Final CORRIM Report

Module N

Life-Cycle Inventory of Manufacturing Prefinished Engineered Wood Flooring in the Eastern United States

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Conversion Table

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

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Executive Summary

This study summarizes the environmental performance of prefinished engineered wood flooring using life-cycle inventory (LCI) analysis. Using primary mill data gathered from manufacturers in the eastern United States and applying the methods found in Consortium for Research on Renewable Industrial Materials (CORRIM) Research Guidelines and International Organization of Standardization (ISO) standard for conducting life-cycle assessments, the environmental impacts in making engineered wood flooring were estimated. This study is a follow-up to the CORRIM Report Module G—Life-Cycle Inventory of Solid Strip Hardwood Flooring in the Eastern United States. Life-cycle impact assessment was beyond the scope of this study.

Engineered wood flooring is designed to be more dimensionally stable than solid strip wood flooring because it is less susceptible to width shrinkage from increases in moisture. Engineered wood flooring as defined by the National Wood Flooring Association consists of several sheets of solid wood (veneer) bonded together with an adhesive under heat and/or pressure. Although plies having 2, 3, 5, 7, or 9 sheets are available, 3 and 5 are most common. Thicknesses can range from 3/8 to 9/16 in. (9.5 to 14.3 mm). Typical manufacturing includes the following eight unit processes: log yard, debarking and bucking, block conditioning, peeling and clipping, veneer drying, lay up, trimming, sanding, sawing and moulding (profiling), and prefinishing. Inputs and outputs to these unit processes were collected from a survey of manufacturers. The multi-unit process approach is the preferred evaluation method because it helps identify possible process improvements by showing the energy and environmental contribution of each unit process.

We determined the environmental impacts based on resource and energy consumption and releases to air, water, and land for making prefinished engineered wood flooring in the eastern United States. Of the five companies contacted in the eastern United States, four companies (comprising four veneer mills and five flooring plants) completed the mill survey. These facilities well represented the industry as a whole, and their manufacturing technology was average. Primary data were collected for the production period January to December 2007. Input data collected included raw materials such as hardwood logs with bark and water, resins, electricity, fossil fuels, prefinishing materials, transportation distances for materials used onsite, and the breakdown of logs into co-products sold (not flooring) such as wood chips and wood fuel burned onsite to produce thermal energy. Allocation of environmental inputs was done on a mass basis because the highest volume product had the highest economic value. This was true for all unit processes. Production unit bases of 1 m^3 and 1,000 ft^2[1] were selected to standardize the results to alternative products.

Based on surveyed data from the eastern United States, flooring production of 64,840 m^2 (73,270 thousand ft^2) was found. This was approximately 19% of the total 2007 engineered wood flooring production in the United States of 346,400 m^2 (391,400 thousand ft^2). No U.S. wood flooring production data were available by individual states. Surveyed mill production exceeded the minimum CORRIM production data requirement of 5%. In addition, this study met the minimum number of product manufacturers (four). Detailed inputs and outputs of unit processes were collected from these manufacturers and weight-averaged to allow modeling in SimaPro 7.1.8 to estimate emissions to air, water, and land. Results also include a carbon balance of the entire process.

After developing a mass balance from inputs and outputs, an ovendry density of 656 kg/m^3 (40.9 lb/ft^3) prefinished engineered wood flooring including wood, resins, and finish (coatings) was estimated.

[1] 1,000 ft^2 equals 92.9 m^2.

Assuming a specific gravity at 6% MC of 0.656, the density was 695 kg/m^3 (43.4 lb/ft^3). At 0% MC, the largest component of the flooring is wood (578 kg) and represents 88.2% of the final product mass, resins (65 kg) are 9.8%, and the remaining 2.0% finishing material (13 kg). Hardwood plywood and prefinished engineered wood flooring had wood recoveries of 43% and 35%, respectively. These numbers were determined by the output of wood in the form of plywood as a percentage by weight of the wood input to the manufacturing facilities in the log form (white wood only).

Energy consumption and type have significant effects on the environmental performance of all products. In this LCI study, unallocated thermal process energy and electricity consumed was 6,418 MJ/m^3 (5.38 million Btu/thousand ft)[2] and 1,113 kWh/m^3 (985 kWh/thousand ft^2), respectively. Wood fuel at 300 ovendry kg or 6,263 MJ/m^3 (5.26 million Btu/thousand ft^2) contributed 97.6% of process thermal energy required with the remainder from propane (2.2%) and natural gas (0.2%). Results showed a cumulative allocated value of manufacturing prefinished engineered wood flooring starting with logs at the forest landing to the final product leaving the flooring plant of 22,990 MJ/m^3 (19.3 million Btu/thousand ft^2)[3]. Unfinished engineered wood flooring showed a cumulative allocated value of 13,600 MJ/m^3 (11.4 million Btu/thousand ft^2).

Tracking emissions is increasingly important in terms of applying proper emission controls. Two different scenarios were created to track emissions and involved system and onsite boundary conditions. First, the total (cumulative) system boundary covers both onsite and off-site emissions for all material and energy consumed. This includes the fuel resources used for the production of energy and electricity and is part of this LCI. Examples of off-site emissions are grid electricity production, transportation of logs to the mill, and fuels produced off-site but used onsite. The onsite system boundary covers emissions developed just at the prefinished engineered wood flooring facilities (i.e., onsite) from the seven unit processes. Environmental impact outputs from SimaPro were allocated to the production of 1 m^3 of prefinished engineered wood flooring. A certain portion of the environmental impacts were assigned to the co-products such as wood chips and were not included in the LCI output for prefinished engineered wood flooring.

Data quality is considered excellent based on the data collected from the manufacturing facilities. We developed detailed surveys (questionnaires) that were reviewed by a CORRIM representative before distribution. In addition, a CORRIM representative reviewed the SimaPro model for this report. Onsite visits to a veneer mill and flooring plant allowed for provides greater insight into the manufacturing process, thus providing higher quality data. The multi-unit process method allows for unit process improvements to be evaluated more precisely than a system process approach.

Modeling data estimated biogenic and fossil CO_2 emissions at 623 and 1,049 kg/m^3, respectively, and VOCs at 1.04 kg/m^3. A cubic meter of prefinished engineered wood flooring stores 1,096-kg CO_2 equivalents/m^3 as a final product.

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

- The amount of carbon stored in prefinished engineered wood flooring exceeds the fossil carbon emissions by about 4%. Therefore, as long as prefinished engineered wood flooring and its carbon stay in products held in end uses, the carbon stored will exceed the fossil carbon emitted in manufacturing.

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[2] Process energy was calculated based on the following higher-heating values (HHVs) in MJ/kg: Ovendry wood 20.9, coal 26.2, distillate fuel oil 45.5, LPG 54.0, natural gas 54.4, gasoline 48.4, diesel 44.0, and uranium 381,000.
[3] Cumulative allocated value considers electrical efficiency of grid power provided.

- A trade-off exists between prefinished and unfinished engineered wood flooring. The prefinishing unit process consumes a large amount of electricity from controlling emissions from staining and coating the wood flooring in addition to the prefinishing. As a result, the environmental impact is significantly higher for prefinished engineered wood flooring than for unfinished engineered wood flooring. However, finishing the wood floor after installation in a residential or commercial building (an uncontrolled environment) would result in greater harm to the environment. This harm results from uncontrolled emissions released from the staining and coating process that are now captured or destroyed onsite at the flooring plant.

- Burning fuel for energy generates CO_2. Nearly all energy burned onsite for manufacturing prefinished engineered wood flooring comes from woody biomass. Burning biomass for energy does not contribute to increasing atmospheric CO_2 provided forests are growing and absorbing the emitted CO_2 on a sustainable basis.

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

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1 Introduction

Environmental performance of products that are components of residential or commercial buildings is increasingly being examined because of concerns over the impacts of such structures on the environment. For example, some research claims the main cause of climate change is from burning fossil fuels (IPCC 2007). In addition, some building products consume large amounts of fossil fuels during their processing (Khatib 2009). However, wood building products typically consume more biomass than fossil fuels during their manufacturing, a significant environmental advantage (Puettmann and Wilson 2005a). Biomass carbon dioxide (CO_2) is considered carbon neutral because the CO_2 emitted from burning biomass will not increase total atmospheric CO_2 if the consumption of biomass is done on a sustainable basis (UNFCCC 2003, EPA 2003).

