diameter of 15 in. reported from a random sample of the participating mills and assuming a mixture of long and short logs (Spelter 2002).

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 5.35 cubic meters per thousand board feet and an average green density of 864 kg per m^3. Green lumber weights were developed from the National Hardwood Grading Rules (NHLA 2007). In this study, a 3.0% difference was calculated before and after sawing which fell within the CORRIM protocol.

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

A standard check was done on energy use for drying hardwood lumber. This study considered energy used on-site that included drying lumber but also energy for plant heating, walnut steaming, and electrical cogeneration. Walnut steamers are chambers used to color green walnut to a single consistent color. Direct steam or indirect steam piped through water vats are two of the common methods used to cause the color transformation. The direct steam method consumes a significantly larger amount of energy therefore the indirect method is becoming the preferred method. These sub-processes are typically not associated with values found in previous studies when calculating energy used in drying. Therefore, the three just stated sub-processes were not included in the following energy checks.

Using the following conditions: initial moisture content on a dry basis (MC_{DB}) of 80%, final MC_{DB} of 7%, boiler efficiency of 66.7%, kiln efficiency of 50%, and 15.2 MJ of energy to remove 1% moisture from 1.0 m^3 rough green lumber (34,561 BTU for 1% moisture per MBF) based on literature values, a total of 3,308 MJ per 1.0 m^3 (7.53 million BTU per MBF) rough green lumber was calculated (Wengert 1980). An estimated value of 3,560 MJ per 1.0 m^3 (7.65 million BTU per MBF) found from actual mill data resulted in a 1.6% difference between the literature and the actual values. Also, 9.82 MJ per kg (4,230 BTU per lb) of water would be removed during the drying process assuming using a moisture loss of 40% on a wet basis.

Energy use varied greatly for the drying process was determined to be ±152% of the average weighted value for the 18 mills drying lumber. This percentage indicated the large variance found was due to the different ages and types of drying technology and types of species being dried. Average technology was assumed with processes producing similar outputs in North America for modeling the environmental burden.

Primary data were collected through the pre-tested questionnaire in accordance with ISO protocol and CORRIM research guidelines. Missing values were not weight averaged for that particular process per ISO protocol to maintain good data quality. Primary data showed that the major species represented were red oak, white oak, yellow poplar, hard maple, soft maple, and black cherry of total sawn wood. These percentages varied notably from the US Census Bureau 2005 data (Table 2.1) with red and white oak percentages lower and yellow poplar and hard maple percentages higher compared to the 2005 Census figures. Red oak's plunge in the market during the end of 2005 and beginning of 2006 may account for the difference.

Logging transportation data assumed the same number of full trucks to empty trucks because logging trucks are usually built for only hauling logs not for hauling either lumber or wood residue. Each truck logging hauled roughly 6,000 bf or 48 tons (8 tons per MBF). Five mills did not report logging transportation data and were not weight averaged. The logging trucks were assumed to be empty upon return to the forest for more logs.

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

Green and dry wood density and specific gravity values found in the Wood Handbook (1999) for the 10 major wood species were used to determine the mass basis conversion from board feet. A weighted density of 854 kg/m^3 (53.3 lb/ft^3) and 624 kg/m^3 (38.9 lb/ft^3) was used for green and kiln dry lumber, respectively.

Volatile organic compound gas emissions were found through a secondary data source (Rice and Erich 2006) because primary data were not provided by the mill questionnaires.

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. 2004). Allocation refers to the distribution of environmental burden.

The LCI study covered one full year during the period 2005 and 2006 depending on when an operational (fiscal) year started at each hardwood lumber company. The geographical area covered the NE/NC United States shown in Figure 1.

2.5 Modeling Software Selection

Modeling software was needed to generate LCI air, water, and land emission data from the weight averaged results of material flow and energy use and type for hardwood lumber manufacturing in a systematic and transparent way. Also, the software would follow the ISO 14040 protocols related to environmental management when the LCI practitioner followed the basic four steps of life-cycle research. 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 has been 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 US 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.

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 down into three main sections: project data, library data, and general data. In this LCI study, the project data section is where all the new 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 2006).

2.6 Material Properties

2.6.1 Wood Species Composition

There are a large number of commercial hardwood species sawn in the NE/NC United States. Often, there are several species within one species group that are averaged together to find specific gravity and densities; red oak has nine species: black, cherrybark, laurel, northern red, pin, scarlet, southern red, water, and willow, hard maple has two species: sugar and black, white oak has six species: bur, chestnut, post, swamp chestnut, swamp white, and white, ash has three species: black, green, and white, soft maple has two species: red and silver, birch has three species: yellow, sweet, and birch. Table 2.1 shows the break down of primary mill data compared to the data found in the US Census Bureau for the 20 individual states reported as an aggregate for the entire NE/NC region.

Table 2.1 Species hardwood lumber production for the northeastern US compared to LCI survey data

	Species	US Census Bureau[1] (%)	LCI Survey Data (n=20) (%)
1	Red oak (mix)	35.2%	27.6%
2	Yellow poplar	14.4%	20.8%
3	Hard maple (mix)	7.0%	16.3%
4	White oak (mix)	16.8%	8.6%
5	Black cherry	3.7%	5.0%
6	Soft maple (mix)	5.2%	4.7%
7	Ash (mix)	4.2%	3.8%
8	Birch (mix)	1.1%	1.9%
9	Basswood	-	2.1%
10	Black walnut	0.9%	1.5%
11	Hickory	2.3%	1.1%
12	Other hardwoods 4/	2.4%	6.2%
	Total	**100%**	**100%**

[1] (USCB 2006a)

2.6.2 Wood Density and Specific Gravity

Logs

Wood density and specific gravity were calculated for incoming hardwood logs by weighted averages based on species distribution percentages (Table 2.1) from primary mill data and each species' specific density (Table 2.2) from secondary data found in the manual, Hardwoods of North America (1995). A weighted average green density of 854 kg per m^3 and a weighted average green specific gravity of 0.51 were calculated as shown in Table 2.2.

Table 2.2 Physical data for the species logged in the northeastern United States

		Density		Specific Gravity	
		Green	12%[1]	Green	12%[1]
	Species	(kg/m3)	(kg/m3)		
1	Red oak (mix)	1,023	716	0.57	0.64
2	Hard maple (mix)	881	673	0.54	0.60
3	Soft maple (mix)	761	569	0.47	0.51
4	White oak (mix)	1,035	756	0.60	0.67
5	Yellow poplar	609	449	0.40	0.42
6	Black cherry	721	561	0.47	0.50
7	Ash (mix)	796	620	0.51	0.55
8	Black walnut	929	609	0.51	0.55
9	Birch (mix)	876	678	0.54	0.61
10	Basswood	673	417	0.32	0.37
11	Hickory	1,025	801	0.64	0.72
12	Other	848	623	0.51	0.56
Weight Average		**854**	**624**	**0.51**	**0.56**

(Source: Hardwoods of North America 1995) [1] Moisture content is on dry basis

Lumber

Wood density and specific gravity were calculated for rough green lumber by weighted averages based on species percentages (Table 2.1) from primary mill data and each species' specific density (Table 2.3) from secondary mill data found in the National Hardwood Lumber Association Grading Rules 2007 calculated from values in the Wood Handbook (1999) and Hardwoods of North America (1995). A weighted average green density of 2,063 kg per MBF and 863 kg per m^3 were calculated as shown in Table 2.3.

Table 2.3 Physical data for the species sawn in the northeastern United States

		Density		Specific Gravity	
		Green	Green	Green	12%[1]
	Species	(kg/MBF)	(kg/m3)		
1	Red oak (mix)	2,415	1,023	0.57	0.64
2	Hard maple (mix)	2,117	897	0.54	0.60
3	Soft maple (mix)	1,890	801	0.47	0.51
4	White oak (mix)	2,407	1,020	0.60	0.67
5	Yellow poplar	1,436	608	0.40	0.42
6	Black cherry	1,701	721	0.47	0.50
7	Ash (mix)	1,877	795	0.51	0.55
8	Black walnut	2,192	929	0.51	0.55
9	Birch (mix)	2,067	876	0.54	0.61
10	Basswood	2,041	865	0.32	0.37
11	Hickory	2,419	1,025	0.64	0.72
12	Other	2,051	869	0.51	0.56
Weight Average		**2,063**	**863**	**0.51**	**0.56**

(Source: Wood Handbook and Hardwoods of North America)
[1] Moisture content is on a dry basis

2.6.3 Wood Fuel

Types

Distinguishing between the different wood fuels is necessary when entering wood fuel values into SimaPro 7.0.2. SimaPro lists three types of wood fuels used in this project. The major distinction between the three types concerned whether or not the wood fuel required energy and material inputs to process or combusted producing emissions or is as found in nature. The first type is entitled Wood boiler fuel which is listed as a raw material and it as found in nature therefore has no processing or combustion values assigned to it. The other two wood fuels are listed in the database as processes. The first one is Wood FAL found under the Material/Wood section and the process data given is for the cradle-to-gate resource requirements and emissions for providing 1000 pounds of wood (4.5 Million Btu in 1996) at 50% moisture content wet basis 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" (SimaPro 2007). As for the last type, Wood into industrial boilers, the process given is for the cradle-to-gate resource requirements and emissions for the combustion of 1000 lbs of wood (4.5 Million Btu in 1996) at 50% moisture content wet basis in industrial boilers.

