CORRIM: Phase II Final Report

Life-Cycle Inventory of Solid Strip Hardwood Flooring in the Eastern United States

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EXECUTIVE SUMMARY

This study had the primary objective of developing a gate-to-gate life-cycle inventory (LCI) for the production of solid strip[2] hardwood flooring in the eastern United States. Methodology and guidelines developed by the Consortium for Research on Renewable Industrial Materials (CORRIM) and the International Organization for Standardization (ISO) were used (CORRIM 2001; ISO 2006). Solid hardwood flooring is available in a wide range of dimensions and species. This study did not consider parquet, pre-finished, or engineered wood flooring.

Primary data for this study was collected using a survey instrument administered to flooring manufacturers located in the eastern United States with dedicated production to solid strip and solid plank hardwood flooring. The National Wood Flooring Association identified mills representative of the industry and furnished contact information. Eighteen self administered questionnaires were sent to nine companies in April 2007. Companies that had more than one production mill were asked to complete a questionnaire for each mill in the company with dedicated production of solid strip or solid plank hardwood flooring. It was estimated that these mills could account for greater than 50% of total domestic solid strip and solid plank flooring production. Data collection terminated in August 2007. Three of the nine companies participated. Ten surveys were returned and usable. Secondary data was used to supplement primary data where necessary. Targeted study mills were considered mid to large sized and characterized by average technology for the industry. Solid strip hardwood flooring production in the United States for the year 2006 was an estimated 483 million square feet (Wahlgren 2007). Respondent mills in this study produced a combined total of 133,746,847 square feet (12,425,488 square meters) in that year- representing nearly 28% of total U.S. hardwood flooring production stated above and exceeding ISO and CORRIM requirements of 5% for captured production in studies of this type.

Data was collected for the major material and energy inputs and outputs required to produce solid strip hardwood flooring. Input data consisted of rough kiln dry hardwood lumber, electricity, water, transportation, on-site fuels, and packaging material. Output data consisted of products, co-products, and emissions to air, water, and land. Input and output data representing less than a 2% impact contribution were not considered. The on-site production process for producing hardwood flooring in this study included: planing, ripping, trimming, side and end matching, packaging, on-site energy generation for facility heating, and emissions control. The inventory was modeled as a single box process. Pre-finishing processes are not included in the scope of this study[3]. Impacts associated with kiln drying are included in the cumulative site boundary through the raw material input to the flooring model developed in a parallel gate-to-gate inventory model for hardwood lumber production (Bergman & Bowe 2007a). The hardwood lumber module documents four unit processes (Sawing, Energy Generation, Drying, and Planing) required to produce hardwood lumber in the northeast/northcentral region of the United

[2] Includes solid plank hardwood flooring
[3] Data for pre-finished flooring was requested in the survey. Respondent mills were unable to supply usable data for this process since most finishing operations were completed at off-site facilities.

States (Bergman & Bowe 2007b). A full cradle-to-grave life-cycle analysis is beyond the scope of this study.

Data collected from the mills on individual response categories is presented as averages derived by weight averaging each mills contribution to total production. Results reflect the environmental impact of material and energy flows required to produce 1.0 cubic meter (423 board feet) of solid hardwood flooring. Data quality was very good for this study based on mill representativeness, captured production, and peer review. External reviews of this study were conducted by members of CORRIM, scientists at the University of Wisconsin-Madison, and flooring industry representations. Consistent with previous CORRIM modules this study utilized SimaPro software (Milota *et al.* 2005; Kline 2005; Puettmann & Wilson 2005b; Wilson & Dancer 2005b; Wilson & Sakimoto 2005).

For the on-site boundary, it was found that the electrical energy used to operate machine centers in a typical flooring mill required several non-renewable fuel inputs for its production in the eastern United States. Considering the cumulative site boundary, the greatest portion of energy consumption was associated with the process of kiln drying hardwood lumber. Continued innovation in drying techniques, and equipment upgrades represent potential environmental improvements in these areas.

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1.0 INTRODUCTION

Recent years have seen an increase in the growth of environmental certifications and green building programs. The latter, green building, seeks to reduce the environmental footprint of residential and commercial building constructions through the selection of products and processes deemed energy efficient and environmentally benign. Market share of green built structures is growing and is forecasted to be five percent ($19 billion) of new residential starts by the year 2010 (MHC 2006). Careful attention is needed in evaluating the claims and selection criteria for building materials classified as "green."

Baseline data which provides an accounting of the raw materials, energy, and wastes required to produce solid hardwood flooring can be obtained in a gate-to-gate life-cycle inventory. Results are useful for examining the environmental impact of this popular wood product and also play a broader role by providing benchmarks for process improvements and tracking carbon flows. This study is intended to become part of a larger effort connected to a scientific database managed by the National Renewable Energy Laboratory (NREL 2007). This database is a tool for interested stakeholders to evaluate the comparative impacts of various building products and assemblies.

A full cradle-to-grave life-cycle assessment considers the materials, energy, and wastes characteristic of a given product from the origin of its materials extraction to its manufacturing process through its service life and eventual re-use or disposal. This broader form is beyond the scope of most studies including this one. The gate-to-gate life-cycle inventory in this study chronicles solid strip hardwood flooring production. An extended gate-to-gate which includes impacts associated with the production of rough kiln dry hardwood lumber at a typical sawmill through its delivery to the flooring mill to the point at which it leaves the flooring facility as solid hardwood flooring is also presented.

Life-cycle studies for wood flooring have been conducted in regions outside of that defined for this study. Jönsson *et al.* (1997) examined the environmental impacts of linoleum, vinyl, and untreated solid wood flooring in Sweden using life cycle assessment. This study was furthered in its inclusion of an impact assessment. Both primary and secondary data were utilized to construct the life-cycle inventories. The functional unit was defined as one square meter for each floor covering. In their study only flooring for domestic use was examined, the production of electricity was not included in the analysis, and impacts from adhesives were omitted. For purposes of comparison, the completed inventories were simplified by decreasing the number of parameters (Jönsson *et al.* 1997). The floor coverings were compared on their resource and energy use, emissions to air and water as well as generated waste. Because linoleum and vinyl both require extensive material inputs relative to wood, the authors report solid wood flooring was clearly more "environmentally sound." Vinyl was found to be the least environmentally sound (Jönsson *et al.* 1997). Caution is needed on this point as the authors make it clear that data for material inputs to linoleum and vinyl were difficult to ascertain and in some instances left out of the inventory. With regard to the aforementioned comparison criteria, the authors found wood had the least emissions associations to air and water, generated less waste, and used the least amount of energy among the three floor coverings (Jönsson *et al.* 1997).

Nebel *et al.* (2006) completed an extensive LCA study examining the flooring industry in Germany. In their study, Nebel, Zimmer, and Wegener (2006) examined the whole life-cycle of four wood floor coverings including solid parquet (8mm, 10mm, and 22mm), multilayer parquet, solid floor boards, and wood blocks. Their work utilized ISO 14040-14043 guidelines and included primary data from 15 manufacturers. Multiple stages were evaluated including, forestry, sawmilling, production of the floorings, laying, and use. Nebel *et al.* (2006) make it clear that kiln drying represents the most energy intensive process and that solar, air, and wind drying of the solid floor coverings prior to entry into the kiln could reach a lower moisture content (around 17%) and therefore represented a higher average energy savings compared to the other floor coverings. Perhaps more important in the overall energy balance is the fact that despite being an energy intensive process, residual wood waste was adequate to provide the energy needed in the kilns and much of the production facilities. Production of the flooring was identified as the second most energy intensive process. Interestingly, unlike the kiln drying operations observed, the authors point out that the process procedures to manufacture each flooring category were similar among the mills they examined and conclude little opportunities for energy savings can be found here. Parquet flooring requires adhesives as well as coatings and therefore did not perform as well as solid wood flooring on environmental indicator criteria such as global warming potential or photo-oxidant formation. Nonetheless, Nebel *et al.* (2006) are quick to point out that compared with all German Gross Domestic Products, wood flooring contributed significantly less (factors of 5 to 50 lower) to impact categories including climate change, acidification, eutrophication, photo-oxidant formation, and ozone depletion. The authors concluded that substituting water-based glues for those borne of solvents could reduce photo-oxidant formation by nearly 70% and that the storage of carbon inherent in wood flooring coupled with energy production alternatives to fossil fuels realized by residual wood and post consumer wood streams represents significantly reduced, perhaps even negative global warming potential for these products (Nebel *et al.* 2006). The authors highlight the need to understand that decision tradeoffs made in drying procedures or glue and finishing choices for example can dramatically alter the observed results.

Floor covering options available to consumers are staggering. Today's flooring mix is no longer confined to traditional species, materials, or sizes. During a wood flooring exposition in Charlotte North Carolina in 2004, 98 different species used in solid strip wood flooring products were documented (Anonymous 2004). Wood reclaimed from historic buildings and barn disassemblies has become increasingly popular for use in flooring. While these latter products have a small share of the overall market, they illustrate the diversity and inherent long life of wood derived product offerings. Solid wood flooring is popular in both residential and commercial building applications. Competing products include, but are not limited to, vinyl, carpet, and ceramic flooring.

The solid hardwood flooring industry in the United States is well established. Continued innovation makes product specific estimates difficult. In addition to its historic inclusion with millwork and dimension data the growing popularity of wide plank, recycled, parquet, and engineered wood flooring are exacerbating this hardship and make current industry census data for solid strip and solid plank hardwood flooring production difficult to decipher. In personal communications with company owners, industry experts, and scientists involved with this industry segment, it is clear that no single authoritative, comprehensive, and exhaustive source of concise demographic information exists. Information presented in this document represents thorough treatment of data gathered from a variety of sources involved in tracking and reporting U.S. solid wood flooring activity.

There are an estimated 100 to 150 manufacturing facilities in the United States with dedicated production to solid hardwood flooring (Locke 2006). Annual production from these mills in 2006 was estimated to be 483 million square feet (Wahlgren 2007). Flooring production is located within states that have well established transportation channels and a close proximity to the raw hardwood resource. This is evidenced in 2002 census data for the value of shipments of hardwood flooring in the United States (Table 1). Tennessee leads all states in total U.S. flooring production while 39 other states have little or no representation in this industry.

Table 1: 2002 Value of US Hardwood Flooring Shipments by State

State	2002 Value of Hardwood Flooring Shipments (US $)	Percent (%) of US Total
Arkansas	94,313,000	6
California	15,713,000	1
Kentucky	78,506,000	5
Michigan	47,339,000	3
Mississippi	58,048,000	4
Missouri	119,538,000	8
North Carolina	176,645,000	11
Pennsylvania	24,928,000	2
Tennessee	364,232,000	23
Texas	138,068,000	9
Wisconsin	86,360,000	5
Total All Other States	375,378,000	23
Total US	**1,579,068,000**	**100**

Source: adapted from (USBC 2002)

1.1 Inventory Goal

The goal of this solid hardwood flooring gate-to-gate life-cycle inventory is to satisfy the following objectives:

1) To document the resource use, energy use and generation, and outputs including products, co-products, and emissions associated with solid hardwood flooring manufacture in the eastern United States.

2) To make the baseline information obtained in objective 1 available for interested stakeholders to compare solid hardwood flooring to that of

substitute or alternative floor coverings derived from non-wood material inputs.[4]

3) To provide a benchmark for extending the findings encountered in objectives 1 and 2 into opportunities for waste reduction, improved energy and resource efficiencies, and scenario modeling.

4) To furnish the inventory data to CORRIM for that organizations use in developing broader scale cradle-to-grave life cycle inventories.

5) To communicate the gate-to-gate life cycle inventory findings to flooring manufacturers, policy makers, and the general public.

1.2 Scope and System Boundaries

Please refer to Figure 1 showing an initial eastern region that was defined by two sub-regions in the eastern United States, the northeast shown in blue and the southwest shown in green. It was decided to redefine the study region for this gate-to-gate life cycle inventory of solid hardwood flooring as one comprehensive eastern region shown in gray (Figure 2).

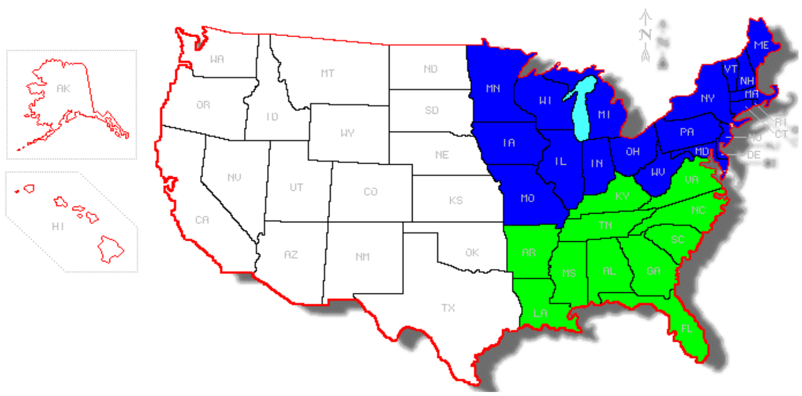

Figure 1: Originally Proposed U.S. Study Regions

This was accomplished by combining the aforementioned sub-regions and includes the states, MN, IA, MO, WI, IL, NJ, OH, IN, MI, WV, PA, MD, DW, NJ, NY, ME, VT, NH, RI, MA, CT, VA, KY, AR, LA, MS, AL, FL,GA, NC, SC, TN, and TX. Departure from

[4] Life-cycle models for many substitute materials have been constructed and are available from the National Institute of Standards and Technology (NIST 2007). The NIST developed the Building for Environmental and Economic Sustainability (BEES) database and software version 4.0 (NIST 2007). The database is accessed at: http://www.bfrl.nist.gov/oae/publications/nistirs/7423.pdf and contains life-cycle inventory data for more than 30 non-wood floor coverings. Users are cautioned that methodologies to construct alternative product LCIs may differ from those used in this study.

the original sub-regions was justified[5] because, 1) no significant deviance was found in flooring and energy production in the two sub-regions, 2) targeted survey respondents were concentrated along the sub-regions' boundary's, and 3) species utilization was consistent among respondent mills.

Figure 2: Comprehensive Eastern U.S. Study Region

For accounting purposes, boundary selection is a key aspect of all life-cycle studies. The system boundary for the gate-to-gate LCI of solid hardwood flooring[6] manufacturing and the processes associated with its production appear in Figure 3 . The gate-to-gate system boundary for the flooring mill is denoted by the solid line box. The environmental impacts associated with producing solid hardwood flooring from the point at which hardwood lumber arrives at the mill to the point it is converted and packaged as hardwood flooring is considered. Combustion of fuels and associated electricity generation required to produce the final product are included. Within the gate-to-gate system boundary is a second system boundary that is denoted by the dotted line box. This is the on-site system boundary which considers only site-generated emissions and impacts.

[5] Decision made in telephone conversation with Dr. Jim Wilson and Dr. Maureen Puettmann 6/19/2007 (OSU and CORRIM advisors) and discussion with major advisor Scott Bowe.
[6] Includes solid strip and solid plank hardwood flooring; domestic species only.