“Green building” is defined as the practice of improving the energy efficiency of materials, construction, and operation of buildings while reducing the overall environmental impact. The green building market including non-residential and residential is likely to almost triple from $36 to $49 billion in 2008 to $96 to $140 billion by 2013 (MHC 2008, Murray 2008). Developing a sound policy for building practices, especially for green building, must be a priority if the United States is to decrease its environmental burden. In addition, carbon emissions during manufacturing of building materials are expected to play a larger role in consumer selection in the future. A scientific method for analyzing product claims to determine their actual environmental performance is often lacking in the “green” building movement.

Conducting a Life-Cycle Inventory (LCI) for products is part of a science-based approach to addressing environmental claims. LCI data are a major part of Life-Cycle Assessments (LCA). LCA uses rigorous methodology to find the total environmental impact for a particular product referred to as “cradle-to-grave” (raw material extraction to waste disposal) analysis. These analyses include the environmental and energy costs on a per-unit basis using the data from individual LCI studies. These LCI studies are resource extraction, transportation, primary and secondary processing, final product use, maintenance, and final disposal for a particular product. LCI measures all the raw material and energy inputs and outputs to manufacture a particular product on a per-unit basis within carefully defined system boundaries. This is often referred to as a “gate-to-gate” LCI. Results from the LCI are used to assess the environmental impact (ISO 2006a, ISO 2006b). The Consortium for Research on Renewable Industrial Materials (CORRIM) has developed many LCI datasets for structural wood materials (NREL 2011).

CORRIM is a research entity comprised of 15 universities and research institutions (Lippke 2004). CORRIM has set out to evaluate wood as an appropriate environmental choice by researching the impacts of wood materials using the standardized tools of LCI analysis. CORRIM is helping build a multinational database of the environmental and economic impacts associated with using renewable materials (Bowyer et al. 2001). The LCI model, which is well documented in the literature, is a central element of this work (Sundin et al. 2002, Yaros 1997, Kuuluvainen and Salo 1991). This LCI study for prefinished engineered wood flooring will use the methodology and protocols put forth by CORRIM and the International Organization for Standardization (ISO) (CORRIM 2010, ISO 2006a, ISO 2006b).

1.1 Review of Relevant LCI Studies

1.1.1 Previous studies

Previous studies on flooring products include both the United States and Europe. Hubbard and Bowe (2008) evaluated unfinished solid wood flooring in the eastern United States. About 86% of the total energy (including electricity) needed for making the flooring came from biomass (wood residue). This result is consistent with other LCI studies on wood products that show a high percentage of process energy coming from biomass (Puettmann and Wilson 2005a). Additionally, Gustavsson et al. (2010)

found that substituting biomass residue from wood products for fossil fuels significantly lowers net carbon dioxide emissions. Petersen and Solberg (2005) reviewed 14 LCA studies from Norway and Sweden, whereas Werner and Richter (2007) reviewed international research from the past 20 years. The main conclusion is that wood tends to have a favorable environmental profile particularly regarding greenhouse gas emissions (GHGs), compared with competing materials such as steel and concrete.

In Sweden, Jönsson et al. (1997) reported that solid wood flooring showed significant environmental advantages over linoleum and vinyl flooring. Vinyl flooring had the highest environmental burdens. Raw materials play a significant role on the environmental impact for each product because the final product with the highest burdens tended to be the product using synthetics derived from fossil fuels. For example, polyvinyl chloride (PVC) used in vinyl flooring production is synthesized from ethylene made from crude oil. Another reason for the impacts associated with vinyl flooring was that its production consumed the most nonrenewable energy resources. Wood flooring used the least nonrenewable energy resources and its main raw component was from trees, a renewable resource.

A 2006 German study provided data on the environmental impacts of types of prefinished wood flooring including solid wood, solid and multilayer parquets, and wood blocks (Nebel et al. 2006). Nebel et al. found that solvent use and energy consumption had the most effect on the environmental performance of these products. This life-cycle study provided results from the extraction of raw material to the final disposal of material. One important factor is the expected lifetime of a given product and its ability to be refurbished. Wood blocks, wood floor boards, and 22-mm parquet flooring had an expected useful life of 50 years, which was at least twice the useful life of the other wood flooring products such as multilayer parquet flooring. Wood block flooring is made from tongue and grooved wood blocks that are 19 to 38 mm thick, up to 90 mm wide, and 150 to 380 mm long. In this study, wood block flooring was 38 mm thick, nearly twice as thick as the wood floor boards. In addition, the 50 years corresponded to the expected useful life of the house. An environmental advantage was the air drying of wood floor boards to 17% moisture content (MC) that reduced primary energy consumption to 25% of multilayer parquet. The reference flow was 1 m^2 of laid flooring for 50 years. Multilayer parquet had only an expected useful life of 10 years. As other studies have shown, energy consumption during manufacturing was the highest of the individual life-cycle stages. In addition, burning the disposed material for energy lowered the flooring's impact at end-of-life. Solvents used in lay up, prefinishing, and refurbishing played the largest role in photo-oxidant formation, caused mainly by emissions of volatile organic compounds (VOCs).

Coatings play a large role in some wood products, and the choice of coating with the lowest environmental burden is not always obvious. Gustafsson and Börjesson (2007) found through a cradle-to-grave evaluation that a "green" wax produced from rapeseed oil had a greater environmental impact overall than the two ultraviolet light hardening lacquers (UV lacquers), while the "100% UV" lacquer showed the least environmental impact. In addition, Tufvesson and Börjesson (2008) found that wax ester made from rapeseed oil had about a 3.5 times higher Global Warming Potential (GWP) than paraffin wax. Furthermore, cultivation of the rapeseed oil causes soil emissions of ammonia and nitrous oxides, resulting in potential acidification and eutrophication. These results indicate that more work is needed to find coatings with a minimal environmental burden.

1.1.2 Lessons learned

The initial work of CORRIM examined structural wood building products used in residential home construction (Puettmann and Wilson 2005a, Perez-Garcia et al. 2005, Lippke et al. 2004). In each of these studies, wood building materials were found to have smaller environmental impacts than competing non-wood materials such as steel and concrete. Current CORRIM efforts are focusing on nonstructural building products such as interior finish materials. Wood products tend to have lower environmental impact than competing wood products because biomass, considered carbon neutral, is used as a primary energy source in their production.

The useful life of a product plays a large role in its environmental impact. Some flooring products need to be replaced multiple times during the life of a house while others are more durable. Some products are able to be refurbished more easily than others, and refurbishing flooring instead of replacing it reduces its overall environmental impact as shown by Nebel and others (2006).

Caution is needed when addressing coatings to ensure that the whole life-cycle of the material is evaluated for its environmental burdens. A “green” coating does not mean a product contains less environmental burden than a competing product. It is necessary that a product be examined from the raw material stage to its final disposal (i.e., cradle-to-grave life-cycle analysis) to provide the most accurate evaluation of environmental impact.

1.2 Industry Overview

Prefinished engineered wood flooring is a non-structural wood product. Prefinished engineered wood flooring is more dimensionally stable than solid strip wood flooring because it is composed of cross-laminated veneers; this arrangement reduces the shrinking and swelling in width that results from changes in moisture content. Engineered wood flooring as defined by the National Wood Flooring Association (NWFA) consists of several sheets of solid wood (veneer) bonded together with an adhesive under heat and/or pressure. Although plies having 2, 3, 5, 7, or 9 sheets are available, 3 and 5 are most common. Prefinished engineered wood flooring is one of many commercially used flooring products. Competing products include solid wood, laminate, carpet, vinyl, ceramic tile, and laminated bamboo-flooring.

In 2007, wood flooring manufacturers in the United States produced 448.5 million ft^2 solid wood and 391.4 million ft^2 engineered wood flooring for a total of 839.9 million ft^2 (CRI 2008). The market percentage of engineered wood flooring out of the total wood flooring market increased from 42.1% in 2004 to 46.6% in 2007 (CRI 2008). This increase in market share occurred even though its production had actually decreased due to the severe decline in domestic housing construction (USDC 2011a,b,c). However, hard surface flooring demand is expected to increase 2.8% annually from 2008 to 7.6 billion ft^2 by 2013, and the wood flooring market share is expected to increase with vinyl flooring continuing to lose market share. As before the recession, the remodeling market will be the driving force for hard surface flooring consumption, as new residential construction consumes only 20% (Freedonia 2009a). In addition, the market for wood coatings has declined because of the U.S. housing market decline, although is it also expected to rebound.