Wood fuel used at the mill but either produced on-site or purchased off-site required two new types using both Wood into industrial boiler and Wood FAL processes. First, we worked on creating a new category for purchased wood fuel. In SimaPro 7, the default wood fuel inputted into the technosphere for the Wood into industrial boiler is Wood FAL. This setup is right for wood fuel purchased off-site and then combusted on-site because both the required energy and material to bring the wood fuel from nature to the mill gate and the emissions released during this process as well as the cradle-to-gate resource requirements to combust the material and emissions released during combustion is already accounted for. This new category was called "Wood into industrial boiler, NE/NC hardwood lumber, purchased". However, wood fuel generated on-site only needs values assigned to it of cradle-to-gate resource requirements and emissions for the combustion of this material, not the wood fuel. The reason is because the hardwood LCI already accounts for cradle-to-gate resource requirements and emissions for bringing the wood fuel to the boiler through the incoming logs. Therefore, the green and dry wood residue produced on-site used for fuel replaces Wood FAL. The second new category is called "Wood into industrial boiler, NE/NC hardwood lumber, generated".

Moisture Content

Wood FAL and Wood into industrial boilers are based on average USA technology, late 1990's (FAL 2001) and uses green wood at 50% MC (wet basis). In accordance with CORRIM guidelines, wood fuel values were entered into SimaPro using oven-dried weights with proper documentation of how this conversion was done for easier tracking.

2.6.4 Wood Residue

Green

Nearly half of the mills, (9 out of 20), use a water spray to keep their logs from staining especially during the summer. This water spray usually only affects the moisture content (MC) of the bark which can easily reach 60-70% MC and higher on a wet basis. Bark is not used as wood fuel for most mills and is less than 0.25% of total wood fuel consumed on-site. Moisture content of bark usually is not monitored or reported because its end product is mulch and sold by the green ton or cubic yard.

The average moisture content of hardwood logs was estimated at 50% MC_{WB} for the mass balance calculation. Physical properties used for green wood residues in calculations are listed in Table 2.4

including moisture content. As shown, weight percent can be significantly different from volume percent for the total log because of different densities.

Table 2.4 Physical properties of green wood residues plus conversions

	Co-Product MC (wet basis)	Weight Percent of Total Log	Weight Percent of Total Log[1]	Density	Density	Volume	Volume Percent of Total Log[1]
	(%)	(%)	(%)	(lb/ft^3)	(yd3/ton)	(ft^3)	(%)
Green Chips	46.3%	17.9%	20.1%	20[1]	3.7	1.01	32.4%
Green Sawdust	47.7%	14.9%	16.7%	20[1]	3.7	0.84	27.0%
Green Bark	52.4%	11.0%	N/A	25[1]	3.0	N/A	0.0%
Green Hog	45.6%	3.5%	4.0%	15	4.9	0.27	8.5%
Green Lumber	46.5%	52.6%	59.2%	53.3	1.4	1.11	35.7%
Total		100.0%	100.0%			3.11	100.0%

[1] Density values used were based on primary mill data for the wood residue sold as co-products

Kiln Dry

The planing process produces three types of kiln dry residue: shavings, sawdust, and mixings and their moisture content and other physical properties are listed in Table 2.5. Dry mixings are a combination of kiln dried wood residues not defined by the mill and the term is used to prevent confusion with hogged material which most people assume is green.

Table 2.5 Physical properties of dry wood residues plus conversions

	Co-Product MC (wet basis)	Percent by Wei ght	Density	Density
	(%)	(%)	(lb/ft^3)	(yd3/ton)
Dry Shavings[1]	10.6%	11.6%	11.5	6.4
Dry Sawdust[1]	7.3%	6.2%	6.0	12.3
Dry Mixings[2]	10.0%	6.0%	8.75	9.4
Planed Dry Lumber	9.6%	76.2%	38.9	1.9
Total		100.0%		

[1] The Industrial Wood Energy Handbook: Georgia Institute of Technology p. 61 (Table 3-1)
[2] Density for dry mixing is an average of dry shavings and dry sawdust

2.6.5 Lumber Volume Conversion Factors

The purpose of developing conversion factors is to derive material and energy use based on 1.0 cubic meter of planed dry lumber since not all rough green lumber is processed at the facility. Estimates of different size material from the sawmill, dryer, and planer were developed based on standard (Wood Handbook p.5-6) dimensional sizing of rough and planed hardwood lumber. The ratios show that for 1.0 cubic meter of planed dry lumber, 1.46 cubic meter of rough green lumber, and 1.37 cubic meter of rough dry lumber was used. These numbers indicate that there is shrinkage from rough green lumber and material loss from the planning regarding the planed dry lumber.

For example, wood fuel consumption was based on the actual rough green lumber entering and rough dry lumber leaving the drying process instead of total rough green lumber produced since some mills sold part or all of their rough green lumber. After the wood fuel values were found for drying based on the rough dry lumber produced, the energy values were then converted to a per unit basis of planed dry lumber basis using values calculated in Table 2.6.

Table 2.6 Conversion of nominal measurement to actual volumes

	Nominal	Rough Green Lumber	Rough Dry Lumber	Planed Dry Lumber
	(in)	(in)	(in)	(in)
Selected Width	6	5.6875	5.625	5.5
Thickness	1	1.125	1.0625	0.8125
Length	96	98	98	96
Actual to Nominal Ratio	---	1.09	1.017	0.745
MBF per actual cubic meter	2.36	2.57	2.40	1.76

3.0 Product Yields

Mass and energy values, including emissions for hardwood lumber production, were found by surveying 20 mills in the NE/NC United States with detailed questionnaires 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.

All energy and material values were weight averaged from 20 mills across the NE/NC United States. For the 20 mills, 305 million BF rough green lumber was produced in 2005 out of a total production from this region of 5,100 million BF. This value is roughly 6% (USCB 2006a) of the total U.S. annual 2005 production that exceeded the minimum CORRIM protocol guideline for data representation (ISO 1998). Also, 180 million BF and 130 million BF of rough dry lumber and planed dry lumber, respectively, were produced. Not all sawn lumber was dried or planed prior to shipping.

For the mass balance, the LCI study examined the four unit processes and the overall process to track material flow. Overall, 1,170 oven-dried (OD) kg (2,633 OD lb) of incoming hardwood logs with a density of 854 kg/m^3 (53.9 lb/ft^3) produced 1.0 m^3 (637 bf) of planed dry lumber (Table 3.1). Sawing produced 712 OD kg of rough green lumber; the drying process did not result in any loss of wood substance. Planing reduced the 712 OD kg of rough dry lumber to 535 OD kg of planed dry lumber, for a 25% reduction in mass. Input and output sums of 1,301 and 1,311 for the sawing process indicated the difference in calculating the oven-dry mass of incoming logs and the oven-dry mass of green lumber and the associated green wood residue. Boiler process input sum of 217 OD kg (Table 3.1) closely approximated the sum of total differences shown in the last column (206 OD kg). Overall, the log was reduced to 45.8% of its original mass in converting it to the final product of planed dry lumber. See Appendix B-1 for flowchart showing material flow including co-products.

Table 3.1 Overall wood mass balance for 1.0 cubic meter of planed dry lumber (oven dry kilogram)

	Sawing Process		Boiler Process	Drying Process		Planer Process		All Processes Combined		
Material	Input	Output	Input	Input	Output	Input	Output	Input	Output	Diff
(oven-dried kg)[1]										
Green logs	1170							1170	0	-1176
Green chips		227	30.3					30	227	196
Green sawdust		189	140					140	189	49
Green bark[2]	131	139	0.5					132	139	7.9
Green hog fuel		45	18.4					18	45	26
Rough green lumber		712		712				712	712	0
Rough dry lumber					712	712		712	712	0
Planed dry lumber							535	0	535	535
Dry shavings			0				86	0	86	86
Dry sawdust			27.4				46	27	46	19
Dry Mixings			0				44	0	44	44
Sum	**1301**	**1311**	**217**	**712**	**712**	**712**	**712**	**2941**	**2735**	**-206**

[1] Values given in oven-dry weights
[2] Bark volume is not included in log scale

Mills are concerned with their lumber recovery factor. Lumber recovery factor is the board feet produced per cubic feet of log inputs. Therefore the volume reduction and an average lumber recovery factor were determined. Most mills in the US use volumetric values such as board feet to purchase and sell their products. In the northeastern region of the US, 2.29 m^3 (142 ft^3) of hardwood logs are sawn, dried, and planed into the final product of 1.0 m^3 (658 nominal bf) of planed dry lumber for a total volume conversion of 43.7% of incoming logs (Table 3.2). An average lumber recovery factor of 6.29 BF rough green lumber per cubic foot of logs was calculated. The difference for total volume and total mass conversion was due to shrinkage during the drying process.