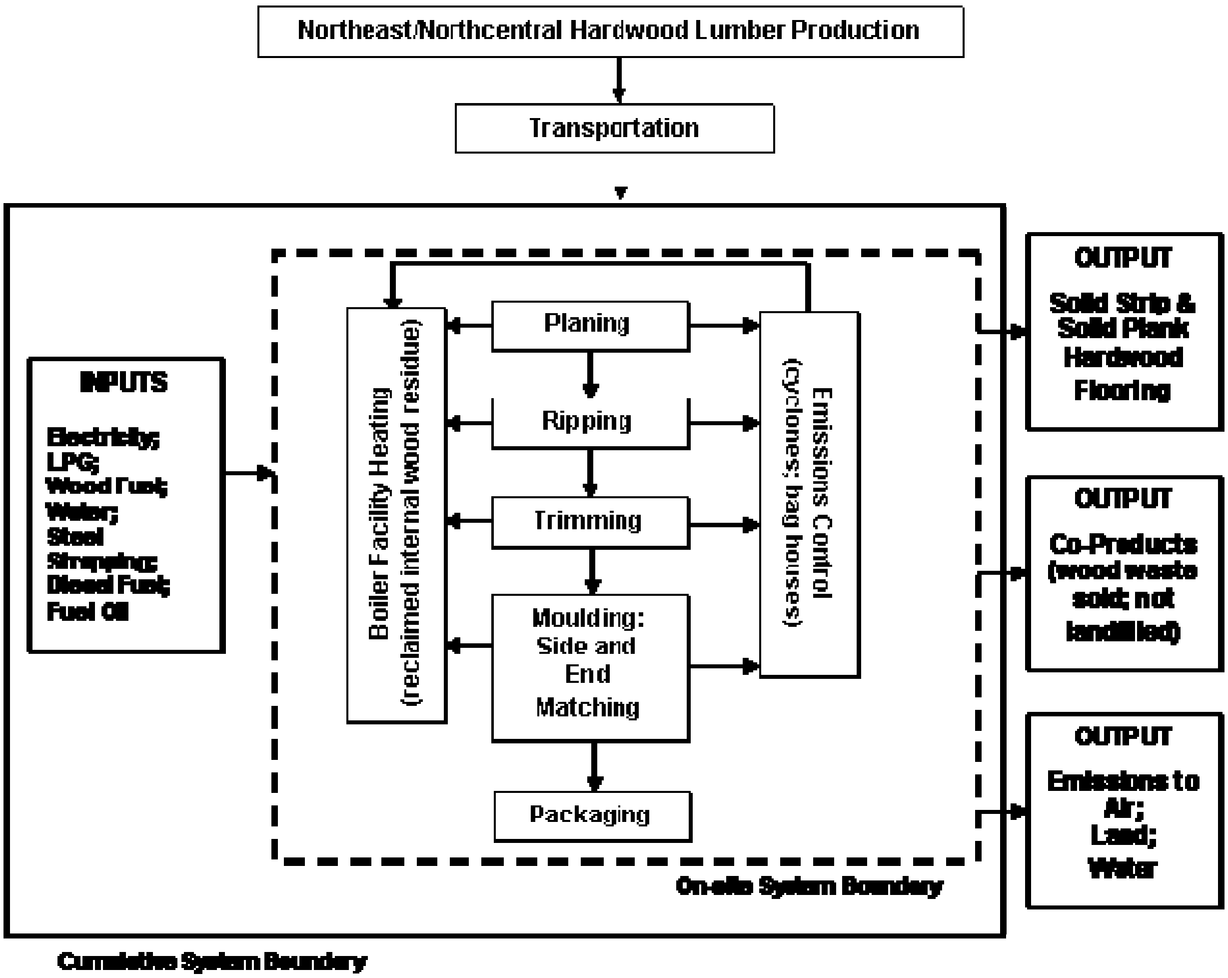

Figure 3: System Boundaries for Solid Strip and Solid Plank Hardwood Flooring Production in the Eastern United States

This study was expanded further by making use of a recently completed hardwood lumber production module (Bergman & Bowe 2007a). The expanded gate-to-gate boundary is shown in Figure 4. This scenario makes it possible to examine the cumulative effects of producing solid strip and solid plank hardwood flooring by including the impacts associated with producing the hardwood lumber input as well as the transportation burdens required to deliver the lumber from the sawmill to the flooring mill. To be clear, we first examine the on-site impacts associated with producing solid hardwood flooring. We then expand our discussion to include environmental burdens inherent in kiln dried lumber production and over the road transportation of that lumber. Environmental impacts from this boundary are cumulative impacts. Both on-site and off-site emissions are considered in the gate-to-gate system boundary. Impacts associated with the growing, harvesting, and transportation of logs are not included.

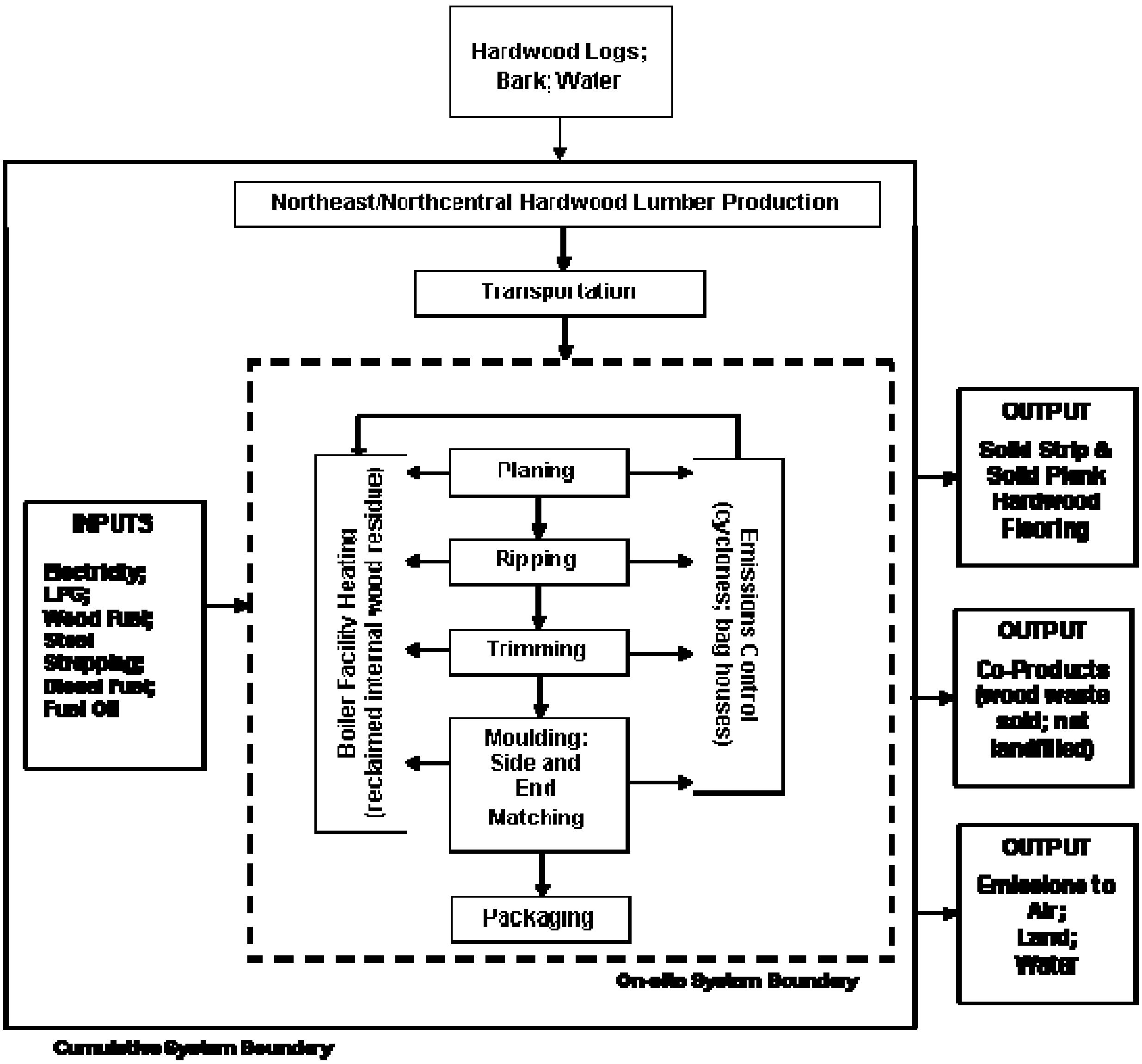

Figure 4: Expanded Gate-to-Gate System Boundaries for Solid Strip and Solid Plank Hardwood Flooring Production in the Eastern United States

1.3 Product Description and Manufacturing Process

1.3.1 Product Categories

Solid hardwood flooring is referenced by length, thickness, width, profile, finish, grade, species or a combination of these. The National Hardwood Lumber Association has outlined rules and grading procedures for hardwood lumber (NHLA 2003). Traditional hardwood flooring manufacture has made use of lower grade lumber including number 2A and 3A common lumber (Hosterman 2000). Number 1 common and higher lumber grades are not often used. Table 2 lists common dimensions used in hardwood flooring.

Table 2: Common Harwood Flooring Dimensions

Flooring Classification	Face Widths Inches (mm)	Thickness Inches (mm)
Solid Strip Hardwood	1.5 (38.1), 2.25 (57.2), 3.25 (82.5)	1/3 (7.62), 1/2 (12.7) 3/4 (19.0)
Solid Plank Hardwood	3.0 (76.2), 8.0 (203)	

Note: most common thickness for both flooring classifications is ¾ inches

Solid hardwood flooring has three classifications: strip, plank, and parquet. Strip flooring dominates overall production. It is considered to be flooring with face widths of 1.5, 2.25, or 3.25 inches (38.1, 57.2, and 82.5 mm respectively). Plank flooring is classified as having a face width between 3.0 and 8.0 inches (76.2 and 203 mm respectively). Alternatively, parquet flooring is a one foot square assemblage of thin wood strips. Parquet flooring is not considered in this inventory. Both strip and plank flooring share traditional thicknesses of 0.75 inches (19.0 mm). Consumer preferences and technological innovation in milling equipment has made thicknesses ranging from 0.3 to 0.5 inches (7.62 mm to 12.7 mm) available (Hosterman 2000).

In the United States, the most commonly used domestic hardwood species for solid flooring include: Red Oak, White Oak, Sugar Maple, Red Maple, Ash, Birch, Walnut, Cherry, Beech, Hickory, and Pecan. Of these, Red Oak captures nearly 70% of the market.

1.3.2 Product Manufacturing Process

Hardwood flooring manufacture is accomplished through a series of unit processes. A unit process may be thought of as a machine center, a work cell, or a specific operational task which both requires and modifies a material input in some way. A representative approach to flooring production appears in Figure 5 and includes the following sequence of activities: receiving lumber, drying lumber (if in the green state), planing, ripping, trimming, moulding (side and end-matching), pre-finishing[7], and packaging. It has been estimated that a representative flooring operation realizes yields of roughly 50% of the original raw lumber input (Hosterman 2000;Bond *et al.* 2006). Co-products associated with the process including trimmings, edgings, planer shavings, wood flour, and sawdust are considered useful and given careful attention. They may be sent to energy producing systems for use in the plant or serve as raw material furnishes for other value added wood products such as particleboard, animal bedding, or medium density fiber board. The unit processes illustrated in Figure 5 are discussed next.

[7] Finishing refers to the application of any final coating material such as stains or protective emulsions. Not all flooring manufacturers employ this unit process.

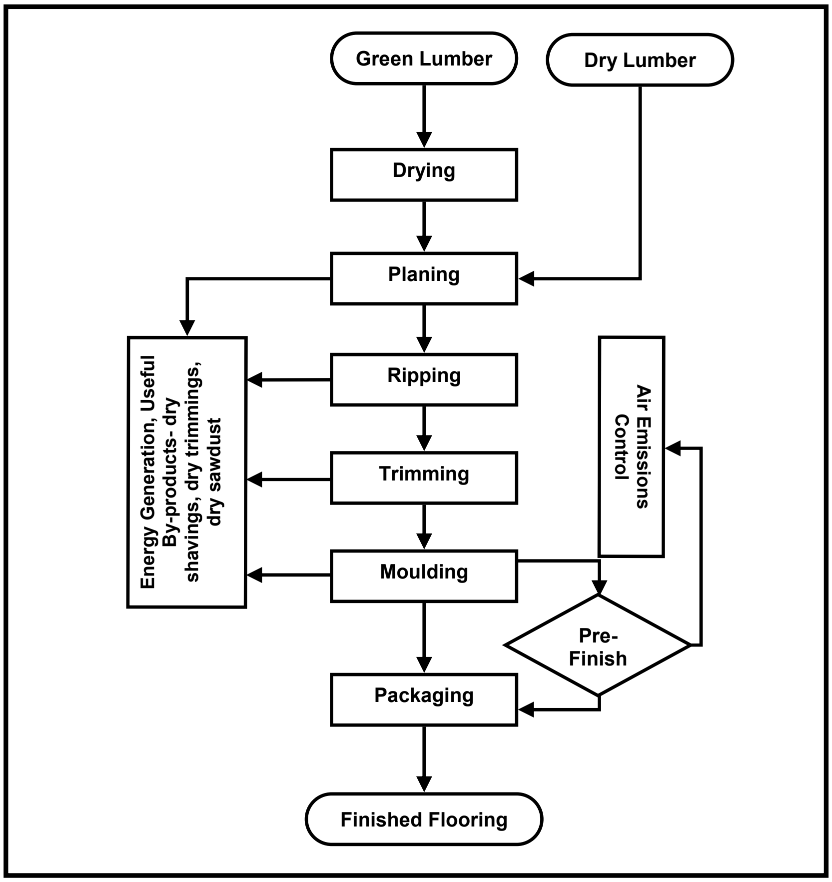

Figure 5: Simplified Process Flowchart of Hardwood Flooring Manufacture

Receive Lumber[8]

The first unit process entails unstacking lumber upon its arrival to the mill. Lumber may arrive green or kiln dry and is unbundled, sorted by species, dimension, and grade. Sorted lumber is restacked onto drying stickers and may be end sealed and oriented in the mill yard such that air drying of the lumber is optimized. Manual labor and fork trucks are used in this process. The output of this unit process is stacked green lumber ready for kiln drying or kiln dried lumber ready for planing.

Drying[9]

This unit process starts with stacked and stickered green lumber. The lumber is loaded into a conventional kiln and subjected to an optimal drying schedule for the given species. Wood used for flooring is typically dried to a final moisture content of between 6 and 9 percent oven dry basis. Other activities included in the drying process are: kiln and transportation maintenance, handling of kiln emissions (steam and water), and

[8] The impacts of this process are assumed in the transportation and total mill energy use contributions.
[9] Not included in primary data collection. Impacts are reflected through data from a recently completed hardwood lumber LCI (Bergman & Bowe 2007b).

transport of the newly dried lumber. The output of this unit process is rough kiln dried lumber.