An increase in wood flooring production results in an increase in wood coatings (protection) production. Total value of the wood protection and preservative market is forecasted to be $3.3 billion by 2013. Although this value does include the treated wood market, the greatest increase in demand is expected to occur in interior wood applications such as flooring. The release of VOCs including formaldehyde during prefinishing and refurbishing will be an issue that is likely to affect the market share. A coating with improved formulation shows better environmental performance and is expected to gather a higher market share (Freedonia 2009b).

1.3 Goal of the Study

The goal of this study is to document the LCI of prefinished engineered wood flooring production from incoming hardwood logs to prefinished engineered wood flooring. This study shows material flow, energy consumption, and air, water, and land emissions for the prefinished engineered wood flooring manufacturing process on a per-unit basis for the eastern United States (Figure 1.1). We collected primary data by surveying veneer mills and flooring plants with a questionnaire, telephone calls, and a site visit; secondary data were collected from peer-reviewed literature per CORRIM guidelines (CORRIM 2010).

Figure 1.1 The shaded area was selected for life-cycle inventory of engineered wood flooring production in the United States.

We calculated material and energy balances by a spreadsheet algorithm using data from primary and secondary data sources. From these material and energy inputs and reported emissions, environmental impacts were estimated by modeling through SimaPro 7 software (PRé Consultants, Amersfoort, Netherlands) (PRé Consultants 2011). SimaPro has been used in previous CORRIM-initiated LCI projects: hardwood lumber (Bergman and Bowe 2008), softwood lumber (Milota et al. 2005), softwood plywood (Wilson and Sakimoto 2005), I-joist production (Wilson and Dancer 2005a), glue-laminated timbers (Puettmann and Wilson 2005b), and laminated veneer lumber (Wilson and Dancer 2005b). This LCI study conformed to relevant ISO standards (ISO 2006a,b).

Every day, consumers make decisions about whether to purchase and use wood and other non-wood products. In recent years, there has been increasing public interest in the environmental impacts associated with the manufacture, consumption, disposal, and re-use of products that originate from the forest (Bowyer et al. 2001). An assessment of the environmental impact of renewable and nonrenewable raw materials use and the resultant products is needed to enable consumers and policy makers to make informed choices. In addition, climate change policy makers require critically reviewed scientific data to make sound scientific decisions. Furthermore, the market for green building products continues to increase as homeowners and builders desire green products. LCI is a sound scientific method to measure and compare the extent to which products are green. Results from LCI aid in conducting comparative assertions to competing products.

2 Methodology

2.1 Scope of the Study

The scope of this study covers the life-cycle of manufacturing prefinished engineered wood flooring from hardwood logs in the eastern United States. LCI data from this study will help conduct a comparative analysis of prefinished engineered wood flooring to other wood and non-wood flooring options. The life-cycle inventory model provides a gate-to-gate analysis of the cumulative costs of manufacturing and shipping industrial products. Analyses include engineered wood flooring's contribution to energy consumption, air pollution, water pollution, solid waste pollution, and climate change relative to competing non-wood products.

2.2 Functional Unit

Material flows, energy use, and emission data are standardized to a per-unit volume basis for 1.0 m^3 of prefinished engineered wood flooring, the final product of the engineered wood flooring manufacturing process. Based on U.S. industry measures, 1 m^3 of prefinished engineered wood flooring equals 1,130 ft^2 (3/8 in. basis) or 1.13 thousand ft^2 (3/8-in. basis). Wood flooring is usually sold in square feet at various thicknesses. Rough green veneer and rough dry veneer are assumed to be 2.62 and 2.43 m^3/thousand board feet (bf) after shrinkage and sanding, respectively (Bergman 2010, Koch 1985). Allocating all material and energy on a per-unit basis of 1.0 m^3 prefinished engineered wood flooring standardizes the results to meet ISO standards, and the unit processes can be used to construct a cradle-to-gate LCI and LCA (ISO 2006a,b, CORRIM 2010).

2.3 Reference Flow

The reference flow is defined as the ovendry mass of 1 m^3 or 1,000 ft^2 (3/8-in. basis) prefinished engineered wood flooring. In climate-controlled living environments, installed wood flooring typically equilibrates to 8% MC (Bergman 2010).

2.4 Data Quality and Data Gathering

2.4.1 Data collection and treatment

The eastern United States was selected because the majority of wood flooring production occurs in this region because of available resources (Hubbard and Bowe 2008). Primary mill data as required by CORRIM research guidelines were weight-averaged to maintain confidentiality of surveyed facilities and to develop a composite engineered flooring plant (CORRIM 2010).

2.4.2 Validation of data

We conducted the following analyses to ensure validation of raw and LCI data: 1. Comparison of conversion rates from incoming logs to dry veneer to literature values; 2. Performed mass balance to track wood material through the entire process; and, 3. Comparison of LCI data to both a U.S. (CORRIM) hardwood flooring study and to European studies on flooring. Results are shown in Section 10 starting at page 24.

2.4.3 Sensitivity analysis for refining the system boundaries

We performed a sensitivity analysis on burning different types of fuel for process energy. This analysis provided the changes in environmental impacts based on fuel use. Results are shown in Section 9 starting at page 23.

2.4.4 Data quality statement

Data quality was high due to site visits and the extensive and comprehensive questionnaire used to survey the industry (See Section 14 Appendix questionnaire starting at page 36). Primary mill data were collected for the year 2007 from facilities across the eastern United States from average technologies ranging from 1940s to 2000s that produced (83,230 thousand ft^2) or nearly 19% of total engineered wood flooring production in the United States. Approximately 30 engineered wood flooring facilities existed in the surveyed area (NWFA). We surveyed five of the 30 available, about 17%. Most flooring plants produce their own veneer although one flooring plant completely used veneer from another vendor. Based on surveyed mill data,[4] total incoming hardwood log volume of 119,400 m^3 (25.6 million bf)[5] produced total dry veneer production of 67,770 m^2 (76.58 million ft^2). Adding 35,600 m^2 (40.28 million ft^2) of purchased dry veneer to dry veneer produced onsite resulted in total dry veneer of 103,400 m^2 (116.86 million ft^2). Total flooring produced was 73,660 m^2 (83.23 million ft^2). We estimated an overall efficiency of 30.1% from logs to prefinished engineered wood flooring. In addition, a log to dried veneer conversion

[4] Wood veneer and flooring values provided on a 3/8 in. basis.
[5] Estimated 1,000 board feet of logs equaled 5.32 m^3 (Fonseca 2005).

of 40% was calculated. To ensure data completeness, we performed a mass balance and results compared to literature values.

2.4.5 Aggregation

Method of aggregation for primary data from the mill questionnaire was weight-averaged as in previous CORRIM reports (Milota et al. 2004) using,

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

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

2.4.6 Elementary flows

Figure 2.1 shows how wood flows through the system. The manufacturing starts with hardwood logs as the raw material and ends with the final product of prefinished engineered wood flooring. Two unit processes of 1) peeling and clipping, and 2) trimming, sanding, sawing, and moulding generate the most co-products (wood residue). In the eastern region, many commercial hardwood species are peeled into veneers for flooring. Often, several species within one species group are mixed; for example, the red oak group comprises the following species: scarlet (*Quercus coccinea*), southern (*Q. falcata*), cherrybark (*Q. falcata* var. *pagodifolia*), laurel (*Q. laurifolia*), water (*Q. nigra*), pin (*Q. palustris*), willow (*Q. phellos*), northern (*Q. rubra*), and black (*Q. velutina*). Other species groups with multiple species are white oak (6): white (*Quercus alba*), swamp white oak (*Q. bicolor*), bur (*Q. macrocarpa*), swamp chestnut (*Q. michauxii*), chestnut (*Q. prinus*), and post (*Q. stellata*); hard maples (2): sugar (*Acer saccharum*) and black (*A. nigrum*); soft maples (2): red (*Acer rubrum*) and silver (*A. saccharinum*); and ash (3): white (*Fraxinus americana*), black (*F. nigra*), and green (*F. pennsylvanica*).