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

	Wood Volume (actual dimensions)[1,2]		
	(m^3 per 1.0 m^3)	(ft^3 per MBF)[3]	(%)
Raw Wood Material			
Incoming green log	2.29	142	100%
Rough green lumber	1.46	90.9	63.9%
Rough dried lumber	1.37	84.9	59.6%
Final Product			
Planed dried lumber	1.00	62.2	43.7%

[1] All values provided in actual dimensions.
[2] Final planed dry lumber dimensions of 19.1 mm (0.75 in) thick by 14.0 mm (5.5 in) wide
[3] 1.76 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber

4.0 Energy Consumption

4.1 Electrical Use

Hardwood lumber production requires both electrical and thermal energy for processing logs into planed dry lumber. All of the thermal energy is produced on-site while most electricity (grid electricity) is produced off-site. Electrical energy is required by all four unit processes while most thermal energy is required by the drying process. Nineteen of the 20 responding mills reported their mill's electrical usage. Total electrical consumption is 608 MJ per 1.0 m^3 (297 kWh per MBF) planed dry lumber. This includes both off-site and on-site electrical sources (Table 4.1).

Table 4.1 Material and energy consumed on-site to produce a cubic meter of planed dry lumber

Fuel Type	Quantity	SI Units per m^3	Quantity	Units per MBF[5]
Fossil Fuel[1]				
Natural Gas	16.4	m^3	1.02	1000 ft^3
Fuel Oil #1	0.02	L	0.009	Gal
Fuel Oil #2	2.08	L	0.964	Gal
Fuel Oil #6	0.01	L	0.004	Gal
Propane	1.21	L	0.560	Gal
Electricity[2]				
Off-site generation	597	MJ	292	kWh
On-site generation	10.2	MJ	5.0	kWh
On-Site Transportation Fuel[3]				
Off-Road Diesel	6.65	L	3.05	Gal
Propane	0.267	L	0.124	Gal
Gasoline	0.571	L	0.265	Gal
Renewable Fuel[4]				
On-site Wood Fuel	217	Kg	478	Lb
Purchased Wood Fuel	35.4	Kg	78	Lb
Water Use				
Municipal water	-	L	-	Gal
Ground water	244	L	113	Gal

[1] Energy values were found using their higher heating values (HHV) in MJ/kg: 54.4 for natural gas, 43.3 for fuel oil #1 and #2, 45.5 for fuel oil #6, and 54.0 for propane (LPG)
[2] Conversion unit for electricity is 3.6 MJ/kWh
[3] Energy values were found using their higher heating values (HHV) in MJ/kg: 45.5 for off-road diesel and 54.4 for gasoline
[4] Values given in oven-dried weights (20.9 MJ per OD kg)
[5] 1.76 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber

4.2 Electrical Energy Composition for Unit Processes

For the unit processes, sawing, drying, energy generation (boiler operation), and planing the distribution of electrical energy consumption was 50%, 25%, 5%, and 20% of the total, respectively. Based on these percentages, the four unit processes use 304, 152, 31, and 121 MJ per cubic meter or 148, 74, 15, and 60 kWh per MBF planed dry lumber, respectively.

4.3 Sources of Energy

4.3.1 Major Sources

The thermal energy required for drying and other associated drying processes including walnut steaming, 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, 217 OD kg, and some purchased wood fuel, 35.4 OD kg, is combusted to generate heat for the mill per 1.0 m^3 planed dry lumber. Thermal energy produced on-site makes up the largest proportion of energy used on-site. Overall, wood fuel composed 87% of total energy consumed on-site with the next largest contributor being natural gas at 11%. Coal was the largest source of energy used off-site (beyond the mill's boundary) because most grid electricity is from coal power plants in the northeastern United States.

4.3.2 Transportation Fuel

On-site transportation of wood stock is a major fuel consumer with off-road diesel having the highest consumption. Propane and natural gas are also used for forklifts, front-end loaders, trucks, and other equipment used within the system boundary of the facility. Off-road diesel consumption is 6.57 liters (L) per unit basis of planed dry lumber and is consumed at ten times the rate of either propane or gasoline on average. Fuel consumption is broken down for the unit processes into the following percentage; 60%, 10%, 10%, and 20% for sawing, drying, energy generation, and planing. The corresponding values of the four processes for off-road diesel are 3.94, 0.66, 0.66, and 1.31 L, respectively.

4.3.3 Off-site Electricity

The location of the hardwood lumber facility affects the environmental impact since most electricity is used from the electric power industry. The Pacific Northwest region produces most of their electricity from hydro (Milota et al 2005). Average composition of (off-site) electrical generation was found for the NE/NC region by totaling the amount of the different fuel sources for each of the 20 states given in thousand kWh and calculating the percentages (USDOE 2006). The most significant electric power contributor in the northeastern region is coal with 58.0% 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 23.7%, 10.3%, 3.4%, 2.7%, and 1.9%, respectively (Appendix C-1).

4.4 Water Consumption

Water use was mainly for sprinkling logs, boiler make-up water, and dust control of the mill yards during the dry season. Water consumption was based on responses from 15 mills with one mill using over 50% of total reported use for mostly dust control and some boiler make-up water. Dust control is a problem for several mills having dirt air yards especially during the dry season. Some mills are actively examining alternative methods that would also have a minimal environmental impact. A weight average water consumption of 244 liters per cubic meter (113 gallons per MBF) of planed dry lumber was calculated.

4.5 Log Transportation

Logging transportation data were required to connect the forest resource LCI to the hardwood lumber LCI. An average one-way haul distance of 125 kilometers (77.5 miles) was calculated from primary mill data with 100% empty backhaul for hardwood log transportation.

5.0 Environmental Impact

SimaPro 7 modeled output factors during the manufacturing process with major consumption for raw materials, other than wood, from electrical generation. Wood, coal, and natural gas are the largest accumulative contributors with the allocated values of 51.2, 36.9, and 15.5 kg, respectively, for energy consumption and 1,218 OD kg of wood used in processing (Table 5.1). Most of the coal and natural gas was used to produce off-site electricity but some was for producing transportation fuel used on-site. The region selected for production affects the environmental impact of hardwood lumber production because coal is the off-site material used most for electrical power in the Northeast, whereas most power in the Pacific Northwest is produced from hydro and natural gas.

Table 5.1 Raw materials consumed during production of planed dry lumber

Raw Material[5]	Quantity[1]	SI Units per m^3	Quantity	Units per MBF[2]
Wood, unspecified, standing[3]	1.43	m^3	88.5	ft^3
Water, well, in ground	0.15	m^3	9.43	ft^3
Wood and wood waste	26.2	kg	101	lb
Coal, in ground	35.3	kg	137	lb
Gas, natural, in ground	14.4	kg	55.7	lb
Oil, crude, in ground	8.16	kg	31.6	lb
Limestone, in ground	5.34	kg	20.7	lb
Energy, from hydro power[4]	11.5	MJ	5.6	kWh
Energy, unspecified[4]	8.12	MJ	4.0	kWh
Uranium, in ground	0.00093	kg	0.00361	lb

[1] 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,
[2] 1.76 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber
[3] Amount of wood in lumber form entering the planing process
[4] Conversion units for electricity is 3.6 MJ/kWh
[5] Values are allocated and accumulative

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. Emission values of 428 and 139 kg were reported from SimaPro for CO_2 (biogenic) and CO_2 (anthropogenic), respectively (Table 5.2). Research into measuring volatile organic compound (VOC) gases produced from drying lumber generated the value of 1.26 kg and is specie, temperature, and moisture dependent with the highest VOC emissions from red oak (Rice and Erich 2006).