Planing

A charge of freshly dried hardwood lumber can have variations in thickness. A planer brings lumber thicknesses into uniform tolerance limits while simultaneously producing smooth face surfaces which aid visual grading and sorting. Manually or with specialized machinery, the dried lumber is unstacked and destickered. Next, referred to as "flatting," lumber is conveyed to, and passed through, either a knife planer or abrasive planer whereupon the widest faces of the piece are surfaced smooth. The output of this unit process is surfaced two sides (S2S) lumber ready for ripping and trimming. In addition, this process generates a useful class of byproduct: dry planer shavings.

Ripping

Ripping involves feeding dry, planed, random width lumber along its length through a rip-saw to create stock of desired and uniform widths. The fixed width aspect of flooring often means that ripping is conducted prior to trimming[10]. Rip-saws are classified as straight-line or multirip. Both utilize circular saw blades but differ in the number of blades on a shaft. As the name implies, multirip saws employ several blades running in parallel to execute multiple cuts in a single saw pass. During the ripping process, dry sawdust and edge trimmings are generated. Edgings may be used for value added products such as moldings or parquet flooring furnish. In mills equipped with fuel conversion technologies, these byproducts also support energy generation for the plant. The output of the ripping process is stock of uniform widths.

Trimming

The objective of the trimming process is to eliminate defects while cross-cutting the lumber into desired lengths using a chop saw. Many mills rely on a manual operator to determine and execute the cutting locations. Others have adopted optimization equipment with automated chop saws. Advantages of the latter approach include potential for increased lumber yields, uniformity, and larger throughput. Removal of human operators reduces the likelihood of worker injury and variation in operator decisions across production shifts. Trim pieces generated by the cuttings serve as a useful byproduct and are often sent to in house systems dedicated to energy production. The output of this process is stock of desired lengths and within defect tolerances required of the final flooring product.

Moulding: Side and End Matching

Because it changes the profile of the wood stock so drastically, the moulding process is among the most critical value adding activities in secondary wood processing. The moulding process utilized in flooring has three main objectives. First, the lumber may be edge matched. This is more commonly referred to as tongued and grooved. Typically, a side-matcher modifies one edge of the wood blank lengthwise creating a protrusion. The opposite side is profiled such that a lengthwise gap is created. The

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[10] Some flooring manufacturers may reverse the order of their ripping and trimming unit processes as it is presented here. Generally, firms that trim first do so to optimize aspects of their component products.

protrusion face (tongue side) can now be received by the gap side (groove) of a similarly processed piece of wood. Most hardwood floors are installed by nailing down alternating tongue and groove faces. Many flooring products also utilize an end-matcher to accomplish the same principle on the lumber ends (end matching). In this way, floor strips can be joined end to end over the length of a floor. Finally, though not featured in all strip flooring, a moulder may be used to put a lengthwise bevel along the top flooring face. Flooring pieces without a bevel can be more difficult to install and may not be perfectly level when butted together. Wood flour is created and joins the other by-products in use as fuel or a value added furnish. Moulding profiles today are limited only by design and operator proficiency. Maintenance of the cutting heads can be time consuming and frequent. The output of the moulding process is unfinished, solid strip or plank, tongue and groove flooring.

Sorting[11]

A process that occurs throughout the production flow depicted in Figure 5 is sorting. Because of the inherent character variations that normally occur in wood such as knots or color, sorting is conducted to ensure that flooring stock may realize its full potential value. As lumber is transformed into flooring during the manufacturing process, human operators or scanning technology organize the wood by visual characteristics which ultimately determines the highest potential grade a piece of flooring may achieve. Manufacturers often differ in the number and location of sorts they perform. The intensity with which sorting is performed is often a direct result of species, lumber grade, and the final product mixes offered. The output of sorting units is uniformly grouped flooring stocks. The process may include manual labor, scanners, conveyer systems, and holding bins.

Pre-Finishing[12]

Further value may be added to the flooring by applying a stain or protective coating to the wood. There are several common approaches to adding a finish. One method conveys the unfinished flooring through a series of spray booths where high pressure air is utilized to distribute the coating over the wood. Because the spraying takes place in enclosed chambers, excess coating material can be reclaimed for reuse and solvent emissions can be better captured. A second method makes use of large rollers similar to those used in residential or commercial painting. In this strategy, flooring passes beneath the rollers which spread the coating. Vacuum coating represents a third approach. In this method pressure differentials are utilized to force coatings into contact with the wood surface. Depending on the size and complexity of a particular manufacturers product mix, both combinations of the above methods or hybrid forms of them may be used. Today's factory applied finishes make use of sensors and scanning equipment to trigger precise amounts of desired coatings at equally precise start and stop times. Once the flooring has received its finish, it is cured. Popular methods for curing

[11] Not included in gate to gate LCI model. Sorting is labor intensive but does not consume significant material or energy inputs and outputs.
[12] Not included in initial gate to gate LCI due to problematic weighting and data quality. A subsequent LCI may be constructed for Pre-finished hardwood flooring using unfinished hardwood flooring as product/material input.

include radiant heat, drying ovens, or exposure to ultra violet (UV) light. Because it can cure stains and sealants in a matter of seconds, UV has become a desirable method. With changes in environmental regulations, coatings used to pre-finish flooring have also evolved. Most notably, water-based coatings are gradually replacing traditional solvent based finishes. In addition to application advantages, water-based coatings pose fewer burdens to the environment and human health.

Energy generation

Energy generation refers to the process of combusting propane, wood, or natural gas to furnish useable on-site heat and electricity. This process is typically carried out with large boilers that produce hot water and steam, co-generators that produce electricity or a combination of the two. Outputs associated with energy generation include the produced energy as well as solid waste and emissions to air associated with combustion.

Emissions Control

This process captures wood dusts, finishing gases, and other deleterious substances generated at a given unit process. Typical control devices include cyclones and bag houses. Finish and coating lines use closed spray booths to reclaim furnish and volatile organics. Emission control devices utilize fossil fuels, wood waste, electricity, and water to operate. Collected process emissions are re-used as input furnishes (i.e. wood dust to boiler fuel feedstock) or physically disposed of outside the mill.

Packaging

Packaging provides a final chance to sort and grade the end product. Once organized, the flooring is stacked and bundled using conventional packaging straps and wrap of plastic or steel. The packaged material is conveyed to a staging area or loaded directly on trucks.

1.4 Data Collection, Quality, and Assumptions

Between April and August 2007, primary data was collected from flooring mills considered representative of the industry. Surveyed mills were mid to large size manufacturing facilities. The National Wood Flooring Association identified representative mills and provided detailed contact information for each. Eighteen self administered questionnaires were mailed to nine companies. The survey instrument was constructed such that it was in compliance with CORRIM and ISO 14044 standards and protocol (CORRIM 2001; ISO 2006). Additional questions were included to profile the hardwood flooring industry. The survey was externally reviewed by members of CORRIM, scientists at the University of Wisconsin-Madison, employees at the USDA Forest Products Laboratory-Madison and then pre-tested with a large flooring manufacturer in the study region. The complete survey is given in Appendix 2. All participating companies were assured confidentiality and asked to fill out individual questionnaires for each mill with dedicated production to solid strip or solid plank hardwood flooring. Three of the nine companies responded and ten surveys were returned and useable.

Annual production of solid hardwood flooring for the entire United States in 2006 was an estimated 483 million square feet (Wahlgren 2007). Regional production figures were not found. For the reporting year 2006, the amount of solid hardwood flooring produced by mills surveyed in this study totaled 133,746,847 square feet (12,425,488 square meters). This represents nearly 28% of the total U.S. hardwood flooring production stated above and exceeds minimum ISO and CORRIM requirements of 5% for studies of this type. Data quality was considered very good for this study based on mill representativeness, peer review, and captured production. Additional assumptions and considerations include:

1. All survey data for this report covers the reporting year 2006.

2. Consistent with previous CORRIM studies (Milota *et al* 2005), survey data was weight averaged across all mills by determining each mills production relative to the total production captured for all mills in the survey. This is represented by the formula:

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

   $\overline{P}$ 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 the total production for that response value.

3. Missing or questionable data was addressed by follow up correspondence with survey respondents. Where missing data could not be resolved, care was taken to omit it from the averaging. In this way zeros were not mistakenly included in the calculations.

4. Density values for wood species reported by flooring manufacturers were obtained from the National Hardwood Lumber Association (NHLA 2003). This source provides a concise tabular breakdown of salient data acknowledged to be taken from the Wood Handbook: Wood as an Engineering Material (FPL 1999) and from the USDA Forest Service's Hardwoods of North America (FPL 1995).

5. A single density value for flooring and input lumber was derived by calculating the oven dry weight of weight averaged species input for reported flooring production. Input lumber was not broken down by species in the survey and was assumed to correspond with weight average contributions determined for flooring species. The calculated density value for flooring was 657 kg/m^3 or 41 lb/ft^3.

6. Rough kiln dry lumber input was reported in board feet and converted to cubic meters with the conversion factor 2.36 (Briggs 1994). Conversion from

reported square footage of produced flooring to cubic meters was done in a commercial spreadsheet based on actual reported thicknesses for each flooring width classification.

7. For the wood mass balance 0.6 kg/m^3 (oven-dry basis) was unaccounted for and is assumed to be fugitive wood waste. This unaccounted mass is less than 1% of the total mass.

8. The energy content of fuels in this report are presented as their higher heating values (HHV's). This method is preferred in the United States. CORRIM values are used and discussed.

9. Impacts associated with kiln drying are included in an expanded gate-to-gate analysis through the hardwood lumber input to the flooring model developed in a parallel gate-to-gate inventory model for hardwood lumber production (Bergman & Bowe 2007a). The hardwood lumber module documents four unit processes (Sawing, Energy Generation, Drying, and Planing) required to produce hardwood lumber in the northeast/northcentral region of the United States (Bergman & Bowe 2007b).

2.0 INVENTORY MODEL APPROACH AND SOFTWARE

Primary and secondary data collected for the hardwood flooring gate-to-gate life-cycle inventory was processed using SimaPro life-cycle inventory software version 7.0 (PRe´ 2006). Developed in the Netherlands, this version has a built in database by Franklin Associates containing energy and materials characteristics representative of those found in North America (FAL 2001). SimaPro utilizes internationally recognized (ISO 2006) standards for environmental management and standardized life-cycle inventory formats to record and analyze the model data. Additionally, SimaPro provides sensitivity analyses for a given product (PRe´ 2006). CORRIM has used this software for its life-cycle studies and provided the SimaPro software and licensing for this project.

The survey instrument sent to flooring manufacturers contained a section devoted to detailed inputs and outputs specific to each unit process. A majority of responding mills indicated the level of detail was too difficult to assess accurately and indicated responses were best guess estimates. Most mills were unable to complete this section of the survey and left it blank. To more accurately account for all input and output flows, this inventory was modeled using a single box approach shown in Figure 6.

In effect, the seven unit processes, planing, ripping, trimming, side and end matching, packaging, boiler energy generation, and emissions control are aggregated in the solid line box. The advantage of this approach is that hardships encountered in allocating inputs and outputs to a given machine center (largely best guesses by survey respondents) were avoided.

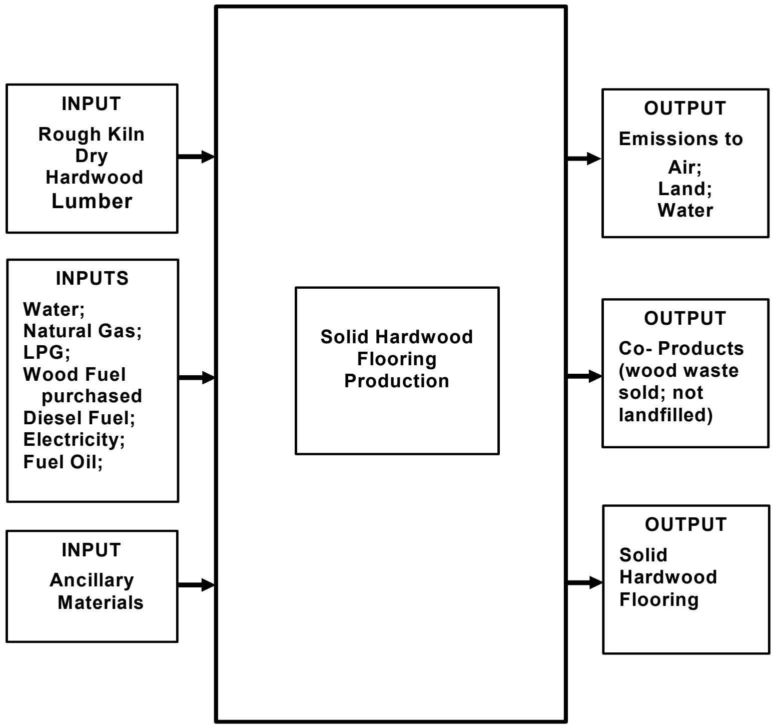

Figure 6: Single Box Modeling Approach for the Production of Solid Hardwood Flooring

2.1 Functional Unit

The functional unit for this gate-to-gate life-cycle inventory is one cubic meter (1.0 m^3) or (35.3 cubic feet) of solid hardwood flooring made from the following species: Red Oak, White Oak, Sugar Maple, Red Maple, Ash, Birch, Walnut, Cherry, Beech, Hickory, and Pecan. Allocation for products and co-products are mass-based on an oven dry basis.

2.2 Material Flows

Raw materials examined in the life cycle inventory analysis appear in Table 3. Input rough kiln dried lumber and associated co-products sawdust, trimmings, edging strips, wood flour, and planer shavings are at the survey reporting average moisture content of 8%. Table 3 excludes the fuel and electricity inputs. Subsequent flows for wood in the process of flooring manufacture are determined on an oven-dried basis.

Table 3: Raw Material Inputs, Co-Products, and Products in Flooring Manufacture

Input Materials[1]	Co-products Produced[2]	Products[3]
Rough kiln dry hardwood lumber	Sawdust	Unfinished solid hardwood flooring
Steel strapping	Planer shavings	
Water, from ground	Edging strips	
	Trimmings	
	Wood flour	

Note: fuels and electricity are not included here
[1]Lumber is at 8% moisture content
[2]Co-products produced are at 8% moisture content
[3]Solid strip and solid plank flooring; does not consider parquet or engineered flooring

A weighted average density for wood (oven-dry basis) was calculated for each wood species reported by respondent mills. Wood species, conversion values, volume, and percent contribution by species appear in Table 4. Values for nominal green weights used in calculating the oven dry weights by species are given by the National Hardwood Lumber Association (NHLA 2003). The given values are reported at identical moisture content to that reported by mills for rough input lumber (8%) making this a logical source.

The U.S. hardwood flooring industry reports product output in square feet (ft^2). For the conversion of square feet into cubic meters, participating mills were asked to indicate the thicknesses of their flooring for each reported width. These were 0.38, 0.50, 0.75, 1.00, and 1.25 inches (9.65, 12.7, 19.05, 25.4, and 31.7 mm, respectively). The reported square footage of product at a given thickness was converted to cubic feet using the following conversion factors for each thickness value respectively, 0.0316, 0.0416, 0.0625, 0.0833, and 0.1041. Cubic foot values were subsequently converted to cubic meters using a conversion factor of 0.028. In accordance with CORRIM and ISO protocol, all input and output data were allocated to the functional unit of product on a mass basis for all products and co-products (ISO 2006; CORRIM 2001).