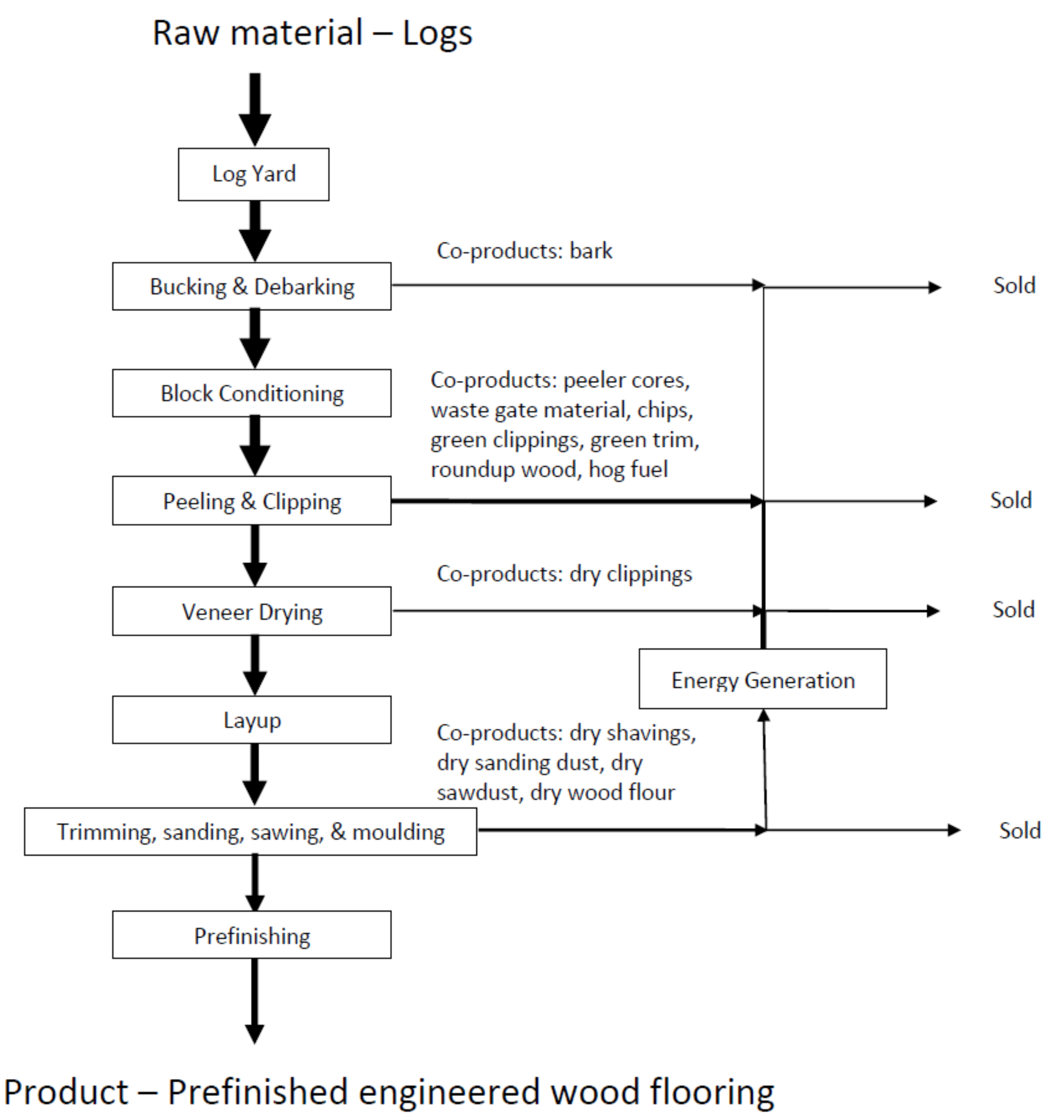

Figure 2.1 Description of product elementary flows.

2.5 Allocation Rules

In the wood products industry, production of a number of co-products including wood residue typically occurs. Residual wood from the process is often burned for process energy. The system boundary was extended to include multiple unit processes; however, co-products that are sold outside the system boundary require an allocation rule. Mass allocation was chosen because the specific gravity of both prefinished engineered wood flooring and the associated co-products are similar (Kodera 2007). This was true for all unit processes. Previous CORRIM studies on wood products also used mass allocation (Puettmann and Wilson 2005a, Jungmeier et al. 2002).

2.6 System Boundary Definition

2.6.1 Definition of product system

Eight unit processes were identified: log yard, bucking and debarking, block conditioning, peeling and clipping, veneer drying, lay up, trimming, sanding, sawing and moulding, and prefinishing (Figure 2.2). Trucks transport logs to the veneer mill. The logs are typically stored wet until needed when temperatures are above 0 °C (32 °F) to prevent staining the wood. Logs are bucked and debarked prior to block conditioning. Block conditioning softens the wood in a hot water bath to allow easier peeling of the logs on the rotating lathes. After trimming the rotary-sliced veneer sheets to 4- by 8-ft (1.2- by 2.4-m) sections, large jet driers dry the thin veneer sheets (plies) to 0–4% MC on an ovendry basis (MC_{DB}). The top, bottom, and core veneer plies are usually from different species. Press-gluing these veneer sheets together forms a veneer panel where 3- and 5-ply panels are common. Before gluing, the sheets are stacked on top of each other with the wood grain facing perpendicular to each subsequent sheet (cross-laminated) for dimensional stability. After trimming, the panels are sanded, sawn, and moulded (profiled) into individual planks that are then pre-finished, resulting in the final product of prefinished engineered wood flooring. The final product is then ready for installation. Final dimensions of the flooring range from 2 1/4 to 7 in. width and 1/4 to 9/16 in. thickness and random lengths.

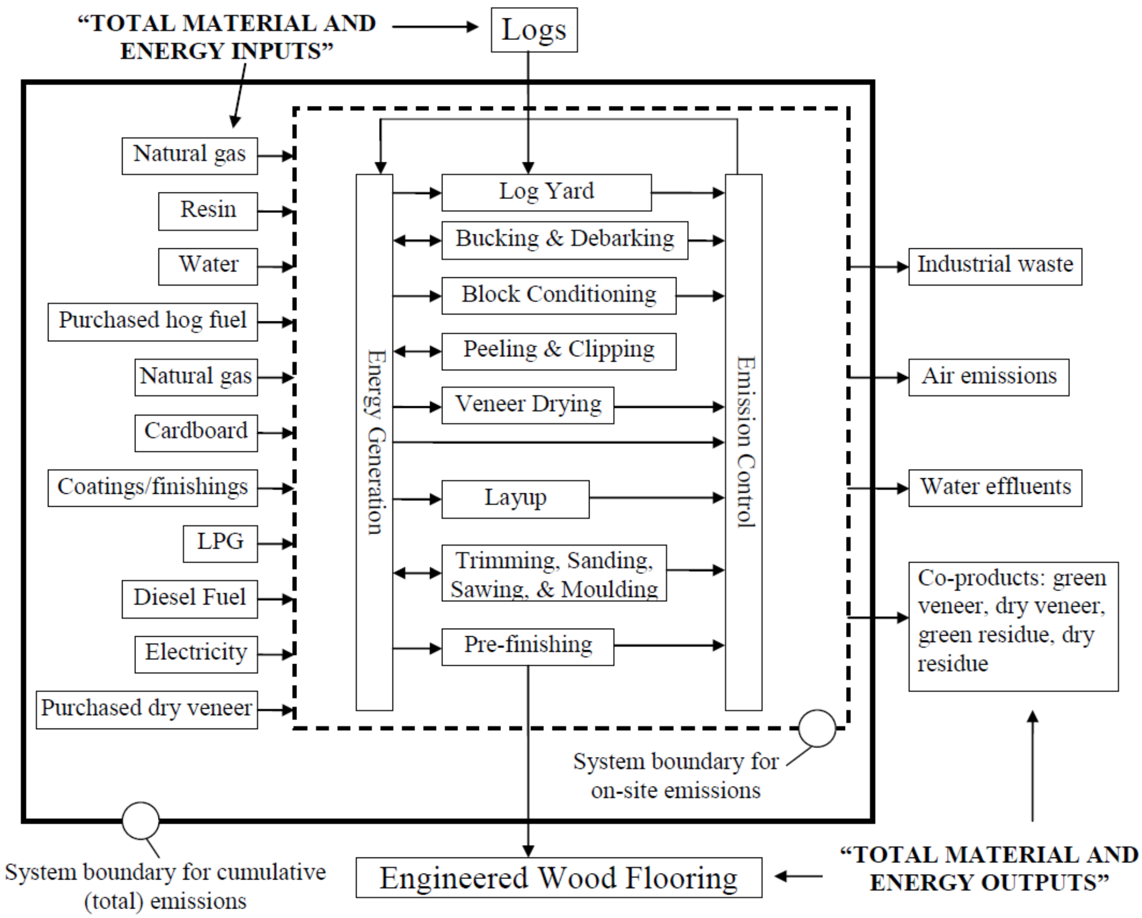

Figure 2.2 System boundaries for engineered wood flooring production.