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

Substance	Allocated total		Allocated on-site	
	kg/m^3	lb/MBF[1]	kg/m^3	lb/MBF[1]
Water Emissions				
Biological Oxygen Demand (BOD)	9.62E-04	3.73E-03	1.62E-04	6.29E-04
Cl^-	4.05E-02	1.57E-01	1.01E-03	3.93E-03
Suspended Solids	6.96E-02	2.70E-01	1.12E-02	4.36E-02
Oils	1.58E-02	5.89E-02	6.42E-04	2.49E-03
Dissolved Solids	8.90E-01	3.45E+00	3.75E-02	1.46E-01
Chemical Oxygen Demand (COD)	1.28E-02	4.97E-02	5.78E-03	2.24E-02
Soil Emissions				
Waste in inert landfill	7.53E+00	2.92E+01	7.53E+00	2.92E+01
Waste to recycling	2.24E-01	8.69E-01	2.24E-01	8.69E-01
Solid Waste	3.57E+01	1.38E+02	1.72E+01	6.67E+01
Air Emissions				
CO	3.13E+00	1.21E+01	2.84E+00	1.10E+01
CO_2 (biomass)	4.28E+02	1.66E+03	3.98E+02	1.54E+03
CO_2 (fossil)	1.39E+02	5.37E+02	4.65E+01	1.80E+02
CH_4	2.73E-01	1.06E+00	3.96E-03	1.54E-02
Non-methane, volatile organic compounds (NMVOC)	2.32E-01	9.00E-01	6.87E-02	2.66E-01
NOx	1.02E+00	3.97E+00	6.37E-01	2.47E+00
Particulate (Total)	1.16E+00	4.49E+00	1.16E+00	4.49E+00
Particulate (PM10)	7.35E-02	2.85E-01	5.33E-02	2.07E-01
Particulate (unspecified)	9.05E-02	3.51E-01	1.40E-03	5.43E-03
SOx	1.15E+00	4.46E+00	7.46E-02	2.89E-01
VOC	1.20E+00	4.67E+00	1.20E+00	4.67E+00

[1] 1.76 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber

6.0 Carbon Balance

Carbon emissions play an increasingly important role in policy decision-making in the US 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 hardwood roundwood values for the NE/NC United States. Carbon input was 914 kg per m^3 planed dry lumber while the total output was 908 kg per unit basis (Table 6.1) resulting in a percent difference of 0.71%.

Table 6.1 Tracking of wood-based carbon inputs and outputs for hardwood lumber

	Elemental Carbon	
Substance[1]	(kg/m^3)	(lb/MBF)[2]
Input		
Logs	670	2,600
Bark	75	291
Wood fuel	170	482
Sum carbon in	914	3,370
Output		
Planed dry lumber	306	1,190
Co-products	444	1,722
Solid emissions	0	0
Air emissions	157	349
Sum carbon out	908	3,260

[1] Wood-related carbon and its emissions

2 1.76 m3 per 1.0 nominal MBF (thousand board feet) planed dry lumber

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

	Total[1]		Carbon[1]		
Substance	(kg/OD kg)	(kg/m^3)	%	Kg/m3	(lb/MBF)[2]
Benzene	1.31E-06	7.35E-04	92.3%	6.78E-04	2.85E-03
Carbon dioxide, biogenic	7.64E-01	4.28E+02	27.3%	1.17E+02	1.66E+03
Carbon dioxide, fossil	2.47E-01	1.39E+02	27.3%	3.78E+01	5.37E+02
Carbon monoxide	5.58E-03	3.13E+00	42.9%	1.34E+00	1.21E+01
Formaldehyde	9.63E-06	5.40E-03	40.0%	2.16E-03	2.09E-02
Methane	4.86E-04	2.73E-01	75.0%	2.04E-01	1.06E+00
Naphthalene	8.73E-07	4.89E-04	93.7%	4.59E-04	1.90E-03
NMVOC, non-methane volatile organic compounds, unspecified origin	4.14E-04	2.32E-01	88.2%	2.05E-01	9.00E-01
Organic substances, unspecified	6.18E-05	3.46E-02	50.0%	1.73E-02	1.34E-01
Phenol	1.46E-05	8.16E-03	76.6%	6.25E-03	3.16E-02
VOC, volatile organic compounds	2.15E-03	1.20E+00	88.2%	1.06E+00	4.67E+00
Total	1.02	572	27.5%	157	2216

[1] All values per unit of planed dry lumber

[2] 1.76 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber

[3] Percentage from Softwood Lumber LCI (Milota *et al* 2004) and Softwood Plywood LCI (Wilson & 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. A sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in hardwood lumber manufacturing, heat is used in several sub-processes, consuming a combination of wood and natural gas 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 using all on-site produced wood fuel—consisting of mostly green sawdust and green chips from the sawing process—or natural gas as a fuel input.

7.1 Alternative Fuel Sources

For the “base” fuel mix in this LCI study, there were four fuel sources with wood fuel and natural gas contributing the majority of the energy. Propane and fuel oil contributed about 2% with the bulk being used for facility heating. The original model based on survey data assumed 87.2% of the fuel used was in the form of wood fuel, with 74.4% produced on-site and the rest purchased, with 10.8% as natural gas. Most mills use only one or two types of fuel, whereas the original study resulted in an average model incorporating different fuel sources taken from primary mill data for all 20 mills. There were two alternative fuel use schemes applied to this “average mill” to be used in this sensitivity analysis. One alternative was assumed total on-site wood fuel use by increasing the initial value of 240 to 300 OD kg for the all (100%) wood fuel case to generate 5,800 MJ of energy per cubic meter (9.66 million BTU per MBF) of planed dry lumber. The second alternative had natural gas use increase from 16.4 to 151 m^3 for the all (100%) natural gas case.

7.2 Three Fuel Source Scenarios

This sensitivity analysis examined three scenarios for heat generation using the base fuel mix, all (100%) natural gas, and all (100%) on-site produced wood fuel cases. These three scenarios were modeled: 1) comparing all (100%) natural gas to the base hardwood lumber fuel mix, with no fuel changes and incorporating both natural gas and wood fuel, 2) comparing all (100%) on-site produced wood fuel to the base hardwood lumber fuel mix, with no changes, and 3) comparing all (100%) natural gas to all (100%) on-site produced wood fuel as energy for heat.

7.3 Sensitivity Analysis Results

Table 7 is a summary of the three fuel use scenarios, with a partial list of air emissions for the Northeast. 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 releases fewer emissions. Scenario 1 indicated that less particulate and biogenic CO_2 but more fossil CO_2, SOx, and NOx were produced when burning 100% natural gas compared to the base fuel mix (original). Scenario 2 showed the opposite as more biogenic CO_2 and particulate but less fossil CO_2, SOx, and NOx were produced when burning 100% wood fuel compared to the base fuel mix (original). In scenario 3, a negative number indicates that the all natural gas case releases fewer emissions than all on-site produced wood fuel case and a positive percentage number means that all on-site produced wood fuel model releases fewer emissions. Scenario 3 highlighted the difference when a larger amount of wood fuel was consumed as the amount of fossil CO_2, SOx, and NOx produced increased from Scenario 1 but less particulate and biogenic CO2 was produced when compared to Scenario 2. For all three scenarios, the amount of VOC produced was significantly different regardless of the fuel used because most VOC originated in the actual drying of the hardwood lumber.

Table 7.1 Sensitivity Analysis for manufacturing hardwood lumber in the Northeast

Substance	Fuel Distribution[1] 100% Natural Gas	100% Wood Fuel	Original	Scenario 1 100% Natural Gas to Original Difference (%)	Scenario 2 100% Wood Fuel to Original Difference (%)	Scenario 3 100% Natural Gas to 100% Wood Fuel Difference (%)
	kg per cubic meter planed dry lumber					
Acetaldehyde	1.14E-06	7.34E-04	6.12E-04	-199.3%	18.2%	-199.4%
Benzene	1.13E-06	8.82E-04	7.35E-04	-199.4%	18.2%	-199.5%
CO_2 (biogenic)	8.50E-02	5.14E+02	4.28E+02	-199.9%	18.3%	-199.9%
CO_2 (fossil)	3.46E+02	1.08E+02	1.39E+02	85.3%	-24.7%	104.5%
CO	7.97E-01	3.63E+00	3.13E+00	-118.9%	14.7%	-128.0%
Formaldehyde	3.48E-03	5.90E-03	5.40E-03	-43.2%	8.8%	-51.5%
Methane	8.98E-01	1.99E-01	2.73E-01	106.8%	-31.3%	127.4%
Naphthalene	1.23E-07	5.87E-04	4.89E-04	-199.9%	18.3%	-199.9%
NOx	1.34E+00	9.94E-01	2.32E-01	140.9%	124.3%	29.6%
Non-methane, VOC	1.12E+00	1.09E-01	1.02E+00	9.2%	-161.3%	164.4%
Organic substances, unspecified	2.10E-03	4.12E-02	3.46E-02	-177.1%	17.3%	-180.6%
Particulate (total)	8.77E-01	1.27E+00	1.16E+00	-27.8%	9.0%	-36.6%
Particulate (PM10)	4.96E-02	7.99E-02	7.35E-02	-38.8%	8.4%	-46.9%
Particulate (unspecified)	8.56E-02	9.33E-02	9.05E-02	-5.6%	3.0%	-8.6%
Phenol	3.71E-06	9.79E-03	8.16E-03	-199.8%	18.2%	-199.8%
SOx	4.50E+00	7.39E-01	1.15E+00	118.6%	-43.5%	143.6%
VOC	1.17E+00	1.22E+00	1.20E+00	-2.2%	1.3%	-3.5%

[1] EPS 2000 V2.02 Method was used in SimaPro 7 to calculate emissions

8.0 Study Summary

A rigorous material and energy balance was completed on 20 hardwood mills located in the northeastern United States. The results indicate that total energy consumption varied significantly, depending on the species sawn, age of the boiler and dry kiln equipment, and method of drying. For hardwood lumber, an average thermal consumption of 5,800 MJ per cubic meter of planed dry lumber (9.66 million BTU per MBF) and electrical energy consumption of 608 MJ per cubic meter of planed dry lumber (297 kWh per MBF) were found. Two mills produced their own electrical power from the wood residue produced on-site and consumed about four times the amount of wood residue than mills that did not produce their electrical power per unit volume of lumber dried.