Reported wood volumes by species across all mills were obtained and totaled (Table 4). Recorded values for each species were then divided by this total to obtain a percentage contribution by species. Oven dry averages for each species were computed by multiplying the percentage contribution of a given species by the oven dry weight for that species. Oven dry averages were summed across all species to obtain a final oven dry mass basis of 657 kg/m^3 (41 lb/ft^3) for the hardwood flooring.

Table 4: Wood Flooring Conversion to Oven Dry Mass Basis by Species

Wood Species	Green Weight[1] (MC 8%) kg/m³	Oven Dry Weight[2] kg/m³	Reported Volume for all Mills (m³)	Total Weight Averaged Volume Contributions %	Oven Dry Mass Basis Conversion kg/m³
White Oak	735	680	111,340	0.228	156
Red Oak	700	648	111,340	0.690	448
Maple (hard)	677	626	111,340	0.0499	31.3
Ash[3]	629	582	111,340	0.000	0.009
Birch[3]	677	626	111,340	0.000	0.215
Cherry[3]	554	512	111,340	0.000	0.323
Beech[3]	691	639	111,340	0.000	0.008
Hickory/Pecan	795	736	111,340	0.0293	21.6
Total					**657**

[1]Nominal green weight values obtained from (NHLA 2003)
[2]Oven dry weight calculated using standard formula with green weight at assumed 8% MC; i.e. OD Wt.= Green weight/1 + (.08/100)
[3]Ash, Birch, Cherry, and Beech have a combined average volume contribution of 1%

2.3 Transportation

Delivery of the hardwood lumber from sawmills to the flooring mills was by truck. None of the mills reported delivery by rail. The averaged one-way delivery distance for the lumber was 283 km (176 mi). Mills reported that these trucks are empty on their backhaul. Burdens associated with this transportation are included in the cumulative system boundary but omitted from the on-site boundary analysis. Transportation data for packaging material was not reported and is not included in the analysis.

3.0 PRODUCT YIELDS

Product yields observed in the survey allow for examination of how the input lumber is realized into products, co-products, and waste. A recovery of 46% was observed in this study. In other words, to produce 1.0 cubic meter (35.3 cubic feet) of solid hardwood flooring, 2.1 cubic meters (74.1 ft^3) of input lumber was needed. The remaining 1.1 cubic meters (38.8 ft^3) of input lumber is classified as wood residue. Wood residue is sold off-site or utilized on-site as hogged fuel for heat generation. Values were obtained by dividing the weight of wood in hardwood flooring by the total weight of input lumber and multiplying by 100%. Findings here are consistent with previous yield studies reported for this product (Hosterman 2000; Bond *et al.* 2006).

To account for all wood reported as input and output to flooring manufacture a mass balance was performed (Table 5). To yield 657 kg/m^3 (oven dry basis) of solid strip hardwood flooring, 1,419 kg/m^3 of rough kiln dry hardwood lumber was needed. A difference of 0.6 kg/m^3 was observed between total recorded wood input and output. The unaccounted wood is well below 1% of the total wood input and is considered excellent for a survey of this magnitude.

Table 5: Wood Mass Balance for 1.0 Cubic Meter of Solid Hardwood Flooring Produced

	kg/m^3	lb/ft^3	Allocation %
Inputs			
Rough kiln dry hardwood lumber	1,419	88	100%
Total wood input	1,419	88	100%
Outputs			
Solid hardwood flooring	657	41	46%
Wood residue[1]	762	47	54%
Total	**1,419**	**88**	**100%**

[1]Wood residue in the black box approach refers to any combination of planer shavings, sawdust, edgings, trimmings, and wood flour. Wood residue is used on-site for energy generation or sold off-site as value added furnish.

Note: all weights on oven-dried basis; 0.6 kilograms per cubic meter unaccounted. Stated in assumptions and assumed as fugitive wood waste.

4.0 MANUFACTURING REQUIREMENTS

4.1 Production Energy

4.1.1 Energy Sources

Solid hardwood flooring production utilizes several energy sources. Purchased electricity is a key source and is used to operate conveyance and pneumatic equipment as well as saws, planers, moulders (matchers) and emission control devices. Thermal energy is used to operate kilns and for facility heating. For the on-site system boundary in this study, thermal energy is confined to facility heating[13]. Energy use associated with kiln drying the hardwood lumber is accounted for in the cumulative system boundary through a hardwood lumber production model input (Bergman & Bowe 2007a). With the exception of one mill, all used industrial boilers to combust wood residue (hogged fuel)

[13] Despite explicit directions in the survey to exclude data associated with on-site kilns, it became clear that some respondents still reported this data. Extensive follow-ups with mill respondents indicated that 10% of thermal energy was associated with facility heating while the remaining 90% is associated with kilns. Care was taken to exclude thermal energy associated with kilns.

generated on-site to provide the thermal energy. On-site forklifts, trucks, and carriers relied on gasoline, diesel fuel, and liquid propane gas.

4.1.2 Electrical Usage

Purchased electricity (off-site electrical grid) required to operate the machine centers was reported by 7 of the 10 respondent mills. For the on-site system boundary, to produce 1.0 m^3 (35.3 ft^3) of solid hardwood flooring, 48.4 MJ of electricity were consumed. Mills were unable to provide a percentage allocation of electrical use per unit process. By comparison, electrical use for the cumulative system boundary which included hardwood lumber production was 656 MJ.

4.1.3 Thermal Usage

Wood residue produced on-site is used to fuel on-site boilers. Extraneous wood residue is sold off-site as value added furnish. No mills in this study reported that they purchase wood residue as they are able to meet internal demands. Thermal energy (associated with the production of 1.0 m^3 of flooring) produced on-site for facility heating required 29 kg/m^3 or 1.8 lb/ft^3 of wood residue (oven-dry basis).

4.1.4 Energy Requirements

Electricity is the most prevalent form of energy used in the system boundary for hardwood flooring manufacture. Coal used to produce this electricity is the largest off-site energy source. Thermal energy produced by combusting wood in on-site boilers is second followed by the fossil fuels natural gas and fuel oil #6. The eastern region produces most of its electricity through a variety of fuel sources. Unlike the Pacific Northwest region, little is produced by hydropower. The average composition of off-site electrical generation was determined for the eastern region by averaging United States Department of Energy values given for the North East/North Central region and those reported for southeastern states (USDOE 2006). Table 6 shows the breakdown by fuel source used to derive the eastern region electricity values. Major fuel sources used to produce the purchased electricity were coal, nuclear, petroleum, natural gas, and hydro. Table 6 includes electrical power requirements for both the on-site flooring system in isolation and with North East/North Central lumber production (Bergman & Bowe 2007b).

Table 6: Electric Power Requirements Allocated to 1.0 m^3 of Solid Hardwood Flooring

		On-Site Hardwood Flooring Only		Flooring Process with NE/NC Lumber Production	
Fuel Source	**Percent of Total Electricity Production 2006**	**MJ/m^3**	**kWh/MBF**	**MJ/m^3**	**kWh/MBF**
Coal	51.8 %	25.1	12.2	340	166
Petroleum	3.9 %	1.89	0.92	25.6	12.5
Natural Gas	16.4 %	7.95	3.88	107	52.6
Hydro	2.3 %	1.11	0.54	15.09	7.37
Nuclear	22.8 %	11.05	5.40	149	73.1
Other Renewables	2.8 %	1.35	0.66	18.3	8.98
Total	**100 %**	**48.4**	**23.6**	**656**	**320**

Note: 1.76 cubic meters per 1.0 MBF. Totals are subject to rounding error. Reported value for total NE/NC electricity was 608 MJ per 1.0 cubic meter (Bergman & Bowe 2007b).

4.2 On-Site Transportation Fuel Use

The on-site transport and handling of materials throughout a flooring mill is accomplished through the use of forklifts, trucks, bob-cats, and other carriers. Three primary fuel sources power this machinery. These are, propane, natural gas, and off-road diesel fuel. To produce the functional unit of hardwood flooring, off-road diesel fuel is the major consumer with 0.27 liters per cubic meter (0.13 gal/MBF) followed by propane and gasoline with 0.12 l/m^3 (0.055 gal/MBF) and 0.02 l/m^3 (0.009 gal/MBF) respectively.

4.3 Water Consumption

Water use in the production of solid hardwood flooring can occur in three primary areas. Consistent with the system boundary and established protocol, human water use on-site (bathrooms, drinking water, etc.) and water used in pre-finishing operations are not included in this report. Therefore, results presented in this report are based on the weighted average amount of water used for on-site industrial boilers. The reader is reminded that only water required in boilers (maintenance and facility heating) is considered on-site. Based on the weight averaged responses for 8 mills, 6.21 liters of ground water is used in the production of 1.0 m^3 of solid flooring.

Water use is much higher when the production of lumber is included. This is due in large part to sprinkling systems or holding ponds used to control yard dust and sapstain fungi at sawmills. The hardwood lumber module introduces 244 liters (113 gallons) of water to the cumulative boundary flooring model (Bergman & Bowe 2007b).

Table 7 shows the on-site data collected in the surveys that was input to the SimaPro model software. The data in the table does not include values for the production of hardwood lumber. Examining Table 7 one can see that hardwood flooring manufacture is a relatively straightforward process.

Table 7: Survey Data Input to the Hardwood Flooring Model by Type Required to Produce 1.0 m^3 of Solid Hardwood Flooring

Inputs to the Model	Quantity in SI Units per 1.0 m^3	Quantity in units per MBF
Materials		
Wood		
Rough Kiln Dry Hardwood Lumber	1419 kg	5509 lb
Water		
From Ground	6.21 l	2.89 Gal
Packaging		
Steel Strapping, cold rolled	0.15 kg	0.58 lb
Fuels		
Electricity		
Purchased	48.4 MJ	13.4 kWh
Wood Hogged Fuel		
Wood Residue Produced On-Site	29.1 kg	113 lb
Fossil		
Natural Gas	0.89 m^3	55.3 ft^3
Fuel Oil #6	0.01 1	0.005 Gal
On-Site Transportation		
Propane	0.12 l	0.055 Gal
Gasoline	0.02 l	0.009 Gal
Off-Road Diesel	0.27 l	0.13 Gal
Emissions		
To Air		
Particulates, unspecified	0.01 kg	0.03 lb
Particulates <10 um	0.007 kg	0.02 lb
To Water		
Discharged to Sewer or Surface	0.01 l	0.005 Gal
To Land		
Fly Ash	1.32 kg	5.12 lb

Weight averaged data from 10 mills; all data allocated by mass to production of 1.0 m^3 hardwood flooring (oven-dry basis 657 kg/m^3); Values in the table are for on-site boundary only (values for hardwood lumber module not included). 1.76 cubic meters per 1.0 nominal Thousand Board Feet (MBF).

5.0 LIFE-CYCLE INVENTORY RESULTS

Results for the life-cycle inventory of solid strip and solid plank hardwood flooring are presented using two scenarios. Scenario one presents the on-site gate-to-gate life-cycle inventory boundary generated in SimaPro 7.0 and appears in Table 8. All results shown in Table 8 are allocated and cumulative. Energy values are reported as the higher heating value (HHV) of a fuel. These values do not ignore energy produced by combustion of hydrogen in fuels. Instead, higher heating values represent the amount of heat released per a specified amount of fuel originally at 25°C that has combusted and returned to a temperature of 25°C. Higher heating values consider the latent heat of vaporization of water that occurs in combustion. Recall that the on-site boundary does not consider the impacts or burdens associated with producing or delivering the hardwood lumber input.

Table 8: On-Site Life-Cycle Inventory Results for the Production of 1.0 m^3 of Solid Hardwood Flooring; data is allocated and cumulative

Substance	kg/ m^3	lb/MBF	Substance	kg/m^3	lb/MBF
Raw Materials Consumed			**Raw Materials Consumed**		
Coal, in ground[a]	4.40E+01 MJ	3.71E+00 Btu	Oxygen, in air	6.83E-03	2.65E-02
Energy,hydro[a]	5.18E-01 MJ	4.36E-02 Btu	Scrap, external	2.71E-02	1.05E-01
Energy,unspcfd[a]	6.29E-01 MJ	5.30E-02 Btu	Uranium[a]	2.92E+00 MJ	2.46E-01 Btu
Natural gas[a]	3.85E+01 MJ	3.25E+00 Btu	Well water	2.86E+00	1.11E+01
Hardwood lumber, dry, NE/NC[1]	6.53E+02	2.53E+03	Wood & wood waste	2.80E+02 MJ	2.36E+01 Btu
Iron ore, in ground	8.25E-02	3.20E-01	Crude oil[a]	7.68E+00 MJ	6.47E-01 Btu
Limestone	1.06E-01	4.13E-01			
Emissions to Air			**Emissions to Air**		
Acrolein	5.91E-08	2.29E-07	Kerosene	1.69E-06	6.57E-06
Aldehydes	2.08E-05	8.06E-05	Lead	1.74E-05	6.75E-05
Ammonia	1.94E-05	7.54E-05	Manganese	1.21E-04	4.70E-04
Antimony	2.63E-08	1.02E-07	Mercury	1.10E-07	4.27E-07
Arsenic	1.30E-06	5.06E-06	Metals, unspcfd	7.73E-07	3.00E-06
Barium	5.90E-05	2.29E-04	Methane	1.26E-02	4.91E-02
Benzene	5.53E-08	2.15E-07	Methane, HCC-30	2.31E-07	8.96E-07
Beryllium	1.46E-08	5.67E-08	Methane, CFC-10	6.46E-08	2.51E-07
Cadmium	1.61E-08	6.26E-08	Nitrodimethylamine	1.25E-08	4.84E-08
Carbon dioxide, biogenic	2.82E+01	1.09E+02	Naphthalene	4.65E-09	1.80E-08
Carbon dioxide, fossil	5.73E+00	2.22E+01	Nickel	7.78E-06	3.02E-05
Carbon monoxide	1.95E-01	7.58E-01	Nitrogen oxides	4.68E-02	1.82E-01
Chlorine	1.05E-04	4.06E-04	VOC, non-methane	8.53E-03	3.31E-02
Chromium	7.83E-07	3.04E-06	Organic, unspcfd	4.49E-05	1.74E-04
Cobalt	5.49E-08	2.13E-07	Particulates	5.00E-03	1.94E-02
Copper	1.04E-09	4.02E-09	Particulates, < 10 um	9.59E-03	3.72E-02
Dinitrogen monox.	3.30E-05	1.28E-04	Particulates, unspcfd	1.46E-07	5.65E-07
Dioxins	3.12E-13	1.21E-12	Phenol	1.05E-02	4.06E-02
Ethene, tetrachloro.	5.59E-08	2.17E-07	Potassium	1.69E-06	6.57E-06
Ethene, trichlor.	5.58E-08	2.17E-07	Radioactive, unspcfd	7.41E+04 Bq	N/A
Formaldehyde	1.13E-04	4.37E-04	Selenium	4.19E-07	1.63E-06
Hydrogen chloride	2.96E-04	1.15E-03	Sodium	2.42E-04	9.37E-04
Hydrogen fluoride	4.11E-05	1.59E-04	Sulfur oxides	4.86E-02	1.88E-01
Iron	5.90E-05	2.29E-04	Zinc	5.91E-05	2.29E-04
Emissions to Water			**Emissions to Water**		
Acidity, unspcfd	1.76E-10	6.83E-10	Manganese	1.32E-04	5.12E-04