2.6.2 Decision criteria (cut-off rule, if applicable)

All materials having a significant environmental impact were tracked. We tracked resin and coating materials because it was expected that these materials would have significant environmental burdens relative to their mass. Wood material that contributed less than 0.1% to the total wood output was not modeled in SimaPro.

2.6.3 Omissions of life-cycle stages, processes, input or output flows

All unit processes within the gate-to-gate system boundary were examined. Human labor and production of machinery and infrastructure were outside the system boundaries. In addition, forest growth and management, harvesting, product use and maintenance, recycling options, and final disposal life-cycle stages were not included in the study.

2.7 Assumptions

- We assumed that purchased dry veneer was produced in the same way as non-purchased (onsite) dry veneer was.
- An average log conversion of 5.32 m^3/thousand bf was calculated based on a surveyed weight-averaged log diameter of 15.1 in., with a range from 13 to 18 in., from the four surveyed veneer mills and assuming all lengths (Fonseca 2005). In addition, we calculated a green log volume of 2.46 m^3 based on 1,255 OD kg of incoming wood volume on a per-unit basis and having a green specific gravity of 0.510. Furthermore, we assumed 85% MC_{DB} for the incoming wood to the mill gate; therefore, a green wood log density of 944 kg/m^3 was calculated.
- As part of the CORRIM protocol for ensuring data quality, an overall "wood balance" was required to fall within 5% from material input to material output. Log mass was calculated based on the previous assumption of 5.32 m^3/thousand bf and an average green density of 944 kg/m^3. In this study, we calculated a 3.7% difference for the overall wood mass balance, falling within the CORRIM protocol.
- Higher heating values (HHV) were used to convert volume or mass basis of a fuel to its energy value. HHV represents the (gross) energy content of a fuel with the combustion products such as water vapor brought to liquid at 25 °C (77 °F), whereas lower heating value (net energy) ignores the energy produced by the combustion of hydrogen in fuel. HHV is the preferred method in the United States (EIA 2011).
- Each logging truck hauled about 3,250 bf hardwood logs or 25 tons (7.7 tons logs per thousand bf logs). All four veneer mills reported logging transportation data. Logging trucks were empty when returning to the logging site.
- Purchased wood fuel transportation data came from four veneer mills and three out of the five flooring plants.
- Water used onsite typically was ground water from wells primarily used for sprinkling logs and for make-up boiler water. Two flooring plants did not report water consumption and were not weight-averaged.
- This LCI study covered one full year (2007) and depended on when an operational (fiscal) year started at each company. The geographical area covered the eastern region shown in Figure 1.1.
- Primary mill data were collected through surveying the engineered wood flooring industry in accordance with ISO standards and CORRIM research guidelines. Missing values were not weight-averaged for a particular process per ISO standards.
- Most of the surveyed sites were medium- to large-size facilities with one small veneer mill providing data. Still, some of the larger facilities did not have the primary mill data requested.
- Primary data indicated the species represented were red and white oaks (*Quercus* spp.), hard and soft maples (*Acer* spp.), hackberry (*Celtis* spp.), pecan/hickory (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera*), ash (*Fraxinus* spp.), sweetgum (*Liquidambar styraciflua*), beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), elm (*Ulmus* spp.), and yellow birch (*Betula alleghaniensis*).
- The type of species processed at individual mills alters the density of the final product but not the volume. We noted a range of 0.43 (yellow-poplar) to 0.72 (white oak) ovendry specific gravity for all the different wood species (Alden 1995). A mixed OD wood specific gravity of 0.578 was calculated.
- U.S. LCI database was the primary database used for materials and energy including electricity (NREL 2011).
- Franklin database provided the necessary boiler emission LCI data (FAL 2003a).

- U.S. EcoInvent (US-EI) database provided material LCI data such as stain and coatings that were not found in either the U.S. LCI or Franklin databases (PRé Consultants 2011).

2.8 Impact Categories

No impact assessment was conducted.

2.9 Critical Review

James Wilson, past vice president of CORRIM, reviewed the questionnaire used to survey the industry. Maureen Puettmann of WoodLife Consulting conducted a review according to ISO standards on both the report and the SimaPro module used to develop this report (ISO 2006 a,b).

3 Inventory Analysis

3.1 Log Yard

This unit process begins with transporting logs from the forest landing to the veneer mill and included the following operations: Transporting veneer logs from forest landing to log yard; sorting veneer logs by grades and size; storing logs either wet or dry, depending on season and species; transporting logs in-yard from point of unloading to log deck storage, and; transporting logs in-yard from log deck storage to the veneer mill infeed (debarker and log bucking saw). Inputs include fossil fuel for the log haulers and water and electricity for the sprinklers. This unit process generates no co-products. The log wetting process releases water emissions.

3.2 Debarking and Bucking

This unit process begins with logs at the debarker and included the following operations: Mechanically removing the bark from the logs and cross-cutting long logs to make wood “blocks” for peeling (cut-off saw). Inputs include electricity to operate the debarker and saw and diesel fuel for the log haulers. Co-products generated include green bark and some green wood waste including material lost as end cuts. The green wood residue are either ground into wood fuel that is burned onsite or sold as mulch. In this study, the surveyed mills listed roughly 50% of the bark as hog fuel.

3.3 Block Conditioning

Wood blocks are heated in vats with either hot water or direct steam to soften the log to improve the quality of the peeled veneer. Inputs include steam or hot water and electricity for the vats and fossil fuel for equipment to load and unload vats. This unit process produces no co-products. Emissions associated with this unit process include air and water emissions from the boilers providing heat for the vats.

3.4 Peeling and Clipping

A rotary lathe slices the hot, softened veneer blocks into thin veneer sheets and a clipper trims the sheets to size. Inputs include electricity to run the lathes, conveyors, clippers, hog fuel grinders, and waste gate equipment and fossil fuel to transport veneer sheets to veneer dryers. Co-products include green roundup wood, green peeler cores, green wood chips, green waste gate material, and green veneer clippings. Roundup wood is the wood material lost from peeling the block to create a cylindrical shape. Green roundup wood and green veneer clippings are ground into wood fuel that is burned onsite. Ground green wood fuel is also listed as hog fuel. Green peeler cores, green chips, and green waste gate material are sold.

3.5 Veneer Drying

Jet dryers dry the green veneer sheets down to 0–4% MC_{DB}. Inputs include electricity to run fans and steam or hot oil for heating the coils inside the dryers and fossil fuel consumed in forklifts transporting veneer from the peeling and clipping operation to the veneer drying process. Veneers are clipped after drying. Co-products include dry clippings. Air emissions occur. This unit process generates air emissions as the wood dries and dryer temperature rises, and resulted in large amounts of volatile organic compounds compared to the other unit processes. Other emissions associated with this unit process include air emissions from the boilers or direct-fired burners providing heat for the dryers.

3.6 Lay up

This unit process involved bonding thin veneer sheets, also called plies, together with resin to form panels. The resins are urea-formaldehyde (UF) and polyvinyl acetate (PVA). The plies are stacked on top of each other with the wood grain oriented perpendicular to each subsequent sheet for dimensional stability. Depending on the resin, pressure and heat are applied to the sheets to cure the resin and bond the sheets to form veneer panels. Three- to 5-ply veneer panels are common for engineered wood flooring. Inputs included heat and electricity to apply the resin and run the presses and fossil fuel for forklifts and for transporting material to the trimming, sanding, sawing, and moulding unit process. Other inputs are water to produce the resin and diesel fuel to transport purchased and non-purchased dry veneer from veneer mills. This unit process generates no co-products. The pressing and heating processes release air emissions as the resin cured. In addition, emissions associated with this unit process include air emissions from the boilers providing heat for the panel presses.