Electrical consumption varied significantly, depending on whether the mill used dehumidification, predryers, or air yards to dry lumber. Two mills using dehumidification kilns consumed 45.3% more electrical energy compared to the other mills, although dehumidification kilns used less than 5% of the average thermal energy. Most mills producing red and white oak lumber used predryers and air yards to lower moisture content prior to kiln drying to reduce time in the kilns. Mills running predyers used 64.5% more electricity than did the average mill.

Thermal energy use also varied considerably, depending on whether the mill ran a walnut steamer or a cogeneration unit. Four mills operated a walnut steamer. Thermal energy was reduced by 45.3% for on-site wood fuel use from 151 to 83 OD kg per m^3 planed dry lumber when the mills steaming walnut and producing on-site electricity were not used in calculations. This is significant because wood fuel produced on-site provides about 74% of the total thermal energy required.

LCI projects for softwood lumber production consumed less electrical and thermal energy in their production (Milota et al 2005) compared to hardwood lumber (Table 8.1). There are several reasons for this. One reason is that hardwood lumber requires longer drying times to prevent lumber degrade. Also, more thermal energy is consumed because of the higher amount of water in hardwoods due to their typical higher density than softwoods for the same volume of product (Simpson 1991). Another reason is that hardwood logs are more likely to be converted to high-grade lumber. Also, hardwoods are typically dried to a lower final MC of 6 to 8% compared to 15 to 19%MC for softwoods depending on intended end use.As stated, hardwoods are generally more dense than softwood lumber and since hardwood lumber is typically sawn to thinner dimensions, more electrical energy is consumed in the sawing process (more sawlines are required to breakdown the log into lumber). In this study, the Northeast used more energy to keep the facility heated during winter months compared to the Pacific Northwest and Southeast, the primary regions for softwood lumber production.

Table 8.1 Comparison of hardwood to softwood lumber energy use

	Overall Energy Consumption [1,2]			
	Electrical Energy		Thermal Energy	
	(MJ per m^3)	(kWh per MBF)	(MJ per m^3)	(BTU per MBF)
Hardwood Lumber	597	297[3]	5,400	9.6 million[3]
Softwood Lumber	335[4]	151	3,600	5.5 million

[1] All values provided in actual dimensions.

[2] Final planed dry lumber dimensions of 19.1 mm (0.75 in) thick by 14.0 mm (5.5 in) wide

[3] 1.76 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber and includes walnut steaming and plant heating

[4] 1.623 m^3 per 1.0 nominal MBF (thousand board feet) planed dry lumber; 3.6 MJ per kWh, 1054 MJ per million BTU

9.0 Discussion

Total energy consumption per cubic meter of planed dry hardwood lumber was found to be comparable to published data (Armstrong and Brock 1989; Comstock 1975). However, unlike previous studies, processes such as walnut steaming, 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 or in a finished wood product from hardwood lumber 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. The most energy efficient method would be upgrading or refurbishing the mill’s aging dry kiln facilities at mills currently using more than 1.5 times the amount of energy per MBF as compared to the mill using similar drying technology with similar specie composition. This may also improve lumber quality because the newer dry kilns will probably have greater precision and accuracy in maintaining kiln temperatures and fan speeds. Sawing lumber manually (without computer assistance) may increase sawing errors, and thus sawing time and electrical costs. Using improved sawing practices such as the Best Opening Face program (Harpole and Hallock 1977) and thinner saw kerfs have increased lumber yields while lowering electricity consumption.

Another approach reduces thermal energy use. Several different drying methods 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 degrade and large quantity of drying stock required except for slow-drying species like red and white oak. 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 lowest 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 1999a; Denig *et al* 2000).

10.0 Conclusion

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

- Sawing consumes the highest proportion of electricity in the manufacturing of hardwood 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 LCI 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 drying kilns commonly used in the Scandavian countries would also significantly reduced energy consumption
- Increasing on-site wood fuel consumption would reduce fossil greenhouse gases but increase other gases especially particulate emissions.

Region selected for production affects the environmental impact of this product because coal is largest 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 while most power in the Southeast is produced from coal and uranium just like 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 hardwood lumber.
- Once the competing non-wood substitutes have been inventoried, product selection for sustainable building could be used to compare vinyl to hardwood moulding or carpet systems to solid hardwood flooring.

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 hardwood 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 results give all values based on a cubic meter; therefore, thickness of material is a critical dimension for consideration.

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Appendix

Appendix A-1: Primary Mill Data questionnaire: Introduction and Questionnaire.

Hardwood 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. hardwood 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 Eastern Region (all states bordering as well as east of the Mississippi River), my final report will describe a gate-to-gate analysis of hardwood sawmills. The information collected will show the comparison of wood versus 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 **December 29, 2006**.

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.

Hardwood 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. Rough Green Lumber Production

For reporting year __________ thousand board feet (BF)

Percent kiln dried __________ %

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 _____ ○ resaws, how many: ______ ○ edgers, how many: ______ ○ edger optimizer ○ trimmer optimizer ○ trimmer ○ sorter, # bins: ______ ○ sticker stacker	❑ dryers ○ predryer ○ conventional steam (10-15 psig) ○ high temperature steam ○ direct-fired ○ dehumidification ○ transfer car system ○ air drying yard ❑ boiler ○ wood-fired boiler ○ gas-fired boiler (natural or propane) ○ oil-fired boiler ○ cogeneration facility ○ 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 – see Block Diagram on page 6)

- 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. If less than 2% of total, use category labeled "Other".

Species	**% of total log input into sawmill**
Total	100%

TOTAL (NON-TRANSPORTATION) FUEL USE (see Block Diagram on page 7)

- Wood
  1. On-site wood boiler fuel ______________ @ ________ %MC tons
  2. Purchased wood boiler fuel ______________ @ ________ %MC tons

- Fossil Fuel
  3. Natural Gas ______________________ thousand cubic feet (ft^3)
  4. Fuel oil #1(kerosene) ______________________ gallons
  5. Fuel oil #2 (heating oil) ______________________ gallons
  6. Fuel oil #6 ______________________ gallons
  7. Propane ______________________ gallons
  8. Other ______________________
  9. Electricity for entire facility ______________________ kilowatt-hours (kWh)

TOTAL WATER USE

- Water ______________________ gallons or ft^3

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 (-).

Co-products and By-Products	Moisture Content	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

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

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

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

TRANSPORTATION – LOGGING TRUCKS

Mileage logging/lumber trucks travel annually ______________miles
______________% One-way
______________% Empty backhaul

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	Quantity (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	[1]Usage, kWh						
	included in energy table, Y or N						
Type of emissions controlled							

[1]Or state other units

Glossary

Product = the primary material produced from manufacturing and "sold outside of the system boundary;"

Co-product = a material produced from manufacturing and "sold outside of the system boundary;"

Internal by-product = a material produced during the manufacturing that is recycled or used "within the system boundaries"

Industrial waste = a material produced during the manufacturing that requires "disposal outside of the system boundary"

HAPs = Hazardous Air Pollutants

ROG = Reactive Organic Gases (also referred to as Volatile Organic Compounds (VOCs)

Slabs = 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 = these pieces of board that passed through a machine called an edger that can make two or more lineal cuts simultaneously

General refuse = waste collected from the sawmill operation that is mixed with dirt and cannot be sent to the boiler

Recycled material = material collected from the sawmill operation that is recycled

Packaging material = steel strapping, plastic lumber covers, and cardboard corners

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)

