Environmental Impact of Producing Hardwood Lumber Using Life-Cycle Inventory

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ABSTRACT

Using sustainable building materials is gaining a significant presence in the United States therefore proving sustainability claims are becoming increasingly more important. Showing wood products as green building materials is vital for the long-term productivity of the wood building industry. This study examined hardwood lumber manufacturing using Life-Cycle Inventory methodology. Material flow and energy type and use were identified for hardwood sawmills in the northeastern United States. A hardwood log volume conversion of 43.7% to planed dry lumber was found. Values 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 burning mostly green wood residues on-site for energy. Emission data produced from modeling estimated biomass and fossil carbon dioxide production of 428 kg per m^3 and 139 kg per m^3, respectively. Increasing wood fuel use, a carbon-neutral process, would decrease the environmental impact of hardwood lumber manufacturing and increase its use as a green building material.

INTRODUCTION

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

Economic and energy costs and environmental impact for building products are increasingly important since the average U.S. new single-family residential housing unit continues to increase in size. The average-size single-family residential home increased from 2,075 square feet in 1991 to 2,434 square feet in 2005. Also, completed units have roughly increased by 100% to 1.64 million during the same period (USCB 2006b).

Green building is the sustainable practice of improving energy efficiency for materials, construction, and operation while reducing the overall building environmental impact. 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 5% ($19 billion) by 2010 (MHC 2006). Developing a sound residential building 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 support claims for using green building materials.

Providing accurate baseline data for hardwood lumber production through a Life-Cycle Inventory (LCI) is important for future housing policies on building styles, construction materials, product improvements for energy consumption, and carbon sequestration policies. Using Life-Cycle Inventory on hardwood lumber production will provide the data necessary for the scientific database managed by the National Renewable Energy Laboratory to support wood industry claims and complete a Life-Cycle Analysis (NREL 2007).

Life-Cycle Inventory (LCI) is an accounting of the energy and waste associated with the creation of a product through use and disposal. In this study, the 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. This is known as cradle-to-grave assessment and is beyond the scope of this study.

Hardwood logs sawn into rough green lumber are typically dried in conventional dry kilns using wood fuel and fossil fuels as heat sources (Denig et al. 2000). Prior to drying the lumber, the boards are stickered (separated by thin wood strips) and stacked to aid drying and prevent drying defects. The rough dry lumber is planed to the required dimensions when drying is complete. The drying process consumes roughly 70% to 80% of the total energy required for producing hardwood lumber (Comstock 1975). The sawing process consumes the highest percentage of electrical energy.

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 United States (Figure 1). Primary data were collected through questionnaires mailed to lumber mills and secondary data were collected from peer-reviewed literature per Consortium for Research on Renewable Industrial Material (CORRIM) guidelines (CORRIM 2004). Material and energy balances were calculated from primary and secondary data. 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) and softwood plywood (Wilson and Sakimoto 2005).

METHODOLOGY

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 upon specie and season.

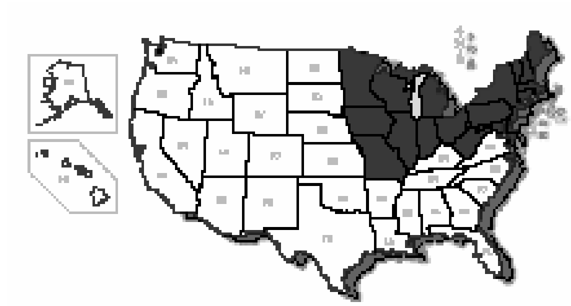

Figure 1. Region selected (dark area) for life-cycle inventory of hardwood lumber production

There are four main unit processes in producing hardwood lumber: sawing, drying, energy generation, and planing (Figure 2). 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-ft (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% to 8% moisture content on a dry basis (MC_{DB}) using mostly energy-extensive drying methods. After drying, the rough dry lumber is planed to the required dimension. The energy generation process provides electricity and heat primarily produced on-site for the other three processes.

Sawing

This unit process begins with logs in the mill yard and ends with sawn rough green lumber and wood residue from the sawing process: bark, sawdust, slabs, edgings, and chips. Any combination of these materials is termed hog fuel. Most wood residue is sold, as a co-product, while the other residues, especially sawdust, are combusted as fuel.

Drying

This unit process begins with rough green lumber and ends with rough dry lumber bound for the planar

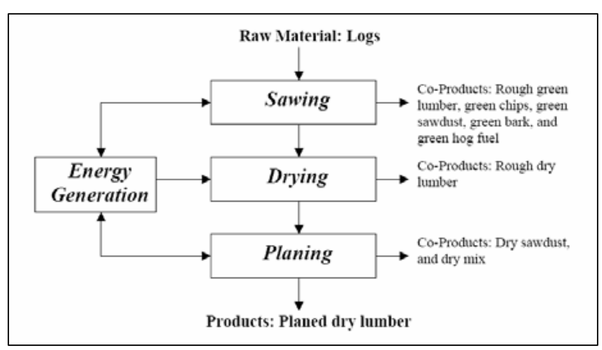

Figure 2. Description of the four unit processes for hardwood lumber manufacturing showing material flow

mill. Drying produces most of the volatile organic compounds (VOC) generated on-site and uses the most energy produced on-site from wood and fossil fuel combustion. Several different drying methods are employed depending on species and wood residue use.

Energy generation

This unit process provides all on-site heat and some on-site electricity for the other three processes by burning wood, natural gas, oil, or propane. 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. CO2, CO, and particulate) from combustion.