3.7 Trimming, Sanding, Sawing, and Moulding

Veneer panels are trimmed to standard dimensions, 4 by 8 ft (1.22 by 2.44 m). The trimmed panels are sawn into individual boards and sanded. After sanding, the boards are moulded (profiled) into tongue and groove flooring of random lengths. Inputs included electricity for the trim saw, the gang rip saw, sanding, hog fuel grinding, and fossil fuel to transport the unfinished wood flooring to the prefinishing unit process. Co-products include dry trim material, dry sanding dust, dry sawdust, and dry shavings.

3.8 Prefinishing

Prefinishing the unfinished wood flooring protects the surface. This unit process includes the following operations: sanding, priming, staining, filling, curing, sealing, and topcoating. Sanding the wood prepares the surface for priming, staining, filling, sealing, and topcoating. The primer coat promotes adhesion of the other materials and is ultra violet (UV)-cured. Staining material includes a mixture of water-based, solvent-based, and UV-cured types. Rollers typically apply the stain, filler, sealer, and topcoat. Solvents clean the rollers. All the filler, sealer, and topcoats are UV-cured. Aluminum oxide added to the finish increases surface durability. After finishing, the flooring is placed into small cardboard boxes for shipment. Inputs include steam for the stain drying ovens; electricity for UV-curing ovens, conveyors, and wood dust collectors; and cardboard for boxing up flooring for sale. Air emissions released include sanding dust, PM10, hazardous air pollutants (HAPs), and volatile organic compounds (VOCs).

3.9 Auxiliary Processes

3.9.1 Energy generation

This auxiliary process provides heat for use in other parts of the veneer mill and flooring plant. A fuel such as wood, propane, or natural gas is burned; green wood residue from peeling and clipping and dried wood residue from trimming, sanding, sawing, and moulding generates most of the thermal energy produced and used at the plant. This energy is typically in the form of steam used for the presses, jet dryers, and ovens and for facility heating. This process involves the following operations:

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

Outputs of this auxiliary process are steam and hot water from boilers, combustion gases for drying, solid waste (wood ash), and air emissions (e.g., CO_2, CO) from combustion. In addition, production of grid electricity used onsite releases emissions off-site.

3.9.2 Emission controls

This auxiliary process reduces the amount of air emissions released to the atmosphere. Wood dust collectors collect particulate and PM10 from sanding and finishing operations. Input includes electricity.

4 Limitations of LCI

4.1 Data Quality and Reliability

Franklin database, not primary mill data, provided boiler emission data as part of SimaPro 7 (FAL 2003a,b).

Close proxies were used when available that best matched the material. All resin and finishing materials using close proxies came from the U.S. EcoInvent database (PRé Consultants 2011).

4.2 Function and Functional Unit

For this study, the unit basis was 1 m^3 of prefinished engineered wood flooring. To conduct a comparative assertion on other flooring products, this value needs to be converted to 1 m^2 installed flooring of 9.5 mm thickness for the expected life of the prefinished engineered wood flooring in relation to the life of the building.

4.3 System Boundaries

Not applicable.

4.4 Assumptions

Polyvinyl acetate (PVA) LCI data are not available in the United States, therefore a proxy was developed by using the ethylene acetate polymerization process found in the US-EI database. The one PVA supplier contacted would not provide primary data on its product to develop the needed LCI data.

4.5 Limitations Identified by the Data Collection and Analysis

- Wood flooring production was not available by state.
- U.S. LCI data were not available for polyvinyl acetate resin used in gluing veneers into panels. Staining and coating materials were also not available in SimaPro (U.S. LCI database).

4.6 Conclusions and Recommendations

Not applicable.

5 Results

5.1 Product Yields

Mass and energy values, including emissions for prefinished engineered wood flooring production, were obtained by surveying four veneer mills and five flooring plants in the eastern United States. These facilities provided detailed data on mass flow, energy consumption, and types of fuel. Survey weight-averaged data were modeled in SimaPro 7 to find non-wood raw material use and emission data. Input data collected by survey are provided in Section 14 Appendix LCI inputs on page 33.

Weight-average annual production for the prefinished engineered wood flooring was 19.8 thousand m^3 (0.700 million ft^3) with a range of 6.1 to 31.1 thousand m^3 (0.215 to 1.10 million ft^3). Weight-averaged mill features included a log diameter (small end, inside the bark) of 384 mm (15.1 in.) with a range of 330 to 457 mm (13 to 18 in.). In addition, wood chips were the largest proportion of wood residue produced at 533 OD kg per production unit (Table 5.1). Flooring plants purchased 177 OD kg of dry veneer per production unit. The species veneered were red oak (roughly half), white oak, hard and soft maple, yellow-poplar, yellow birch, black cherry, ash, sweetgum, pecan/hickory, hackberry, elm, and some miscellaneous species.

For the mass balance, the LCI study examined the eight main unit processes and the overall process to track material flows. Using a weight-averaged multi-unit approach, 1,255 OD kg (2,760 OD lb) of incoming hardwood logs with a density of 944 kg/m^3 (58.9 lb/ft^3) and 177 OD kg of purchased rough dry veneer with a density of 613 kg/m^3 produced 1.0 m^3 (1.13 thousand ft^2 (3/8 in. basis)) of prefinished engineered wood flooring. Boilers burned 194 OD kg of both green and dry wood fuel produced onsite (Table 5.1). Overall, a difference of 3.7% was calculated based on the overall mass balance that included intermediate products such as rough green and rough dry veneer.

Table 5-1 Wood mass balance for 1.0 m3 of prefinished engineered wood flooring(weight-averaged values in ovendried kilograms)

	Wood Mass Balance			
Material	In	Out	Boiler Fuel	Sold
Green logs (white wood only)	1255			
Green logs (bark only)[a]	66.9			
Dry veneer (purchased)	177			
Green bark		66.9	6.0	60.9
Green roundup wood		2.8	2.8	0.0
Green peeler cores		0.2	0.0	0.2
Green veneer clipping		0.6	0.6	0.0
Green trim		0.6	0.6	0.0
Green chips		532.8	0.1	532.7
Green hog fuel		175.3	175.3	0.0
Green waste gate material		0.1	0.0	0.1
Dry clipping		7.6	4.6	3.1
Dry Sawdust		106	2.7	103
Dry Shavings		11.1	0.8	10.3
Dry Sanding Dust		17.8	0.2	17.6
Engineered wood flooring		578		
Sum	1499	1499	194	728

[a] About half the bark was included under green hog fuel.

Most veneer mills in the United States track log breakdown to find mill efficiency. The veneer recovery factor (VRF) is one way to track the log breakdown. In this study, VRF quantifies productivity as the weight of veneer (minus resin) produced divided by the total weight of incoming wood in log form. A VRF of 42.6% was calculated. Wilson and Sakimoto (2004) showed a VRF of 51% and 50% for production of softwood plywood in the Pacific Northwest and the Southeast, respectively.

5.2 Non-wood Inputs

5.2.1 Water consumption

Water use was mainly for sprinkling logs, steaming vats, and boiler make-up water. Water consumption was based on responses from four veneer mills and three flooring plants. A surface and ground water consumption of 972 and 2,838 L/m^3 (11.3 and 96.6 gal/thousand ft^2) of prefinished engineered wood flooring was calculated, respectively. Water consumption was broken down into the following unit processes: log yard (30%), block conditioning (40%), lay up (10%), and auxiliary energy generation (20%).

5.2.2 Transportation data

Onsite transportation of wood stock is a major fuel consumer, with off-road diesel having the highest consumption. Onsite transportation includes forklifts, front-end loaders, trucks, and other equipment used within the system boundary of the facility. Total diesel consumption is 11.3 L/m^3 of prefinished engineered wood flooring and is consumed at about three times the rate of propane and gasoline combined, on average. Diesel consumption breaks down into fuel used onsite and fuel used to haul dry veneer to flooring plants. Off-road and on-road diesel use is 7.0 and 4.3 L/m^3, respectively. Gasoline and propane use is 0.57 L/m^3 and 3.10 L/m^3, respectively. Transportation fuel consumption by unit processes is shown in Table 5.2.