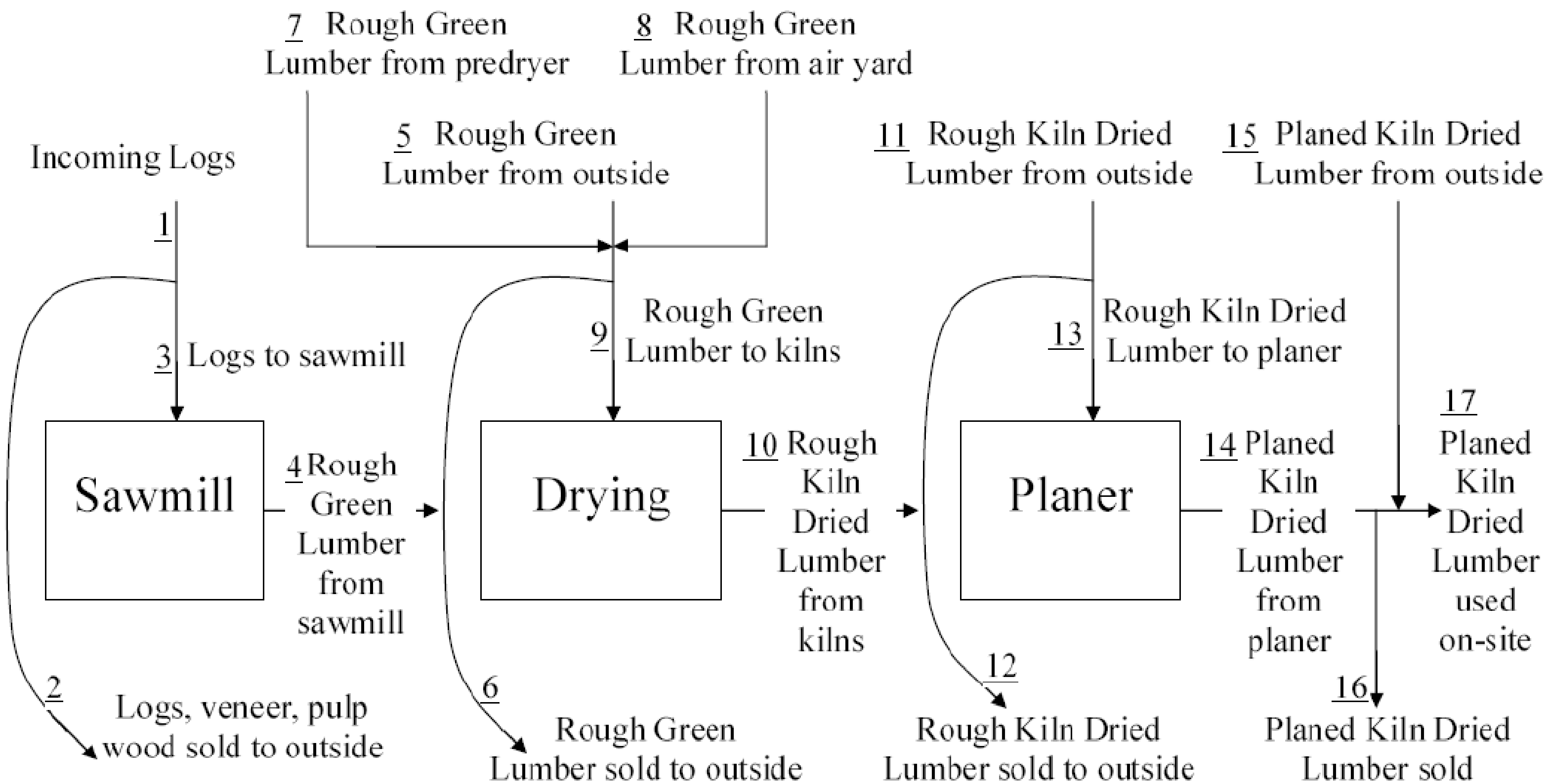
Reporting Year:	Starting Month:	Ending Month:

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.

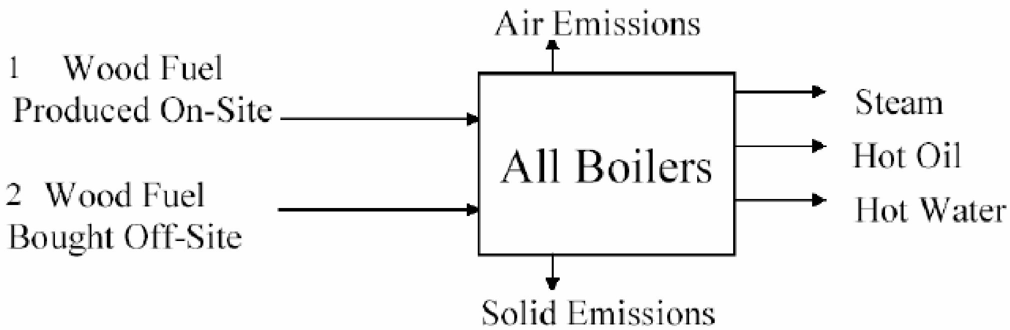
- fuel handling;
- water added to the boiler;
- chemicals added at the boiler or to steam lines;
- distribution of the steam;
- distribution of electricity; and
- the treatment of process air, liquids, and solids.
- The outputs of this unit process are process steam and electricity.