Acids, unspcfd	1.38E-08	5.36E-08	Mercury	1.34E-10	5.21E-10
Ammonia	3.72E-06	1.44E-05	Metal ions, unspcfd	3.77E-06	1.46E-05
Bio Oxy Demand	3.85E-05	1.49E-04	Nitrate	6.36E-07	2.47E-06
Boron	1.46E-04	5.68E-04	Oils, unspcfd	6.66E-04	2.59E-03
Cadmium, ion	1.71E-06	6.64E-06	Organic, unspcfd	1.36E-04	5.26E-04
Calcium, ion	1.46E-06	5.65E-06	Phenol	5.84E-08	2.27E-07
Chloride	1.73E-03	6.71E-03	Phosphate	1.83E-05	7.10E-05
Chromate	9.68E-09	3.75E-08	Sodium, ion	2.68E-06	1.04E-05
Chromium	1.71E-06	6.64E-06	Solved solids	3.78E-02	1.47E-01
Chem Ox Demand	5.35E-04	2.07E-03	Sulfate	2.18E-03	8.47E-03
Cyanide	1.06E-07	4.12E-07	Sulfuric acid	3.66E-05	1.42E-04
Fluoride	6.75E-06	2.62E-05	Suspended solids, unspcfd	3.24E-03	1.26E-02
Iron	2.36E-04	9.16E-04	Water	5.91E-03	2.29E-02
Lead	5.01E-10	1.94E-09	Zinc, ion	5.93E-07	2.30E-06
Emissions to Soil			**Emissions to Soil**		
Waste, solid	1.62E+00	6.30E+00	Fly Ash	6.11E-01	2.37E+00

Values are for on-site flooring production boundary. [1]NE/NC hardwood lumber (Bergman & Bowe 2007a). 1.76 cubic meters per 1.0 nominal Thousand Board Feet (MBF). [a]Per CORRIM protocol, energy values are reported using their higher heating values (HHV) in MJ/kg. HHV's are: Oven dry wood 20.9, Coal 26.2, Distillate fuel oil 45.5, LPG 54.0, Natural gas 54.4, Gasoline 54.4, and Uranium 381,000. Conversion units for electricity are 3.6 MJ/kWh.

Life-cycle inventory results for the impacts associated with hardwood lumber production, transportation of that lumber from the sawmill to the flooring mill, and the subsequent conversion of lumber into solid strip and solid plank hardwood flooring (expanded gate-to-gate boundary model) are presented in Table 9. Ninety-nine substances were observed as part of the collective production process. All results shown in Table 9 are allocated and cumulative on a per unit basis of solid strip hardwood flooring. Energy values are reported as the higher heating value (HHV) of a fuel.

Table 9: Cumulative Site Gate-to-Gate Life-Cycle-Inventory Results for Hardwood Lumber through Solid Hardwood Flooring; (Data is Allocated)

Substance	kg/ m^3	lb/MBF	Substance	kg/m^3	lb/MBF
Raw Materials Consumed			**Raw Materials Consumed**		
Coal, in ground[a]	8.82E+02 MJ	7.43E+01Btu	Oxygen, in air	6.83E-03	2.65E-02
Energy,hydro[a]	1.10E+01 MJ	9.27E-01 Btu	Scrap, external	2.71E-02	1.05E-01
Energy, unspcfd [a]	8.00E+00 MJ	6.74E-01 Btu	Uranium	5.69E+01 MJ	4.79 Btu
Natural gas[a]	1.07E+03 MJ	9.02E+01Btu	Limestone	5.81E+00	2.25E+01
Hardwood bark green, NE/NC	9.50E+01	3.69E+02	Well water	3.03E+00	2.21E+01
Iron ore, in ground	8.25E-02	3.20E-01	Wood & wood waste[a]	1.68E+03 MJ	142 Btu
Crude oil[a]	8.08E+02 MJ	6.81E+01 Btu	Logs (for lumber)	1.66 m^3	------
Emissions to Air			**Emissions to Air**		
Acetaldehyde	7.12E-04	2.76E-03	Kerosene	3.26E-05	1.26E-04

Acrolein	1.21E-06	4.69E-06	Lead	3.45E-04	1.34E-03
Aldehydes	7.68E-03	2.98E-02	Manganese	2.26E-03	8.79E-03
Ammonia	2.86E-04	1.11E-03	Mercury	2.55E-06	9.90E-06
Antimony	1.05E-06	4.08E-06	Metals, unspcfd	2.05E-05	7.94E-05
Arsenic	2.56E-05	9.94E-05	Methane	2.86E-01	1.11E+00
Barium	1.10E-03	4.28E-03	Methane, HCC-30	4.81E-06	1.87E-05
Benzene	8.55E-04	3.32E-03	Methane, CFC-10	2.38E-06	9.22E-06
Beryllium	4.01E-07	1.56E-06	Nitrodimethylamine	2.55E-07	9.91E-07
Cadmium	2.20E-06	8.54E-06	Naphthalene	5.69E-04	2.21E-03
Carbon dioxide, biogenic	5.26E+02	2.04E+03	Nickel	1.69E-04	6.56E-04
Carbon dioxide, fossil	1.70E+02	6.60E+02	Nitrogen oxides	1.34E+00	5.19E+00
Carbon monoxide	4.01E+00	1.56E+01	VOC, non-methane	3.54E-01	1.37E+00
Chlorine	1.96E-03	7.60E-03	Organic, unspcfd	1.76E-01	6.82E-01
Chromium	1.69E-05	6.56E-05	Particulates	1.35E+00	5.23E+00
Cobalt	2.59E-06	1.00E-05	Particulates, < 10 um	1.16E-01	4.49E-01
Copper	1.04E-09	4.02E-09	Particulates, unspcfd	9.39E-02	3.64E-01
Dinitrogen monoxide	6.93E-04	2.69E-03	Phenol	9.49E-03	3.68E-02
Dioxins	6.39E-12	2.48E-11	Potassium	1.96E-01	7.59E-01
Ethene, tetrachloro.	1.16E-06	4.50E-06	Radioactive , unspcfd	1.30E+06	N/A
Ethene, trichloro.	1.14E-06	4.43E-06	Selenium	9.10E-06	3.53E-05
Formaldehyde	5.33E-03	2.07E-02	Sodium	4.51E-03	1.75E-02
Hydrogen chloride	6.05E-03	2.35E-02	Sulfur oxides	1.28E+00	4.98E+00
Hydrogen fluoride	8.40E-04	3.26E-03	Vol Org Compounds	1.40E+00	5.44E+00
Iron	1.10E-03	4.28E-03	Zinc	1.10E-03	4.28E-03
Emissions to Water			**Emissions to Water**		
Acidity, unspcfd	1.88E-08	7.30E-08	Manganese	2.64E-03	1.02E-02
Acids, unspcfd	1.38E-08	5.36E-08	Mercury	3.71E-09	1.44E-08
Ammonia	9.80E-05	3.80E-04	Metal ions, unspcfd	4.03E-04	1.56E-03
Bio Oxy Demand	1.23E-03	4.79E-03	Nitrate	1.22E-05	4.75E-05
Boron	3.22E-03	1.25E-02	Oils, unspcfd	1.89E-02	7.34E-02
Cadmium, ion	4.73E-05	1.84E-04	Organic, unspcfd	3.59E-03	1.39E-02
Calcium, ion	2.80E-05	1.09E-04	Phenol	1.34E-06	5.22E-06
Chloride	4.76E-02	1.85E-01	Phosphate	4.03E-04	1.56E-03
Chromate	1.57E-06	6.08E-06	Sodium, ion	5.15E-05	2.00E-04
Chromium	4.73E-05	1.84E-04	Solved solids	1.06E+00	4.10E+00
Chem Ox Demand	1.56E-02	6.04E-02	Sulfate	5.32E-02	2.06E-01
Cyanide	1.74E-07	6.77E-07	Sulfuric acid	8.05E-04	3.12E-03
Fluoride	1.30E-04	5.04E-04	Suspended solids	7.04E-02	2.73E-01
Iron	4.62E-03	1.79E-02	Water	5.91E-03	2.29E-02
Lead	3.38E-08	1.31E-07	Zinc, ion	1.67E-05	6.47E-05
Emissions to Soil			**Emissions to Soil**		
Waste,inert landfill	8.77E+00	3.40E+01	Waste, solid	3.92E+01	1.52E+02
Waste to recycling	2.61E-01	1.01E+00	Fly Ash	6.11E-01	2.37E+00

[1]NE/NC hardwood lumber module (Bergman & Bowe 2007a). 1.76 cubic meters per 1.0 nominal Thousand Board Feet (MBF). Includes transportation. [a]Per CORRIM protocol, energy values are reported using their higher heating values (HHV) in MJ/kg. HHV's are: Oven dry wood 20.9, Coal 26.2, Distillate fuel oil 45.5, LPG 54.0, Natural gas 54.4, Gasoline 54.4, and Uranium 381,000. Conversion units for electricity are 3.6 MJ/kWh.

The variety of substances and detail contained in both Table 8 and Table 9 illustrates the challenge in interpreting life-cycle inventory results. Consequently the reported values have different levels of significance depending on a stakeholder's interest in an impact to a particular system or process. Depending on the context, some substances, for example, will be of more interest to those examining human health or mammalian toxicity while others will be more discerning of those implicated in global climate change or land use.

6.0 CARBON BALANCE

Carbon emissions are under increasing scrutiny. A carbon balance for the production of hardwood flooring was performed. Consider carbon dioxide (CO_2). There are two major forms of this compound and an important distinction must be made between them. Anthropogenic CO_2 is derived from fossil fuels use. Conversely, biogenic CO_2 is carbon dioxide generated from biomass. Unlike fossil fuel carbon dioxide, this latter form of CO_2 is considered impact neutral (EPA 1999). In other words, carbon dioxide gas emitted in wood combustion and processing may be off-set by the carbon dioxide gas taken up by trees as they grow (Birdsey 1992). Through the process of photosynthesis, carbon dioxide and water are taken from the atmosphere and soil for woody tissue production. In the process, oxygen is released back to the atmosphere. Further, woody biomass used for internal fuel requirements during the manufacturing process can be considered advantageous (Wilson & Sakimoto 2005). As evidenced in Table 8, for the on-site hardwood flooring inventory SimaPro gives per unit flooring carbon emission values of 28.2 kg for biogenic CO_2 and 5.73 kg for fossil fuel CO_2. If impacts associated with lumber production from the cumulative system boundary are taken into account these values rise to 526 kg and 170 kg for biogenic and fossil fuel $CO_{2,}$ respectively.

The carbon balance for the flow of wood in the production of solid strip and solid plank hardwood flooring appears in Table 10. Carbon from lumber, solid wood flooring, and wood residue are tracked. Carbon flows associated with hardwood lumber *production* are not included. The amount of carbon in wood was determined by averaging regional values for the amount of carbon found in hardwoods reported by Skog and Nicholson (1998). The regions included were, North Central, North East, South Central, and, South East. The averaged hardwood factor used for carbon was 305 kg of carbon per cubic meter of wood. Input carbon was 305 kg/m^3 while output carbon totaled 313 kg/m^3. Three percent of the carbon is unaccounted for and is assumed to be fugitive wood waste.

Table 10: Wood-Based Carbon Flow for On-Site Hardwood Flooring Production

Substance	Carbon Content kg/m^3	Carbon Content lb/MBF
Input		
Rough dry hardwood lumber	305	1,180
Sum carbon in	305	1,180
Output		
Solid strip/plank hardwood flooring	145	563
Co-products[1]	159	617
Air emissions	9.36	36.3
Solid emissions	0	0
Sum carbon out	313	1,216

[1]Includes wood residue: sawdust, planer shavings, edging strips, trimmings, wood flour, and wood fuel combusted on-site.

Air emissions associated with wood fuel combustion and processing observed in Table 10 are determined using the relevant on-site inventory results reported in Table 11.

Table 11: On-Site Wood-Based Contribution of Carbon Emissions to Air

Substance	Total kg/m^3	% Carbon Contribution Wood-Based	Carbon kg/m^3	Carbon lb/MBF
Benzene	5.53E-08	92.3 %	5.11E-08	1.98E-07
Carbon dioxide, biogenic	2.82E+01	27.3 %	7.69E+00	2.99E+01
Carbon dioxide, fossil	5.73E+00	27.3 %	1.56E+00	6.07E+00
Carbon monoxide	1.95E-01	42.9 %	8.38E-02	3.25E-01
Formaldehyde	1.13E-04	40.0 %	4.51E-05	1.75E-04
Methane	1.26E-02	75.0 %	9.48E-03	3.68E-02
Naphthalene	4.65E-09	93.7 %	4.35E-09	1.69E-08
NMVOC, non-methane volatile organic compounds	8.53E-03	88.2 %	7.52E-03	2.92E-02
Organic substances, unspecified	1.36E-04	50.0 %	6.78E-05	2.63E-04
Phenol	5.84E-08	76.6 %	4.47E-08	1.74E-07
Total	34.1	27.4 %	9.36	36.3

Carbon flow for wood-based carbon in the cumulative gate-to-gate system boundary which includes the impacts of lumber production is shown for comparison in Table 12.

Table 12: Wood-Based Carbon Flow for Cumulative Boundary Hardwood Flooring Production

Substance	Carbon Content kg/m^3	Carbon Content lb/MBF
Input		
Rough dry hardwood lumber	640	2,480
Wood Fuel[1]	170	660
Sum carbon in	810	3,140
Output		
Solid strip/plank hardwood flooring	305	1,180
Co-products[2]	353	1,370
Air emissions	194	753
Solid emissions	0	0
Sum carbon out	852	3,303

[1]Wood fuel value from (Bergman & Bowe 2007b).
[2]Includes wood residue sawdust, planer shavings, edging strips, trimmings, and wood flour. Flooring mill wood fuel combusted on-site included.

7.0 DISCUSSION and ENVIRONMENTAL IMPACT

As with other inventoried products and processes, care is needed in interpreting the results of this inventory for solid strip and solid plank hardwood flooring. Additionally, those wishing to make direct product comparisons across alternative or substitute products are cautioned that for comparisons to be meaningful it is important that the methods used to derive the inventory results be the same. The repercussions of comparing "apples to oranges" could lead to significantly flawed conclusions. The authors are unable to locate studies for alternative flooring materials that allow an "apples to apples" comparison for this study. Alternative floor covering LCI data does exist however and is incorporated into this discussion.

Recall the two scenarios presented in Table 8 and Table 9. It is clear that boundary selection has a large influence on the observed results. In this study, the manufacturing requirements to produce the kiln dry lumber input for flooring production carries the majority of environmental and fuel use burden. Even so, these associated impacts are consistent with other studies of this type which have consistently shown wood product manufacture to be less energy intensive compared to that of wood substitutes (Lippke *et al.* 2004).