Table 5-2 Percentage of fuel use on-site and between facilities broken down by unit processes

Unit Process	Diesel[a,b]	Gasoline[c]	Propane[c]
Logyard	60%	0%	0%
Bucking and debarking	10%	14.3%	14.3%
Block conditioning	5%	14.3%	14.3%
Peeling & clipping	5%	14.3%	14.3%
Veneer drying	5%	14.3%	14.3%
Layup	5%	14.3%	14.3%
Trimming, sanding, sawing, and moulding	5%	14.3%	14.3%
Prefinishing	5%	14.3%	14.3%
Total	100%	100%	100%

[a] Diesel fuel comprised of on-site transport and off-road transport of dry veneer to flooring plants
[b] Divided evenly between the last six unit processes
[c] Divided evenly between the last seven unit processes

5.2.1.1 Logs

Logging transportation data were required to connect the forest resource LCI to the prefinished engineered wood flooring LCI. An average one-way haul distance for hardwood log (including bark) transportation of 201 km (125 mi) with 100% empty backhaul was calculated from primary mill data. Mill average log MC was 85% MC dry basis (45.9% MC wet basis).

5.2.1.2 Purchased wood fuel

All purchased wood fuel was brought for steaming vats, drying veneer, heat pressing panels, heating facilities, and drying stains and coatings. An average one-way haul distance for purchased wood fuel transportation of 165 km (55 mi) with 100% empty backhaul was calculated from primary mill data. Mill average purchased wood fuel MC was 62.6% MC dry basis (35.8% MC wet basis).

5.2.1.3 Dry veneer (purchased)

An average one-way haul distance for purchased dry veneer transportation of 561 km (348 mi) with 100% empty backhaul was calculated from primary mill data. Mill average log MC was 6% MC dry basis (5.7% MC wet basis).

5.2.1.4 Dry veneer (non-purchased)
An average one-way haul distance for non-purchased dry veneer transportation of 1,043 km (648 mi) with 100% empty backhaul was calculated from primary mill data. Mill average log MC was 6% MC dry basis (5.7% MC wet basis). Surveyed mills made this veneer.

5.2.1.5 Resins
An average one-way haul distance for resin (and associated chemicals) transportation of 477 km (296 mi) with 100% empty backhaul was calculated from primary mill data.

5.2.1.6 Stain and coatings
An average one-way haul distance for both stains and coatings (and associated chemicals) transportation of 205 km (127 mi) with 100% empty backhaul was calculated from primary mill data.

6 Manufacturing Energy

6.1 Overall

Prefinished engineered wood flooring production requires both electrical and thermal energy for processing hardwood logs into prefinished engineered wood flooring. All the thermal energy is produced onsite, whereas electricity is produced off-site and delivered through a regional power grid. Electrical energy is required for all unit processes, whereas most of the thermal energy is used for block conditioning, veneer drying, lay up, and prefinishing processes. All veneer mills and flooring plants reported their electrical usage. Total electrical consumption was 1,113 kWh/m^3 (985 kWh/thousand ft^2) prefinished engineered wood flooring. A total process energy (unallocated) of 6,418 MJ was consumed per cubic meter (m^3) prefinished engineered wood flooring, which corresponds to 5.38 million Btu/thousand ft^2 (Table 6.1). Wood fuel at 300 ovendry kg or 6,263 MJ/m^3 (5.26 million Btu/thousand ft^2) contributed 97.6% of process thermal energy required with the remainder from propane (2.2%) and natural gas (0.2%).

6.2 Electrical

For the unit processes and the auxiliary unit processes (energy generation, emission controls (veneer mill), and emission controls (flooring plant)), the distribution of electrical energy consumption is shown in Table 6.2. Total electrical consumption was 1,113 kWh/m^3 (985 kWh/thousand ft^2). Electrical distribution among the unit processes was provided by the surveyed mill and flooring plants. Of all the unit processes, the highest electrical consumption occurred in the emission control (flooring plant) process with a value of 335 kWh/m^3 (296 kWh/thousand ft^2). Total electrical consumption for hardwood plywood production was 462 kWh/m^3 (408 kWh/thousand ft^2)[6]. For hardwood plywood production, lay up consumes roughly 44% of the total. Wilson and Sakimoto (2004) found a softwood plywood electrical consumption of 138 kWh/m^3 (122 kWh/thousand ft^2) for the Pacific Northwest, a significantly lower value. Softwood plywood veneer drying consumed 57.6 kWh/m^3 (51.0 kWh/thousand ft^2), approximately one-third of this total.

[6] Hardwood plywood production includes all unit processes up to lay up.

Table 6-1 Material and energy consumed on-site to produce 1.0 m3 of prefinished engineered wood flooring (SimaPro input values). Includes fuel used for electricity production and for transportation (unallocated).

Fuel type	Quantity (units/m^3)	(units/thousand ft^2 [f])
Fossil fuel[a]		
Natural gas	0.3 m^3	0.01 thousand ft^3
Propane	5.36 L	1.26 gal
Electricity[b]		
Off-site generation	1,113 kWh	985 kWh
On-site transportation fuel[c]		
Off-road diesel	7.01 L	1.64 gal
On-road diesel[d]	4.26 L	1.00 gal
Gasoline	0.57 L	0.13 gal
Propane	0.04 L	0.73 gal
Renewable fuel[e]		
On-site wood Fuel	194 kg	378 lb
Purchased wood fuel	106 kg	207 lb
Water use		
Surface water	972 L	227 gal
Ground water	2,838 L	664 gal

[a] Energy values were determined using their higher heating values (HHV) in MJ/kg: 54.4 for natural gas and 54.0 for propane.
[b] Conversion unit for electricity is 3.6 MJ/kWh.
[c] Energy values were determined using their higher heating values (HHV) in MJ/kg: 45.5 for off-road and on-road diesel and 54.4 for gasoline.
[d] Transportation of panels and veneer between facilities; not accounted for in other transportation data
[e] Values given in oven-dry weights (20.9 MJ/OD kg)
[f] 0.885 m^3 per thousand ft^2 (3/8” basis)

Table 6-2 Electricity consumption broken down by unit processes

Unit Process	(%)	kWh/m^3	kWh/thousand ft^2 [a]
Bucking and debarking	8.0	89	78
Block conditioning	2.4	26	24
Peeling & clipping	11.9	133	118
Veneer drying	1.2	13	12
Layup	18.1	201	178
Trimming, sanding, sawing, and moulding	6.0	67	59
Prefinishing	6.0	67	59
Energy generation	11.9	133	118
Emissions control (veneer mill)	4.4	49	43
Emission controls (flooring plant)	30.1	335	296
Total	100	1,113	985

[a] 0.885 m^3 per thousand ft^2 (3/8 in. basis); 3.6 MJ per kWh

Off-site generation of electrical power affects the environmental impact from the different fuels used to generate power. Average composition of (off-site) electrical generation for the eastern grid for the United States was taken from SimaPro (i.e., U.S. LCI database) (PRé Consultants 2011). The most significant electric power contributor in the eastern region is coal, with 58.9% of total electrical utility power including both bituminous and lignite coals. Other fuel sources are nuclear, natural gas, petroleum, hydro, biomass, and unspecified fossils, which provide 22.7%, 10.1%, 3.3%, 2.9%, 1.6%, and 0.5%, respectively. Wind power contributes less than 0.05% to the grid.

6.3 Heat

A total process energy (unallocated) of 6,418 MJ are consumed per cubic meter (m^3) prefinished engineered wood flooring, which equals 5.38 million Btu/thousand ft^2. Table 6.3 shows the results by unit processes. The unit processes of block conditioning, veneer drying, and lay up consume 23.7%, 58.8%, 11.3%, and 6.2% of process thermal energy, respectively. Facility heating was divided evenly among these four processes. For an energy check, we estimated a literature value for block conditioning of 1,642 MJ/m^3 assuming frozen oak logs heated to 100 °C, boiler efficiency of 75%, and boiler vat efficiency of 25% due to using live steam (Steinhagen 2005). Previous CORRIM studies on southeast plywood showed a veneer drying value of 1.35 million Btu/thousand ft^2 (3/8 in. basis) (Wilson and Sakimoto 2004). Hardwood plywood may take 4–5 times more energy than softwoods because of the longer times to soften blocks prior to peeling, and hardwood contains more water due to its higher density.[7]

Table 6-3 Thermal process energy consumption broken down by unit processes

Unit Process	MJ/m^3	million BTU/thousand ft^2 [a]
Block conditioning	1,521	1.27
Veneer drying	3,773	3.16
Layup	723	0.61
Stain drying	401	0.34
Total	6,418	5.38

[a] 0.885 m^3 per 1000 ft^2 (3/8 in. basis); 1055 MJ per million BTU

[7] Personal communication with Dr. James Wilson, past vice president of CORRIM on October 10, 2009.