Hardwood Sawmill Block Diagram

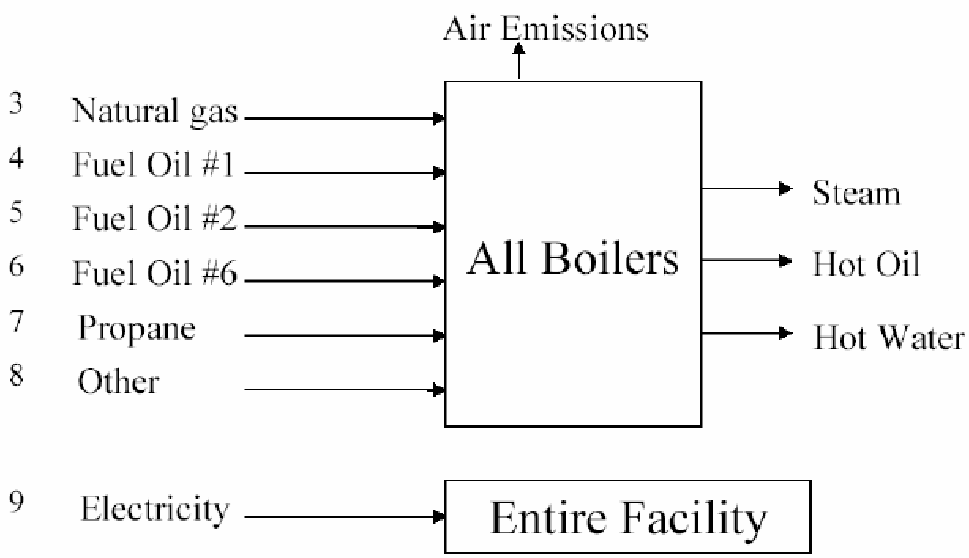


Energy Generation Block Diagram

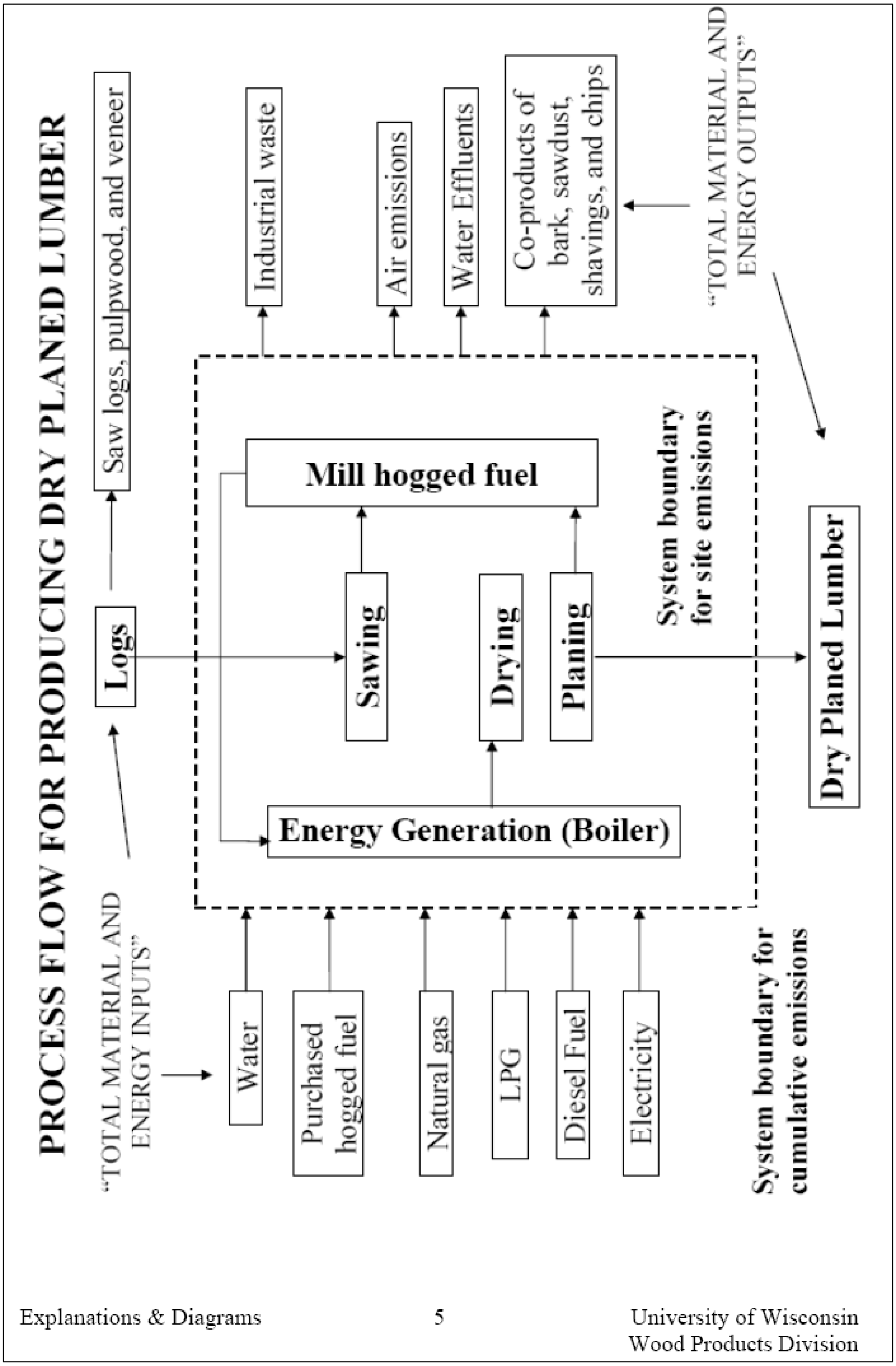
Wood (Biomass) Fuel



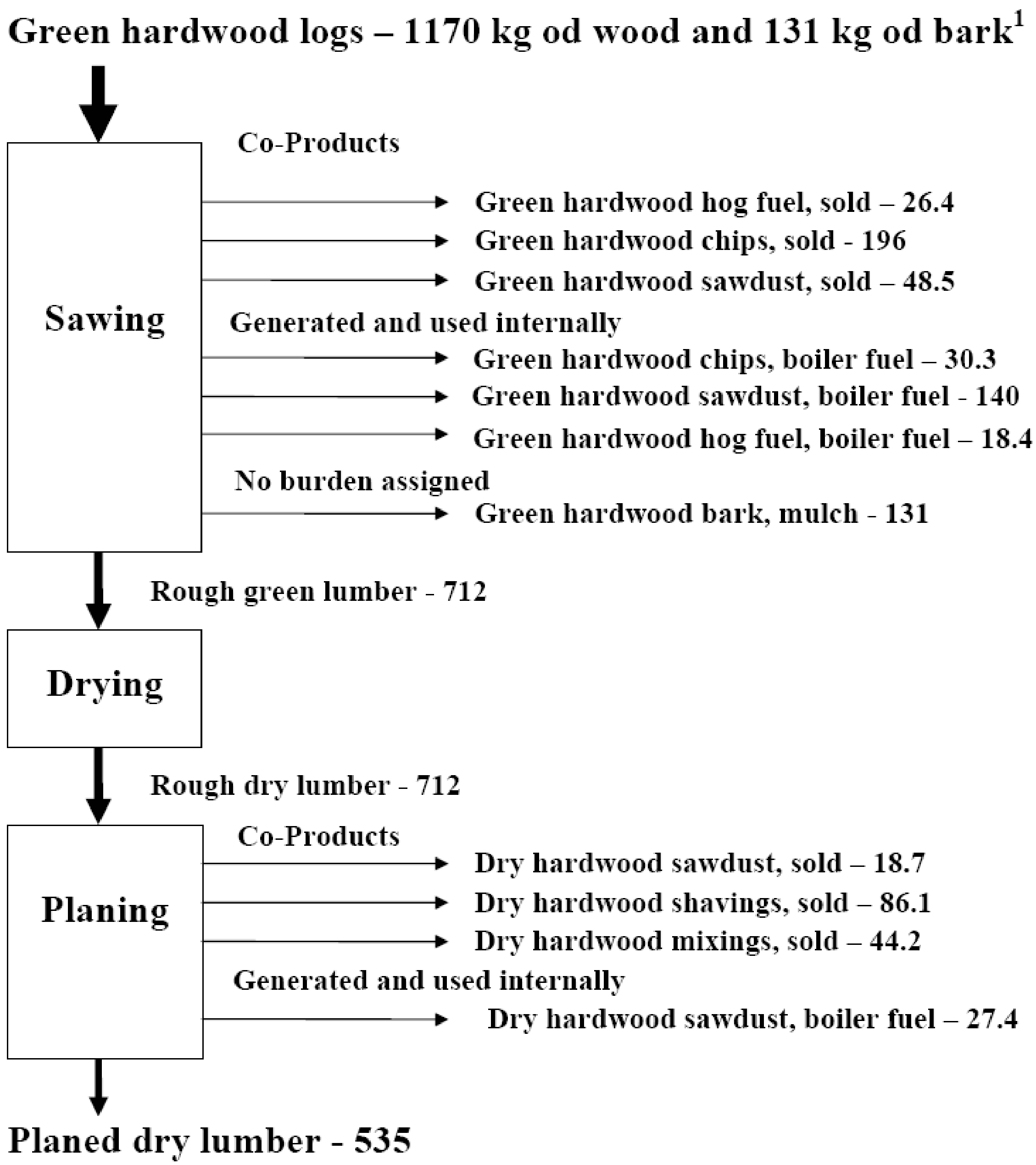
Fossil Fuel



Appendix B-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 and in kg.

Appendix C-1: Total Electrical Power Industry by Source for the Northeast for 2005 by State

STATE	ENERGY SOURCE	GENERATION (Megawatthours)
CT	Coal	3,996,492
DE	Coal	4,832,948
IA	Coal	34,252,392
IL	Coal	92,264,272
IN	Coal	122,817,019
MA	Coal	12,033,546
MD	Coal	29,313,922
ME	Coal	322,359
MI	Coal	70,345,630
MN	Coal	32,910,342
MO	Coal	77,437,142
NH	Coal	4,072,987
NJ	Coal	11,625,410
NY	Coal	20,597,682
OH	Coal	136,874,551
PA	Coal	120,938,406
WI	Coal	41,649,010
WV	Coal	91,419,556
SUBTOTAL	Coal	907,703,666
CT	Other Gases	1,566
DE	Other Gases	496,436
IL	Other Gases	198,788
CT	Other Gases	1,566
DE	Other Gases	496,436
IL	Other Gases	198,788
IN	Other Gases	2,702,750
MD	Other Gases	343,168
MI	Other Gases	697,417
MO	Other Gases	2,383
OH	Other Gases	297,392
PA	Other Gases	511,038
WV	Other Gases	84,396
SUBTOTAL	Other Gases	6,032,124

CT	Petroleum	3,156,048
DE	Petroleum	1,216,423
IA	Petroleum	149,537
IL	Petroleum	326,024
IN	Petroleum	279,038
MA	Petroleum	7,119,369
MD	Petroleum	3,817,584
ME	Petroleum	1,611,697
MI	Petroleum	897,881
MN	Petroleum	783,358
MO	Petroleum	168,418
NH	Petroleum	1,357,142
NJ	Petroleum	1,106,561
NY	Petroleum	24,044,258
OH	Petroleum	1,390,649
PA	Petroleum	4,965,387
RI	Petroleum	55,814
VT	Petroleum	10,179
WI	Petroleum	724,230
WV	Petroleum	223,552
SUBTOTAL	Petroleum	53,403,149

CT	Other	10,356
IL	Other	0
IN	Other	425,310
MA	Other	0
ME	Other	0
MI	Other	0
MN	Other	45,959
NJ	Other	60,915
NY	Other	0
PA	Other	21,556
WI	Other	45,930
SUBTOTAL	Other	610,026

CT	Natural Gas	8,863,687
DE	Natural Gas	1,590,761
IA	Natural Gas	2,480,842
IL	Natural Gas	7,116,309
IN	Natural Gas	3,623,916
MA	Natural Gas	20,276,566
MD	Natural Gas	1,873,659
ME	Natural Gas	8,398,454
MI	Natural Gas	13,631,871
MN	Natural Gas	2,743,986
MO	Natural Gas	3,865,467
NH	Natural Gas	6,784,735
NJ	Natural Gas	15,197,165
NY	Natural Gas	31,831,006
OH	Natural Gas	2,694,229
PA	Natural Gas	10,805,642
RI	Natural Gas	5,990,746
VT	Natural Gas	2,240
WI	Natural Gas	6,376,452
WV	Natural Gas	285,395
SUBTOTAL	Natural Gas	154,433,128

CT	Nuclear	15,562,122
IA	Nuclear	4,538,313
IL	Nuclear	93,263,001
MA	Nuclear	5,475,057
MD	Nuclear	14,703,221
MI	Nuclear	32,871,574
MN	Nuclear	12,835,219
MO	Nuclear	8,030,577
NH	Nuclear	9,455,885
NJ	Nuclear	31,391,685
NY	Nuclear	42,443,152
OH	Nuclear	14,802,733
PA	Nuclear	76,289,432
WI	Nuclear	9,920,991
SUBTOTAL	Nuclear	371,582,962