Considering the hardwood flooring production process in isolation from the additive effects of lumber production, several observations can be made. First, the manufacturing process to produce this product is relatively straightforward. Not surprisingly, therefore, the environmental burdens on-site are confined to select sources. The majority of required energy within the on-site system boundary is in the form of purchased electricity to run conveyance, sawing, and emission control equipment. Coal represents nearly 52% of the regional fuel input used to generate this purchased electricity in the eastern region. The associated carbon from coal is fossil (anthropogenic) and not considered biogenic. Mining extraction and the associated processes required to produce steel strapping material used in packaging the flooring is another consideration since the raw material inputs are not considered renewable resources. Data was not collected for plastic packaging but should be considered in future studies of this type.

Hardwood flooring is dependent on hardwood lumber. The manufacture of hardwood lumber carries its own environmental footprint and it is not reasonable to ignore these associated burdens. In terms of environmental impact, kiln drying lumber is arguably the most intensive process. In this study, kiln drying the lumber was not included in the on-site boundary. This was defined intentionally because the hardwood lumber module (Bergman & Bowe 2007a) was the logical input to extend the gate-to-gate life-cycle inventory for this project and already included the kiln drying process for the same species. Since hardwood lumber used for flooring must be dried to final moisture contents of between 6 and 9 percent for stability in service, the associated burdens of kiln drying should not be excluded. The cumulative boundary is therefore considered.

The energy required (thermal and electrical) during the hardwood drying process is significant. It has been estimated that of the total amount of energy required to produce hardwood lumber, approximately 75% is devoted to drying operations (Comstock 1975). In their study of hardwood lumber production, Bergman and Bowe (2007b) found that electrical energy used in drying consumed 152 MJ per cubic meter of lumber (74 kWh per MBF). Thus, considering the cumulative boundary for flooring production, nearly 25% of the total electricity required is for drying wood. A second consideration in the drying process is the subsequent release of Volatile Organic Compounds (VOC's). VOC's are considered carbon compounds that are capable of photochemical reactions in the earth's atmosphere. Of these, Carbon dioxide is considered the most significant contributor to global warming. Control of this emission class is important since the release of VOC's into the environment is deleterious to groundwater, soil, and air. Table 9 lists the volatile organic compounds and amounts per unit of flooring produced that are allocated and associated with the cumulative system boundary. Finally, it is important to recognize that the majority of thermal energy requirements for kiln operation can be met through the utilization of generated on-site wood residues. This means that most mills are able to successfully utilize significant portions of their wood waste streams; keeping woody biomass out of landfills.

The environmental footprint posed by hardwood flooring manufacture is more easily seen when one views the production impacts of both the lumber and flooring (expanded cumulative boundary) to that of flooring production (on-site boundary) in isolation. To illustrate this, Figure 7 considers carbon related emissions and shows the impacts to air for these two production boundaries. Noteworthy in Figure 7 is the larger scale contribution of biogenic carbon dioxide observed for both production boundaries. Recall that this carbon compound, as opposed to fossil fuel CO_2 is considered environmentally impact neutral (Birdsey 1992; EPA 1999).

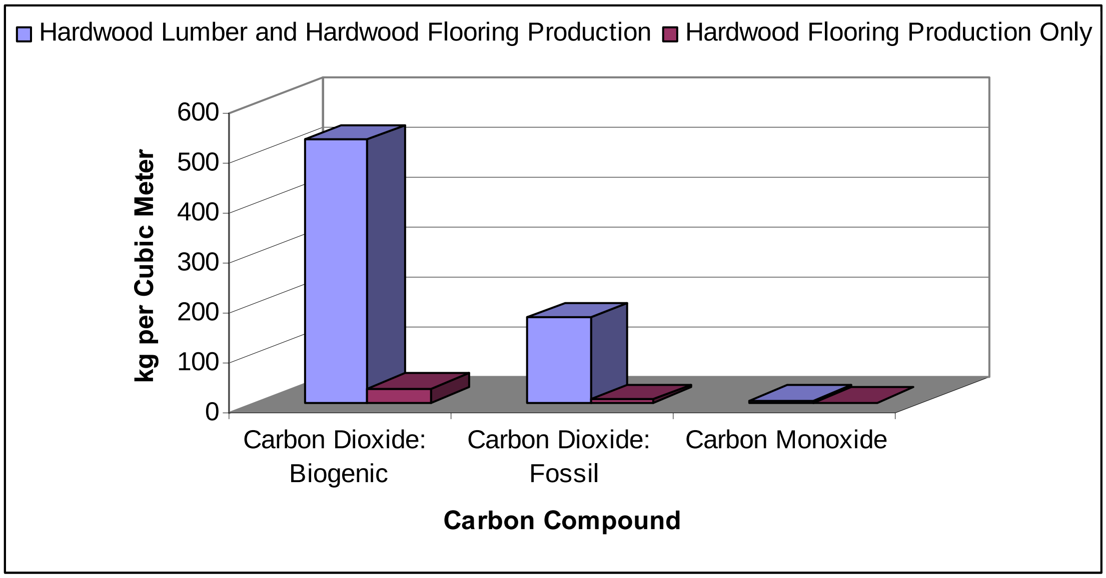

Figure 7: Carbon Emissions by Type for Two Production Boundary Alternatives

Air emissions closely associated with negative impacts to the atmosphere and human respiration appear in Figure 8. The relative contribution by emission type for the two production scenarios shows most of the burden is carried by the production of kiln dry hardwood lumber.

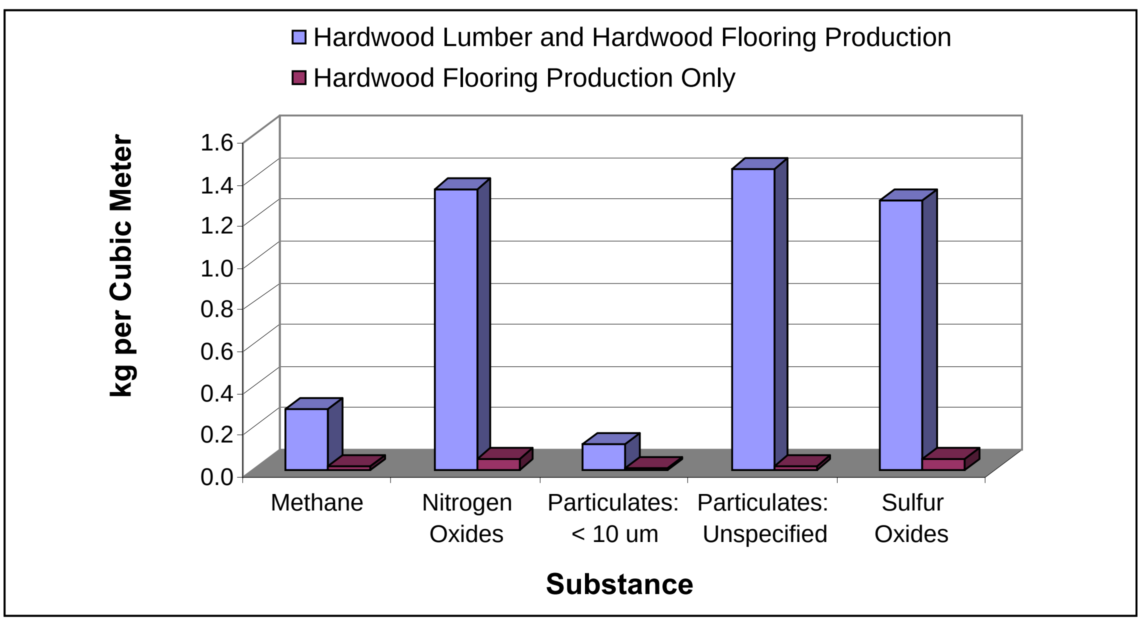

Figure 8: Select Emissions to Air by Type for Two Production Boundary Alternatives

Lastly, Figure 9 shows impacts to water comparisons for the two boundaries.

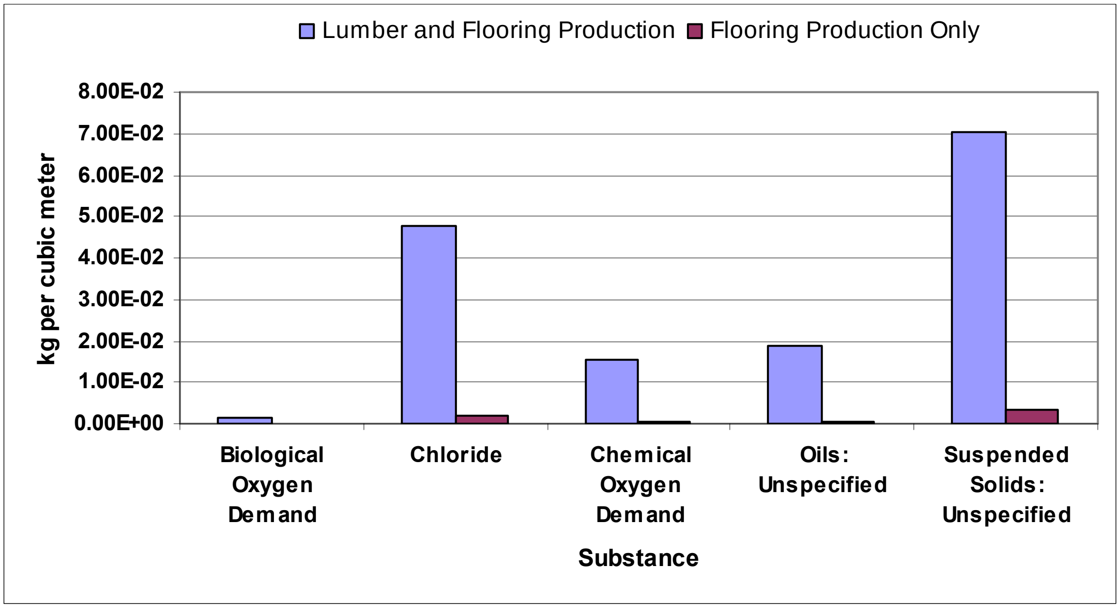

Figure 9: Select Emissions to Water by Type for Two Production Alternatives

A significant factor to consider in evaluating the environmental footprint of solid strip and solid plank hardwood flooring is the renewable nature of the hardwood resource. Sustainable forest management aims to provide a consistent supply of timber while also providing habitat for wildlife and other non-timber forest uses. The same cannot be said for all material inputs used to derive substitute or alternative products (Jönsson *et al.* 1997). Consider the environmental trade-offs associated with various land use and resource extraction scenarios. A case can be made for the benefits of larger mixed hardwood forests than for mining or single crop systems (Wilson 2006). The latter is often characterized by intensive material and energy inputs as well as lower species diversity.

From a human health perspective, it can be argued that wood poses fewer threats to human respiration. Undesirable affects associated with conditions such as asthma, for example, can be lessened or eliminated by employing wood floor coverings (NOFMA 2006b). In addition, hardwood flooring is comparatively easy to maintain (lessened maintenance energy).

Additional considerations are a products service life and disposal. Hardwood flooring has an advantage over other floor coverings such as linoleum and carpet if one considers the service life of the product. It is not unreasonable to expect that, properly cared for, a typical 3/4 inch solid hardwood floor can last from 35 to 75+ years. By comparison, one estimate puts the service life of linoleum to be around 18 years (NIST 2007). A shorter service life means that the product will need to be replaced (more production and associated burdens) with a new one more frequently. The disposal of these products is also important to consider. Wood flooring stores carbon throughout its service life. After its useful service life wood can be recycled or used for fuel.

8.0 CONCLUSION

This study modeled a gate-to-gate life-cycle inventory for solid strip and solid plank hardwood flooring production in the eastern United States. Ten manufacturing facilities with dedicated production of these flooring classifications provided 28 % of total domestic flooring production for the reporting year 2006. Using methodology put forth by the International Organization for Standardization and the Consortium for Research on Renewable Industrial Material, primary data was collected, weight averaged, and modeled using SimaPro software version 7.0 (PRe´ 2006; CORRIM 2001; ISO 2006). Secondary data was obtained from the United States Department of Energy, CORRIM, and a recently completed hardwood lumber production module (USDOE 2006; Bergman & Bowe 2007a). While not included in the on-site flooring production boundary, energy and emissions associated with bringing the needed hardwood lumber to a final dry moisture content of between 6% and 9% represented the biggest environmental impact. The impacts from drying can be categorized as the creation of volatile organic compounds and the thermal and electrical energy requirements to operate the kilns. Biogenic carbon dioxide resulting from the inventory was much greater than fossil derived carbon dioxide. This is seen as beneficial since biomass CO_2 is regarded in many scientific circles to be environmentally neutral (EPA 1999). Some have even argued that it can be viewed as having a negative global warming impact (Nebel *et al.* 2006). It is generally accepted practice that life cycle inventory data be used to contribute to wider life cycle assessments and modular assembly scenarios. Where the methodologies used to generate product life cycle studies for substitute or alternative floor coverings do not employ matching methods, it is not appropriate to make sweeping product comparisons in this regard. The data contained in this study supports other studies reviewed in the literature which have concluded wood flooring is relatively environmentally benign across many of its physical attributes (Nebel *et al.* 2006; Jönsson *et al.* 1997). This study did not examine the burdens associated with coatings or finishing products. Future studies of this type should consider doing so.

As a means of improving environmental performance based on the inventory results in this study the following observations are made:

- Though the use of woody biomass to generate on-site manufacturing energy produces particulate emissions, the benefits of using a carbon neutral fuel source as well as the reduced costs for fossil derived fuels and disposal are large. Mills can benefit by capturing wood residue for use as value added furnish on and off-site.

- Kiln drying is a necessary process to produce stable hardwood flooring. Because kiln drying is energy intensive, continued innovation and use of air drying methods represents potentially large energy savings. Because of discolorations associated with various staining fungi and molds, this is easier said than done.

- Electrical energy used to run rip and chop saws as well as other machine centers should be evaluated on a mill by mill basis. Replacing aging equipment and outdated technology with newer optimized counterparts has the potential to increase efficiency and yields while lowering energy inputs. Mills need to determine costs to benefits of making such changes on a case by case basis.

- Wood is a unique and renewable raw material. Flooring made from wood stores carbon in its service life. During the process of tree growth, trees sequester carbon and release oxygen. This unique process relegates biomass derived carbon dioxide to a carbon neutral substance. At the end of its service in flooring, wood may be re-used or used for fuel.

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APPENDICES

Appendix 1: Select Conversion Factors

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
1.76 cubic meter = 1.0 nominal thousand board feet (MBF)
1 liter = 0.2642 gallons
1 kilometer = 0.621 miles
1 metric ton (1,000 kilogram) = 1.10 tons (2,205 pounds)

Appendix 2: Hardwood Flooring Mill Questionnaire

Solid Hardwood Flooring Life Cycle Inventory and Process Analysis

Project Goals:

- **To inform consumers about the attributes and environmental benefits of wood flooring**
- **To contribute to a growing database of life-cycle inventoried wood products**
- **To identify process improvement options that reduce waste and increase bottom lines**

By Completing This Questionnaire You Will:

- **Show your commitment to helping our domestic forest products industry**
- **Identify opportunities for waste reduction or improved efficiency in your process**
- **Help inform consumers about how wood compares to non-wood materials on an energy, economic, and environmental basis**

I need your help! As a member of the U.S. forest products industry you know that using wood is a sensible choice. Wood is renewable and often poses fewer burdens to the environment than substitute materials. Many public consumers do not understand this. With your input we can test the theory that wood flooring poses less negative impacts to the environment than substitute materials do. Completed projects of this type have shown other wood products to be a sustainable and sound environmental choice over non-wood product alternatives.