Planing

This unit process begins with stickered, rough kiln-dried lumber and produces surfaced and packaged lumber, sorted by type, size, and grade as well as planer shavings, sawdust, and lumber trim ends (dry wood residue). This process is the final stage of manufacturing. Some dry wood residue is combusted on-site in 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.

Functional Unit

All results are normalized to the per unit basis of 1.0 cubic meter (m^3) of planed dry lumber. One cubic meter of planed dry lumber equals 0.568 nominal thousand board feet. U.S. industry standard uses nominal dimensions and commodity lumber is sold by variations of a thousand board feet (MBF). In this study, the standard 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 is required per ISO protocols and CORRIM (ISO 1998; ISO 2005; CORRIM 2004).

System Boundaries

Boundary selection is important because the material and energy that cross this boundary need to be accounted for (Figure 3) through the Life-Cycle Inventory. There are two boundaries as defined by CORRIM (Wilson and Sakimoto 2005) to track the environmental impact of hardwood lumber production. One is the total (cumulative) system boundary (solid line) that includes both on-site and off-site emissions for all material and energy consumed. The site system boundary (dotted line) is the environmental impact for emissions developed 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.

RESULTS and DISCUSSION

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 (9.66 million BTU per MBF) and electrical energy use of 608 MJ per cubic meter (297 kWh per MBF) planed dry lumber 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 per unit volume of lumber dried than mills that did not produce their own electrical power.

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. Thermal energy was reduced by

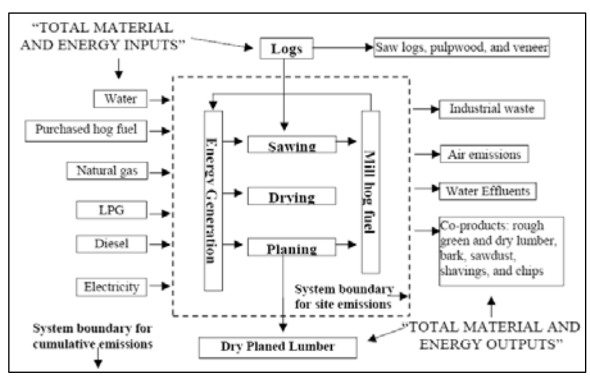

Figure 3. System boundaries for hardwood lumber production

45.3% for on-site wood fuel use from 151 to 83 ovendry 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.

Actual emission rates from facilities can be used to determine regulatory policies. Carbon dioxide and particulates are typically measured although other emissions are frequently monitored to ensure compliance. Carbon dioxide (CO_2) emissions are separated into 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 1). Research into measuring volatile organic compounds (VOC) produced from drying lumber generated the value of 1.20 kg and is specie, temperature, and moisture dependent, with the highest VOC emissions from red oak (Rice and Erich 2006).

LCI projects for softwood lumber production consumed less electrical and thermal energy in their production (Milota et al 2005) compared to hardwood lumber (Table 2). There are several reasons for this. One reason is that hardwood lumber requires longer drying times and more thermal energy is consumed for the same volume of product. Another reason is that hardwood lumber is more likely to be converted to high-grade lumber. Other reasons are that hardwoods themselves are generally more dense than softwood lumber and hardwood lumber is sawn thinner. Based on these stated reasons, more electrical energy is consumed in the sawing process. In this study, the Northeast used more energy to keep the facility heated during winter months compared to the Pacific Northwest and Southeast.

Table 1. Life-Cycle Inventory results for total emissions on a per unit basis of planed dry lumber

	Allocated total		Allocated on-site	
Substance	kg/m^3	lb/MBF[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

Table 2. 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	334.7[4]	150.9	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

A rigorous material and energy balance was completed on 20 hardwood mills located in the northeastern United States. Total energy consumption per cubic meter of planed dry hardwood lumber was found comparable to published data (Armstrong and Brock 1989; Comstock 1975). However, unlike previous studies, sub-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, especially in sawing and drying.

There are several approaches to decreasing energy consumption, and the mills that incorporate these methods would ultimately have significantly lower than average energy use. The most energy efficient method would be upgrading or refurbishing the mill's aging dry kiln facilities. Especially, mills using more than 1.5 times the amount of energy per MBF than the average mill using similar drying technology with similar specie composition. Also, this may 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 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 decreasing electrical 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 so greater control of the drying process typically reduces drying degrade. Keeping a large lumber inventory reduces profits because of the time value of money. Air drying lumber has the lowest control of the different drying methods, resulting in the highest level of degrade although the lowest energy use of all drying methods.

CONCLUSIONS

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

- More on-site wood fuel consumption would produce less fossil greenhouse gases.
- Increasing the level of air drying lumber, especially for species where color is not a problem, prior to kiln drying 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 reduce the environmental impact of hardwood lumber.
- 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 and time.
- Drying consumes the highest proportion of fuel. Decreasing overall energy consumption by upgrading or overhauling existing old and inefficient dry kiln facilities.
- Once the competing non-wood substitutes have been inventoried, product selection for sustainable building can be done using science instead of unsubstantiated claims.

Caution should be shown 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.

Another problem is distortion of data or taking results out of context without considering the true overall environmental effect. Some marketing methods will only highlight certain aspects of their products while minimizing others. Most likely, misuse of LCI studies will cause a loss of faith in the LCA method unless strict guidelines are developed and adopted.

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