CT	Hydroelectric Conventional	478,199
IA	Hydroelectric Conventional	959,526
IL	Hydroelectric Conventional	129,037
IN	Hydroelectric Conventional	438,282
MA	Hydroelectric Conventional	1,041,950
MD	Hydroelectric Conventional	1,703,639
ME	Hydroelectric Conventional	4,090,926
MI	Hydroelectric Conventional	1,461,708
MN	Hydroelectric Conventional	774,729
MO	Hydroelectric Conventional	1,159,326
NH	Hydroelectric Conventional	1,064,180
NJ	Hydroelectric Conventional	31,113
NY	Hydroelectric Conventional	25,782,518
OH	Hydroelectric Conventional	515,744
PA	Hydroelectric Conventional	2,232,179
RI	Hydroelectric Conventional	6,734
VT	Hydroelectric Conventional	1,210,811
WV	Hydroelectric Conventional	1,447,566
SUBTOTAL	Hydroelectric Conventional	44,526,514

CT	Pumped Storage	-1,653
MA	Pumped Storage	-461,643
MI	Pumped Storage	-1,106,241
MO	Pumped Storage	85,932
NJ	Pumped Storage	-282,707
NY	Pumped Storage	-780,731
PA	Pumped Storage	-711,041
SUBTOTAL	Pumped Storage	-3,258,084
TOTAL	All Fuel Sources	1,565,033,485

Addendum

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

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

1. Objective and procedure

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

CORRIM supplied two sources of information:

- The report "Life-Cycle Inventory of Hardwood Lumber Manufacturing in the Northeast and Northcentral 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 hardwood 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);
- All final waste flows were converted to waste management flows. Note that additional information on the management of these waste flows would improve the unit process quality; and
- All electricity flows were converted from MJ to kWh.
- CORRIM amended the specific gravity of the kiln-dried sawn hardwood lumber, changing from 0.535 to 0.572.

3. Changes to individual unit processes

3.1 "Logyard" processes

The CORRIM SimaPro model contained two unit processes that accounted for the transport of logs and bark to the sawmill. These unit processes were not part of the gate-to-gate system presented in the CORRIM report. The changes made to these processes are as follows:

- The two processes were united into one single process to be coherent with other modules. Note however that the transport of bark and roundwood were reported separately.
- The process "Roundwood Transport, Hardwood, NE/NC, USA, U" in the original CORRIM SimaPro model is a process which in turn only uses a transport process from the Franklin database; it was simply eliminated and replaced directly with a transport process from the U.S. LCI database (Transport, combination truck, diesel powered).
- The same change was made with regards to an analog in the "Bark at mill" unit process.
- The amount of transport does not directly consider the actual weight transported:
    - For roundwwod, the conversion from OD weight to actual weight was done in the intermediary transport unit process "Roundwood Transport, Hardwood, NE/NC, USA, U" which was deleted in the U.S. LCI

version of the model. The conversion to real weight is based on an 87% moisture content (OD basis). Per kg, the amount of transport is: 1 kg OD basis * 1.87 * 125 km = 234 kgkm = 0.234 tkm.
  - For bark, the conversion from OD weight to green weight assumed a MC of 100%, oven-dry basis. Note that disregards a personal communication from Jim Wilson (August 27, 2008 in which it was stated that using the same MC as for the roundwood (87%) would be more appropriate.

3.2 Sawing

The "Sawmill" is a multifunctional unit process in which green roundwood is converted to sawn lumber and co-products. The wood inputs include not only the roundwood at mill, but also the bark at mill. The following changes were made to this unit process by Sylvatica:

- In the original CORRIM model, bark was attributed an allocation factor of 0. Based on CORRIM guidelines, the U.S. LCI version of the unit process gives an allocation factor of 10%, based on mass allocation. All other allocation factors were adjusted to account for this.
- The subcategory for water from nature was changed from "biotic" to "in water".
- The subcompartment for emissions to air of "Particulates, unspecified" was set to "low population density".

CORRIM also made the following amendments to the data after the revision process had started:

- Output was changed to 749 kg, oven dry weight. Volume = 1.46 m3 at 87% MC (od basis)
- CORRIM added a "facility heating" input of 570 MJ for the production of 749 rough green lumber. Facility heating represents 10% of total embodied energy. This was modeled by PL using the Heat, from onsite boiler process.

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

The following changes were made by Sylvatica to this unit process:

- For the U.S. LCI, the unit process was renormalized to 1m^3 of rough dry lumber: all process flows were therefore divided by the specific gravity of the sawn lumber (1.31 kg/m^3).
- The uniform distributions were removed from the flows, as these were set up in a fashion that could result in total energy requirements being wrong.

CORRIM also made the following amendments to the data after the revision process had started:

- The proportion of fuel used for equipment allocated to this process (diesel, gasoline and natural gas) was changed from 10% TO 20%.
- The total output of wood, in kg, was modified by CORRIM from 712 kg to 749 kg. The volume output was also changed by CORRIM, from 1.37 m^3 to 1.31 m^3.

3.4 Hardwood lumber planing

The only major modification Sylvatica made to this unit process was to normalize it to 1 m3 of planed, kiln-dried sawn hardwood lumber. However, CORRIM did make amendments to the unit process data after the start of the revision process:

The specific gravity of the final product and was changed from 0.535 to 0.572 (MC=9.6%, oven-dry basis). The volume output in the amended CORRIM unit process and the corresponding masses (oven-dry basis) are presented in the following Table.

Planing Process Output	Amount	
	Volume (m^3)	Mass-OD basis (kg)
Sawn lumber, hardwood, plane, kiln dried, US NE-NC/m3	1	572
Sawdust, hardwood, kiln-dried, US NE-NC	0.03	18.7
Fuel wood, hardwood, kiln-dried, US NE-NC	0.05	27.4
Shavings, hardwood, kiln-dried, US NE-NC	0.15	86.1
Mixings, hardwood, kiln-dried, US NE-NC	0.08	44.2
Total	**1.31**	**748.4**

- The consumption of grid electricity was augmented from 33.3 kWh/m^3 to 41.4 kWh/m^3 (120 MJ/m^3 to 149 MJ/m^3).

- The consumption of "On-Site Electricity" was augmented from 0.56 kWh/m^3 to 0.71 kWh/m^3 (2 MJ/m^3 to 2.55 MJ/m^3) was removed from the boiler and added to this process. This is now consistent with the other processes (sawing and drying).

3.5 Boiler, Northeastern Hardwood Lumber

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

- The amount of produced electricity was netted, i.e. the amount consumed was removed from the amount produced to consider only net flow out of the cogenerating boilers. This had a small effect on the allocation factors.
- The transport of wood fuel from other mills was removed and integrated in the "Wood into industrial boilers, NE/NC hardwood lumber, purchased".
- The allocation factors were calculated using mixed (unconverted) values for energy (kWh and MJ were added).

However, CORRIM later amended the unit process in the following ways:

- Heat output was changed from the boiler was reduced from 5779 MJ to 5129 MJ. Part of this heat was redirected in a new output from the process called "Facility heating" (570 MJ). This split between heat used for facility heating and used for other purposes was not carried over in the Sylvatica version of the model – the total heat produced was however changed from 5779 MJ to 5699 MJ to reflect new CORRIM data.
- The consumed electricity produced onsite was removed from this process and allocated to the planning process. It was therefore no longer useful to net the electricity, and the full amount produced is now accounted for in the outputs to the technosphere.
- The input of grid electricity was removed.
- The "fuel combustion in industrial equipment" inputs were removed and allocated to the drying process (see above).
- The amount of wood combusted was changed from 217 kg to 206 kg.

3.6 Adapted Franklin data

Three processes found in the CORRIM SimaPro model, all related to the combustion of wood in boilers or the acquiring of wood fuel for use in a boiler, were slightly adapted versions of Franklin (FAL 98) unit processes.

1. The basis for modeling purchased wood cradle-to-gate impacts is the Franklin process "Wood FAL";
2. The basis for modeling the actual combustion of the purchased wood is the Franklin unit process "Wood into industrial boilers"; and
3. The same Franklin process was used to model the combustion of wood fuel produced onsite.

The changes to each are outlined 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.

For the "Wood fuel, unspecified" unit process:

- A new elementary flow was created, "Wood and wood waste, 19 MJ per kg ovendry basis", based on recommendations from CORRIM (Jim Wilson). This elementary flow will not have characterization factors in any method for the moment.
- An input of carbon dioxide from nature (1.844 kg CO_2/kg wood fuel) was added to account for carbon uptake during tree growth and storage in wood fuel.
- The comments were adapted to better document the uncertainty regarding the assumed FAL wood density.

For the “Wood into industrial boilers, NE/NC hardwood lumber, purchased” model:

- The CO_2 uptake flow initially added by CORRIM was removed, since this was already accounted for in the “Wood fuel, unspecified” dataset.
- A transport flow, based on a distance reported in the CORRIM “boiler” dataset (10.3 km), was added.

For the “Wood into industrial boilers, NE/NC hardwood lumber, purchased” model:

- The changes made by CORRIM, basically changing the wood fuel inputs to co-products from the NE/NC hardwood lumber processes, were kept as is.

Important note: If ever data specific to hardwood-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 hardwood mills.