The questionnaire focuses on annual production, annual energy use and generation, annual material inputs and outputs, and annual environmental emissions for solid hardwood flooring manufacture in the eastern United States. You may not have all the information requested. The data you are able to provide will be appreciated. **Strict confidentiality will be maintained for all companies that supply data for this project. Only industry averaged data will be used or available to external viewers. Thank you for your time and cooperation with this study!**

Direct questions to:

Steve Hubbard
University of Wisconsin-Wood Products Program
120 Russell Labs
1630 Linden Drive
Madison, WI 53706
Phone (608) 262- 9778 ● Fax (608) 262-9922 ● Email: shubbard@wisc.edu

Please fill in the requested information and read all directions

Company Name: ______________________________

Facility Address: ______________________________

____

Contact Person: ______________________________

Position/Title: ______________________________

Telephone: (   ) ___________ **Fax:** (   ) _______

Contact email: ______________________________

It may be necessary for more than one individual at your mill to help fill out the questionnaire. A mill accountant and mill manager, for example may have the combined information necessary to complete all sections.

HARDWOOD FLOORING ANALYSIS

By flooring, we mean solid strip hardwood flooring 1½", 2¼", and 3¼" in width. Solid plank flooring is defined in this study to be flooring with face widths of 3'', 4", and 5"or wider and made of solid wood. We are not collecting information for engineered, cork, bamboo or parquet flooring in this study. We are only interested in domestic hardwood species- not tropical or softwood species. We have divided flooring manufacturing into eight unit processes. We need information on the total inputs and outputs from your company as a whole and then for each of the eight unit processes individually. We understand that your company may produce flooring of varied widths and thicknesses. Also, your company may not use all eight unit processes we define or may define them slightly different. This is ok. Answer the questions as best you can. The questionnaire is organized as follows:

Part 1: Basic description of facility operations

Part 2: Information about facility total inputs and outputs

Part 3: Information about the total inputs and outputs for each of eight unit processes: planing, trimming, ripping, moulding (side and end matching), pre-finishing, emissions control, energy generation, and packaging

Please provide as much detail as possible for all questions. Units of measure are 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 then simply group by category. For example, you may need to provide one value for all hazardous air pollutants (HAPs) if the quantities of individual compounds are not known. **An abbreviated glossary appears at the end of the questionnaire to help define what is meant by some terms and categories.**

All responses you provide should be for the reporting year (annual basis) you indicate in question 1. Add comments or clarifications directly on the questionnaire if needed. Thank you for your valuable time and careful effort to fill in all the blanks. It should be easier than it looks to complete. Please contact Steve Hubbard at (608) 262- 9778 with any questions.

PART 1: OPERATION OVERVIEW

GENERAL INFORMATION (Please provide responses for all requested information)

1. Reporting Year: ________ Starting Month: ________ Ending Month: ________

2. Mill type (please check one):

- ❑ Solid Hardwood Flooring Producer
- ❑ Other (please specify)____________________

3. How many people does your facility currently employ? ____________

4. Flooring Production (please write in amount for reporting year indicated above):

Total amount of solid strip hardwood flooring this company produced: __________ sq. ft.
Total amount of solid plank flooring this company produced: __________ sq. ft.
Percent of solid strip hardwood flooring that is pre-finished (i.e. stain etc.): _________ %
Percent of solid plank flooring that is pre-finished (i.e. stain etc.): _________ %

5. Please list the top four challenges facing your company today:

1.____

2.____

3.____

4.____

6. Is your company currently involved with formal continuous process improvement tools such as Lean Manufacturing, Six Sigma, or Kaizen? (circle response)

Yes → **If Yes, please list or describe specifically:**

No

7. Which of the following does this mill have? (check all that apply)

Lumber Storage and Handling:
- ❑ Covered storage (dedicated building)
- ❑ Forktruck(s) (how many?)__________
- ❑ Other: ___________________________

Lumber Sorting:
- ❑ Lumber sorter (# bins?) ___________
- ❑ Automated sticker stacker
- ❑ Other: ___________________________

Processing:
- ❑ Trimmer/Chop saw(s) (number?) ____
- ❑ Trimmer optimizer ___________
- ❑ Planer(s) (how many?) ___________
- ❑ In-line moisture meter ___________
- ❑ Scanner ___________
- ❑ Moulder(s) (how many?) __________
- ❑ Side matcher(s) (how many?) _____
- ❑ End matcher(s) (how many?) _____
- ❑ Rip saw(s) (how many?) ___________
- ❑ Sorter (# bins?) ___________
- ❑ Grading station(s) (how many?) ____
- ❑ Other(s): _________________________
- ❑ Other(s): _________________________

Waste Stream and Emissions Control:
- ❑ Hog Grinder(s) (how many?) _____
- ❑ Cyclone(s) (how many?) _____
- ❑ Bag House(s) (how many?) _____
- ❑ Waste Conveyor(s)

Drying and Kilns: (please provide # if more than 1)
- ❑ Air drying yard
- ❑ Predryer __________thousand BF
- ❑ Conventional steam _________MBF
- ❑ Dehumidification ____thousand BF
- ❑ Other: __________________________

Boiler:
- ❑ Wood-fired boiler
- ❑ Gas-fired boiler
- ❑ Cogeneration facility
- ❑ Other: ___________________________

Pre- Finishing Equipment: (please list all)

____
____
____
____
____

Packaging Equipment: (please list all)

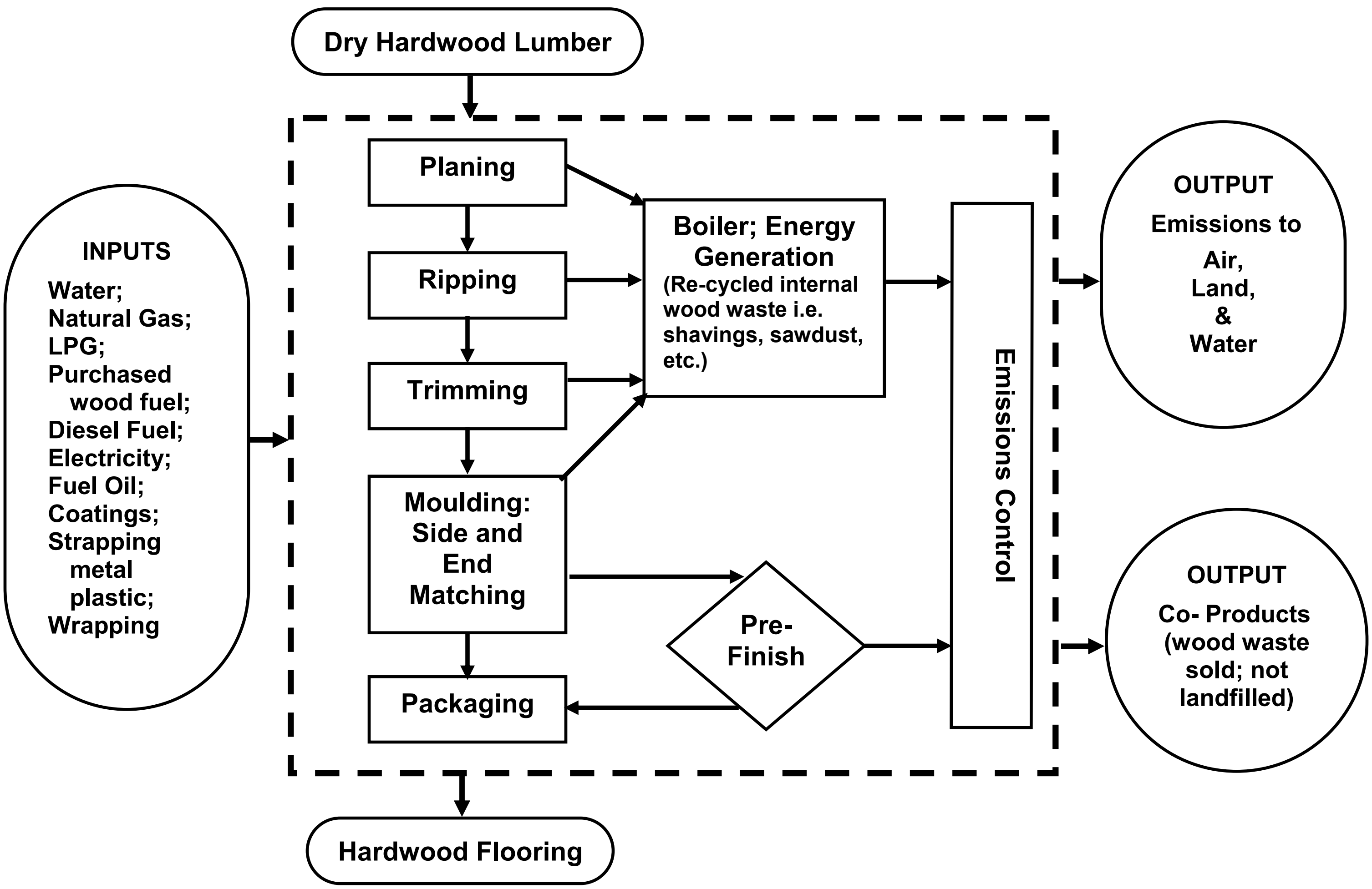
____
____
____
____

Other Major Mill Equipment: (please list all)

____
____
____
____

The diagram below *generalizes* eight unit processes that some mills use to manufacture solid hardwood flooring. The dashed line represents a boundary between the unit processes we are interested in learning more about and the material and energy inputs and outputs that are associated with these processes. In other words, the boxes inside the dashed line represent your manufacturing facility while the ovals outside the dashed line represent items that come into or leave your facility.

Please draw or note any *major* differences between your operation and our diagram. All information is strictly confidential.



Very Important Note:

In the process diagram above, kiln drying is not shown. This is intentional. We are not considering kilns as part of this study. It is very important that the data you provide in the questionnaire does not include energy inputs, outputs, and emissions controls for Kilns. "Facility" or "Mill" in the questionnaire does not include any kilns you may have.

PART 2: TOTAL MILL MATERIAL & ENERGY INPUTS & OUTPUTS

INPUTS (please provide responses for all requested information; annual basis for reporting year)

Total Hardwood Lumber (green and dry):

Total volume of hardwood lumber purchased from outside firms ________________ thousand BF/year

Total volume of hardwood lumber produced on-site (if any) ________________ thousand BF/year

Total volume of hardwood lumber sold to outside firms (if any) ________________ thousand BF/year

Total volume of hardwood lumber processed into flooring[1] on-site _______________ thousand BF/year

Total Dry Hardwood Lumber (only kiln dried):

Total volume of kiln-dried hardwood lumber purchased (if any) _____________ thousand BF/year

Total volume of hardwood lumber kiln-dried on-site (if any) _____________ thousand BF/year

Total volume of kiln-dried lumber sold to outside firms (if any) _____________ thousand BF/year

Total volume of kiln-dried hardwood lumber processed into solid flooring on-site[1]

_____________thousand BF/year

[1]Solid hardwood flooring including both strip and plank face widths; do not include engineered

Total Water Use (for entire facility; annual basis):

Water _________________ gallons / ft3

Total (non-transportation) Fuel Use (annual basis):

Hourly generation capacities:

Electricity:

_______________**kWh**_____

Steam:

_______________**units**_____

Note: If electricity or steam are self-generated (produced on-site), then the fuels used to generate them should be accounted for in the categories at right. Please indicate electricity and/or steam generation capacities per hour in the box above.

Natural Gas	______________	thousand cubic feet (ft^3)
On-Site Hogged Fuel	_______tons @ ________	% MC
Purchased Hogged Fuel	_______tons @ ________	% MC
Coal	_________________	tons
Heavy Fuel Oil	_________________	gallons
Medium Fuel Oil	_________________	gallons
Light Fuel Oil	_________________	gallons
Propane	_________________	gallons
Purchased Electricity	_________________	kilowatt-hours
Purchased Steam	_________________	units___________
Gasoline	_________________	gallons
Kerosene	_________________	gallons
Diesel Fuel	_________________	gallons
Other(s)	_________________	units _________

Total (transportation *On-Site*) Fuel Use: (All energy and fuel sources for on-site transportation equipment, forklifts, and carriers etc.; annual basis)

Fuel Oil #6 ____________ gallons

Propane ____________ gallons

Electricity ____________ kilowatt-hours (kWh)

Gasoline____________ gallons

On-road Diesel Fuel____________ gallons

Off-road Diesel Fuel ____________ gallons

Other(s) ____________ units _______

Total Material Delivery Transportation Fuel Use: (Raw materials delivery to your manufacturing facility; annual basis)

Over the Road:

Average one-way mileage trucks travel to this facility to deliver lumber: _______________miles

Total number of lumber deliveries made to this facility by truck annually: _______________# / year

Average one-way mileage trucks travel to this facility to deliver pre-finishing coatings and pre-finishing related products:________________miles **(If your mill does not make pre-finished flooring leave blank)**

Total number of pre-finishing coatings and pre-finishing related products deliveries made to this facility by truck annually: _______________# / year

What is the percentage of trucks that travel one-way (sole destination is your mill) ____________ %

What is the percentage of trucks that leave your mill empty (no backhaul) ____________%

By Rail:

Average one-way mileage trains travel to this facility to deliver lumber: _______________miles

Total number of lumber deliveries made to this facility by rail annually: _______________# / year

Average one-way mileage trains travel to this facility to deliver finishing coatings and finishing related products:________________miles **(If your mill does not make pre-finished flooring leave blank)**

Total number of pre-finishing coatings and pre-finishing related products deliveries made to this facility by rail annually: _______________# / year

What is the percentage of trains that travel one-way (sole destination is your mill) _____________ %

What is the percentage of trains that leave your mill empty (no backhaul) _____________ %

OUTPUTS **(please provide responses for all requested information for reporting year indicated above)**

Total Wood Product:

Please complete the table for species you used to produce *unfinished solid hardwood flooring.* Do *not* include pre-finished, parquet, cork, bamboo or engineered flooring data in this table; [1]please list only domestic hardwood species. *See example in first line*

Unfinished Solid Hardwood Flooring Annual Production	
Species[1]	**For Each Species Please Write In:** **Square Feet Produced / Width (inches) / Thickness (inches)**
Example: White Oak	4,000,000 ft^2 / $3\frac{1}{8}$"/ $\frac{3}{4}$" & 2,500,000 ft^2/$2\frac{1}{4}$"/1" & etc…
White Oak	
Red Oak	
Maple (hard)	
Maple (soft)	
Ash	
Birch	
Walnut	
Cherry	
Beech	
Hickory/Pecan	
Other (specify)	
Other (specify)	
TOTAL SQUARE FEET PRODUCED FOR ALL SPECIES ABOVE (do not worry about totals by widths and thickness)	**Square Feet** ____________

Please complete the table for species you used to produce *pre-finished solid hardwood flooring.* Do *not* include unfinished, parquet, cork, bamboo or engineered flooring data in this table; [1]please list only domestic hardwood species. *See example in first line*

Pre-finished Solid Hardwood Flooring Annual Production	
Species[1]	**For Each Species Please Write In:** **Square Feet Produced / Width (inches) / Thickness (inches)**
Example: White Oak	3,000,000 ft^2 / $3\frac{1}{8}$"/ $\frac{3}{4}$" & 1,500,000 ft^2/$2\frac{1}{4}$"/1" & etc…
White Oak	
Red Oak	
Maple (hard)	
Maple (soft)	
Ash	
Birch	
Walnut	
Cherry	
Beech	
Hickory/Pecan	
Other (specify)	
Other (specify)	

TOTAL SQUARE FEET PRODUCED FOR ALL SPECIES ABOVE (do not worry about totals by widths and thickness)	**Square Feet** ____________

Total Wood Co-Products and By-Products Produced:

For each co-product and by-product listed in the table below, *please provide the percentages of total production* for the reporting period that are sold (shipped) to other users, used internally (as fuel or for other uses), landfilled, or inventoried for future use. Select categories that best fit your facilities situation. If zero, just leave blank.

Co- and By-Products	Moisture Content	Sold (shipped)	Used Internally (as fuel)	Used Internally (other uses)	Landfilled	Inventory	Total
	(%)	tons	tons	tons	tons	tons	tons
Dry Sawdust							
Dry Shavings							
Edging Strips							
Wood Flour[1]							
Rejected Wood							
Trimmings							
Other							

[1]**Wood flour refers to wood particles smaller than sawdust like moulder or profiling off-fall**

Total Industrial Solid Waste: (please fill in the blank spaces below for material requiring disposal outside of mill; annual basis)

Fly Ash ___________ tons __________% landfilled

Bottom ash ___________ tons __________% landfilled

Inorganic material ___________ tons __________% landfilled

Non-wood organic material ______ tons__________% landfilled

Pallets (not reused) ___________ tons __________% landfilled

General refuse ___________ tons __________% landfilled

Sanding dusts (not reused)_________tons __________% landfilled

Other ___________ lbs. __________% landfilled

Others ___________ lbs. __________% landfilled

Total Air Emissions: **(please fill in the blank spaces below for each emission type; if individual category is not known then group by major category)**

Dust ________________ pounds

Particulates ________________ pounds

PM10 ________________ pounds

Carbon oxides ________________ pounds

Sulfur oxides ________________ pounds

Nitrogen oxides________________ pounds

Volatile organics_______________ pounds

Hazardous Air Pollutants (HAPs) ________ pounds

Other ________________ pounds

Others ________________ pounds

Total Energy: (annual basis)

If present, please write the actual (not rated) production output of *every* process boiler in the table:

Boiler	Size (BTU/hr, HP, or lbs/hr of steam)	Fuel Type	Quantity (units)
#1			
#2			
Others			

If any wood boiler fuel used on-site is *purchased from other off-site sources*, please indicate the amounts by type in the spaces provided below. Otherwise ignore and go to the next table. Please specify units of measure.

Boiler Fuel Input	Quantity	Units	% Moisture Content
Planer shavings			
Sawdust			
Bark			
Hogged fuel (mixed grindings)			
Chips			
Other (specify)			

If present, please write in the cogeneration facility production output in the table:

Electricity (kW or MW)	Process Heat (BTU/hr)	Fuel Type	% Sold Off Site	
			Electricity	Process Heat

EMISSIONS CONTROL EQUIPMENT

If your facility has emission control devices, please complete the table below. For air emissions include devices such as cyclones, bag houses, and electric static precipitators (ESPs). For water emissions, explain how runoff or other water discharges from the boiler and mill are controlled (i.e. settling pond, city sewer, septic; annual basis). Please list ALL devices. If your facility has more than one of the same device please indicate the total number for that type of device.

Type of Emission Control Device (cyclone, bag house, esp, etc.)	How Many?	Equipment Controlled	Type of Emissions Controlled (gas, liquid, solid)	Electrical Usage For Device kWh (annual basis)

PART 3: UNIT PROCESSES

This is the final portion of the questionnaire. We would like to know about inputs and outputs specific to eight unit processes: planing, ripping, trimming, moulding (side and end matching), pre-finishing, emissions control, energy generation, and packaging.

- **You are given a brief process description. Next you will see a series of tables pertaining to inputs and outputs associated with these processes. The tables are necessary to help us quantify detailed inputs and outputs and to help us identify process improvement opportunities (including waste reduction). Please write your responses directly into the tables.**

- **Your mill may not have all eight processes. Some mills for example do not pre-finish. In those cases simply leave the table blank.**

- **The information you supply should be for the reporting period you indicated at the beginning of this questionnaire. Please provide as much detail as you can so we report accurate results.**

We appreciate your time and effort with this project. Thank you for your participation and commitment to the forest products industry!

Unit Process 1: Planing

Description:
This unit process begins with stickered, rough kiln-dried lumber and includes:

- De-stickering/unstacking of dry lumber
- Sorting of planed lumber
- Conveyance of lumber to rip saw
- Maintenance of all planer equipment and associated transportation vehicles
- Treatment of process air, liquids, and solids

Output:
Sorted surfaced lumber that is ready for ripping and dry planer shavings.

Does your mill have a planing unit process as part of its operations?

- ❑ Yes
- ❑ No

Any notes, exceptions, or additions to the process description?

Unit Process 2: Ripping

Description:
This unit process begins with dry surfaced lumber and includes:

- Lumber sawn lengthwise to desired widths
- Ripped pieces sorted by width
- Conveyance of stock to cut-off or chop saws
- Maintenance of all saw equipment and associated transportation vehicles
- Treatment of process air, liquids, and solids

Output:
Stock that is planed and of desired width; dry edging strips and dry sawdust.

Does your mill have a ripping unit process as part of its operations?

- ❑ Yes
- ❑ No

Any notes, exceptions, or additions to the process description?

Unit Process 3: Trimming

Description:
This unit process begins with surfaced dry lumber of desired widths

- Cut-off/chop saw(s) trim lumber to length
- Defects are removed to meet highest grade
- Conveyance of flooring blanks to moulder(s)/side and end matchers
- Maintenance of all saw equipment and associated transportation vehicles
- Treatment of process air, liquids, and solids

Output:
Surfaced flooring blanks ready for side and end matching.

Does your mill have a trimming unit process as part of its operations?

- ❑ Yes
- ❑ No

Any notes, exceptions, or additions to the process description?

Unit Process 4: Moulding (Side and End Matching)

Description:
This unit process begins with dry surfaced lumber and includes:

- Moulder(s)/ Side Matcher(s) profiles the flooring blanks lengthwise (tongue and groove)
- Moulder(s)/ End Matcher(s) end-match flooring blank ends
- Conveyance of moulded flooring to finishing or packaging operations
- Maintenance of all moulding equipment and associated transportation vehicles
- Treatment of process air, liquids, and solids

Output:
Wood flooring ready for pre-finishing or packaging

Does your mill have a moulding unit process as part of its operations?

- ❑ Yes
- ❑ No

Any notes, exceptions, or additions to the process description?

Unit Process 5: Pre-Finishing

Description:
This unit process begins with unfinished solid wood flooring and includes:

- Flooring sanded and conveyed to spray booths
- High pressure spray of stain or sealant
- Roller or vacuum coating of stain or sealant
- Curing/Drying; radiant heat or UV
- Conveyance to packaging center
- Treatment of process air, liquids, and solids

Output:
Pre-finished solid strip or plank wood flooring that is ready for packaging.

Does your mill have a finishing unit process as part of its operations?

- ❑ Yes
- ❑ No

Any notes, exceptions, or additions to the process description?

Unit Process 6: Packaging

Description:
This unit process begins with solid strip or plank wood flooring and includes:

- Sorting and grading of end product
- Stacking, bundling, or piling of end product
- Strap, wrap, and stamp on end product
- Conveyance of packaged flooring to shipping staging area
- Maintenance of all packaging equipment and associated transportation vehicles
- Treatment of process air, liquids, and solids

Output:
Final flooring product ready for shipment.

Does your mill have a packaging unit process as part of its operations?

- ❑ Yes
- ❑ No

Any notes, exceptions, or additions to the process description?

FOR EACH OF THE FOLLOWING TABLES: **Please write your facilities information directly in the blank spaces in the tables. Your facility may not have all the listed processes. Some mills for example do not pre-finish flooring. In those cases simply leave that area in the table blank. *All Annual Basis.***

Table 1: Electrical Use by Unit Process **(Please be as accurate as possible)**

Unit Process	Electrical Use (kW-hr) or Percent of Total
Planing	
Ripping	
Trimming	
Moulding (side & end match)	
Pre-finishing	
Packaging	
Total	

Table 2: Total Transportation Fuel Use by Unit Process (carriers, forktrucks, etc.)

Unit Process	Quantity (gallons/ft3) or Percent of Total
Planing	
Ripping	
Trimming	
Moulding (side & end match)	
Pre-finishing	
Packaging	
Total	

Table 3: Total Energy Used by Unit Process (expressed as percentage of total energy used)

Unit Process	Solid Strip Hardwood Flooring	Solid Plank Hardwood Flooring
Planing	%	%
Ripping	%	%
Trimming	%	%
Moulding (side & end match)	%	%
Pre-finishing	%	%
Packaging	%	%
Overall	100%	100%

Table 4: Total Co- and By- products Produced by Unit Process

Unit Process	dry shavings	dry sawdust	edgings	trimmings	wood flour	rejected wood	other
Planing	%	%	%	%	%	%	%
Ripping	%	%	%	%	%	%	%
Trimming	%	%	%	%	%	%	%
Moulding(side & end match)	%	%	%	%	%	%	%
Pre-finishing	%	%	%	%	%	%	%
Packaging	%	%	%	%	%	%	%
Overall	100%	100%	100%	100%	100%	100%	100%

Table 5: Total Solid Waste Produced by Unit Process: (material requiring disposal outside of mill; expressed as a percentage of the total waste)

Unit Process	Solid Strip Hardwood Flooring	Solid Plank Hardwood Flooring
Planing	%	%
Ripping	%	%
Trimming	%	%
Moulding (side & end match)	%	%
Pre-finishing	%	%
Packaging	%	%
Total	100%	100%

Table 6: Total Water Use by Unit Process:

Unit Process	Water Supplied		Water Discharged	
	Municipal/well (gallons/ft3)	Surface (gallons/ft3)	Sewer (gallons/ft3)	Surface (gallons/ft3)
Planing				
Ripping				
Trimming				
Moulding(side & end match)				
Pre-finishing				
Packaging				
Energy generation (Boiler)				
Overall	100%	100%	100%	100%

Table 7: Total Air Emissions by Unit Process:

Unit Process	Dust (pounds)	Particulate (pounds)	PM10 (pounds)	HAPs (pounds)	VOC's (pounds)
Planing					
Ripping					
Trimming					
Moulding(side & end match)					
Pre-finishing	Please use table 8 below for Pre-Finishing data				
Packaging					
Energy generation (Boiler)					
Overall					

If your facility produces pre-finished flooring, please provide detailed emission information for your pre-finishing process by filling in the table AND answering the questions below. ***Please*

make sure the emissions data you supply here for the pre-finishing process is separate from the total facility emissions data you provided earlier for your facility as a whole***

Table 8: Emissions for Pre-finishing Unit Process

Emission	Units
Dust	pounds
Particulate	pounds
PM10	pounds
HAPs	pounds
VOC's	pounds
Nitrous oxide (N_20)	pounds
Nitrogen oxide (NO)	pounds
Sulfur oxides (S_xO)	pounds
Carbon monoxide (CO)	pounds
Carbon dioxide (CO_2)	pounds
Methane (CH_4)	pounds
Others (please list all known):	units

What method(s) are used at your facility to apply coatings: (check those that apply)

____Spray Booths ____Rollers ____ Vacuums ____ Other(s) (please list)

What method(s) are used at your facility to cure coatings: (check those that apply)

____UV ____Gas Oven ____Other(s) (please list)

Table 9: For your pre-finished flooring process (please provide responses in the table)

Coating Type(s) Used	Brand or Manufacturer of Coatings	Solids Content of Coatings	Total Annual Volume of Coatings Used (gallons)	List any Catalysts Used	Brand or Manufacturer of Catalysts	Solids Content of Catalysts	Total Annual Volume of Catalysts Used (gallons)
		%				%	
		%				%	
		%				%	
		%				%	
		%				%	
		%				%	

This concludes the questionnaire!

- **Thank you for your dedicated time and thorough input!**
- **Place this questionnaire and any attachments into the envelope provided, seal, and put into the mail. The postage and return address are already provided on the envelope.**
- **The responses you have provided will be kept in strict confidentiality. Only industry averaged data will be used or made available and results of this study will not identify participating mills unless an individual mill wishes to be acknowledged publicly for their efforts with this project.**

If you have questions regarding this questionnaire or the project please contact:

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Glossary

Baghouse: Air pollution device which forces gases through a filter thereby capturing gas born particles.
By-product: Material produced during manufacturing that is recycled or used "within system boundaries."
Bottom ash: Residual by-product of burning coal. Porous, grainy, roughly sand sized particles.
Co-product: A material produced from manufacturing and "sold outside of the system boundary."
Cyclone: A device that uses centrifugal forces to collect waste material.
Dust: Dispersion particles formed in grinding a solid; particles may be small enough to temporarily suspend in the air.
Edgings: Pieces of board produced after lumber passes through an edger to achieve desired width.
Electrostatic Precipitator (esp): A type of precipitator which changes the electrical charge on a particle so that it can be captured by electrostatic forces.
Emissions: Expulsion of pollutants to air from a source.
Fly ash: Particulate impurities that come from burning coal and other materials.
General refuse: Waste collected from the facility that is mixed with dirt and cannot be sent to the boiler.
HAPs: Hazardous Air Pollutants (carbon oxides, nitrogen oxides, sulfur oxides).
Inorganic material: Material such as sand and other non-solubles.
Industrial waste: Material produced during manufacture requiring disposal out of the "system boundary."
Packaging material: Steel strapping, plastic lumber covers, cardboard corners, plastic or paper wrap.
Particulates: By-products of combustion or milling; can be solid or liquid state.
PM10: Standard for measuring solid and liquid particulates in suspension in the atmosphere; particulates are defined here as less than 10 micrometers in diameter.
Product: The primary material produced from manufacturing and "sold outside of the system boundary."
Recycled material: Material collected from the manufacturing facility operation that is re-used.
Solid Strip Hardwood Flooring: Solid hardwood flooring 1½", 2¼", and 3¼" in width.
Solid Plank Hardwood Flooring: Solid hardwood flooring with face widths of 3", 4'', 5" or wider.
VOCs: Volatile Organic Compounds- produced in incomplete combustion of carbon based compounds; does not include methane; examples are oil based paints and gasoline fumes.