7 Environmental Impacts

SimaPro 7 modeled output factors during the manufacturing process with major consumption of raw materials, other than wood, for electrical generation. Major uses of raw material, other than logs processed into veneer were coal, purchased wood fuel (residue), natural gas, crude oil, and limestone, with allocated values of 358, 105, 76.2, 75.8, and 14.8 kg per unit production, respectively. Wood log volume of 1.43 m^3 was allocated to produce 1.0 m^3 prefinished engineered wood flooring (Table 7.1). Limestone and most of the coal were used to produce off-site electricity, and oil and natural gas was for off-site electricity, resins and finishing materials, and thermal energy used onsite. Veneer mills and flooring plants burned purchased wood fuel for thermal energy use onsite. Limestone helps remove sulfur dioxide emitted from burning coal.

Table 7-1 Raw materials consumed during production of prefinished engineered wood flooring—cumulative, allocated gate-to-gate LCI values (SimaPro output values). Includes fuel used for electricity production and for log and purchased wood fuel transportation (allocated).

	Quantity[b]	
Raw material[a]	*(units/m³)*	(units/thousand ft^2)[c]
Logs at mill gate[d]	1.43 m^3	44.7 ft^3
Water, well, in ground[e]	2.51 m^3	78.4 ft^3
Water, process, surface[e]	6.35 m^3	198 ft^3
Purchased wood waste	105 kg	205 lb
Coal, in ground[e]	352 kg	686 lb
Gas, natural, in ground[e]	75.6 kg	147 lb
Oil, crude, in ground[e]	74.8 kg	146 lb
Limestone, in ground[e]	14.8 kg	28.8 lb
Energy, from hydro power	3.74 kWh	3.31 kWh
Energy, unspecified	0.41 kWh	0.36 kWh
Uranium, in ground[e]	0.0106 kg	0.0207 lb

[a] Values are allocated and cumulative.

[b] Energy values were found using HHV in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.

[c] 0.885 m^3 per 1000 ft^2 (3/8 in. basis).

[d] Amount of wood in log form allocated to final product; no shrinkage taken into account from drying process. Value contains no co-products but does include amount of on-site generated wood fuel allocated to the flooring.

[e] Materials as they exist in nature and have neither emissions nor energy consumption associated with them.

Table 7.2 shows the allocated cumulative energy of making 1.0 m^3 of prefinished engineered wood flooring. For cumulative energy allocated to prefinished engineered wood flooring, a value of 22,986 MJ/m^3 was found. Coal used to produce electricity provides by far the largest portion of energy needed, and most of this is because of the intensive energy needed for peeling and clipping (11.9%), lay up (18.1%), and for emission controls associated with prefinishing (30.1%).

Table 7-2 Cumulative energy (HHV) consumed during production of prefinished engineered wood flooring—cumulative, allocated gate-to-gate LCI values (SimaPro output values). Includes fuel used for electricity production and for log and purchased wood fuel transportation (allocated).

Fuel[a,b]	*(kg/m³)*	(MJ/m^3)	BTU/thousand ft^2 [c,e]
Purchased wood waste	105 kg	2,195	1,840,000
Coal, in ground[d]	352 kg	9,222	7,740,000
Gas, natural, in ground[d]	75.6 kg	4,113	3,450,000
Oil, crude, in ground[d]	74.8 kg	3,403	2,860,000
Energy, from hydro power[e]	0	13	10,000
Uranium, in ground[d]	0.0106 kg	4,039	3,390,000
Energy, unspecified[e]	0	1	1,000
TOTAL		22,986	19,300,000

[a] Values are allocated and cumulative and based on HHV

[b] Energy values were found using their higher heating values (HHV) in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.

[c] 0.885 m^3 per 1000 ft^2 (3/8 in. basis).

[d] Materials as they exist in nature and have neither emissions nor energy consumption associated with them.

[e] Conversion for units of energy is 948.8 BTU/MJ.

[e] No mass units are assigned to hydro and unspecified energy

Two different life-cycle inventory scenarios for manufacturing prefinished engineered wood flooring were evaluated based on the five veneer mills and four flooring plants surveyed: allocated cumulative and allocated onsite. The method for evaluating the two scenarios followed the ISO 14040 standards and CORRIM guidelines. The allocated accumulative scenarios examined all emissions for electricity and thermal energy generation that are required to produce 1.0 m^3 of prefinished engineered wood flooring starting with hardwood logs at the mill gate. These emissions involve the cradle-to-gate resource requirements (production and delivery) of grid electricity, fossil fuels and purchased wood fuel used in the boiler, and fossil fuels used in yard equipment such as forklifts. In addition, emission data for onsite combustions of the two latter materials and wood fuel generated onsite were included. Transportation of logs (including bark) to the mill gate was included in the cumulative system boundary. The allocated onsite scenario only includes emissions from the combustion of all fuels used at the mills and flooring plants, therefore it did not involve the manufacturing and delivery of materials, fuels, and electricity consumed at the mill.

Table 7.3 shows the lower environmental impact of onsite compared to cumulative emissions for the facilities surveyed. Carbon dioxide and particulates are typically measured, although other emissions are frequently monitored from boilers to ensure regulatory compliance. Carbon dioxide (CO_2) emissions are separated by two fuel sources, biogenic (biomass-derived) and anthropogenic (fossil-fuel-derived). Accumulative total emission values of 623 and 1,049 kg were reported from SimaPro for CO_2 (biogenic) and CO_2 (fossil), respectively (Table 7.3). The percentage of biogenic CO_2 to total CO_2 increased from 37.3% to 64.8% from the total (cumulative) to onsite scenarios. Emissions of volatile organic compound (VOC) gases was roughly the same at approximately 1 kg, regardless of scenario, thus indicating wood drying was a significant contributor to the overall amount of VOCs.

Table 7-3 Life-cycle inventory results for total cumulative and on-site emissions on a per unit basis of prefinished engineered wood flooring (allocated)

Substance	Total cumulative		On-site	
	(kg/m^3)	($lb/thousand\ ft^2$)[a]	(kg/m^3)	($lb/thousand\ ft^2$)[a]
Water emissions				
Biological oxygen demand (BOD)	1.09	2.13	1.06	2.06
Cl^-	14.9	29.1	7.9	15.38
Suspended solids, unspecified	0.933	1.82	0.591	1.15
Oils, unspecified	0.0911	0.178	0.0865	0.169
Dissolved solids	12.6	24.6	3.94	7.68
Chemical oxygen demand (COD)	1.52	2.96	1.45	2.84
Other solid materials[b]				
Waste in inert landfill	28.4	55.4	28.4	55.4
Recycled material	9.34	18.2	9.34	18.2
Solid waste[c]	41.0	81.0	41.0	81.0
Air emissions				
Acetaldehyde	2.17E-01	4.24E-01	2.17E-01	4.24E-01
Acrolein	4.90E-05	9.57E-05	1.10E-05	2.15E-05
Benzene	2.32E-03	4.53E-03	2.14E-03	4.18E-03
Carbon dioxide (biomass)	6.23E+02	1.22E+03	6.10E+02	1.19E+03
Carbon dioxide (fossil)	1.05E+03	2.05E+03	3.31E+02	6.46E+02
Carbon monoxide	5.57E+00	1.09E+01	5.02E+00	9.80E+00
Methane	2.65E+00	5.17E+00	1.21E+00	2.36E+00
Formaldehyde	4.00E-02	7.80E-02	3.98E-02	7.77E-02
Mercury	4.84E-04	9.45E-04	3.36E-02	6.55E-02
Naphthalene	6.99E-04	1.36E-03	6.96E-04	1.36E-03
Nitrous oxides	3.76E+00	7.34E+00	1.61E+00	3.14E+00
Non-methane, volatile organic compounds (NMVOC)	5.79E-01	1.13E+00	5.02E-01	9.79E-01
Organic substances, unspecified	8.05E-02	1.57E-01	7.97E-02	1.55E-01
Particulate (PM10)	1.38E-01	2.70E-01	1.38E-01	2.70E-01
Particulate (unspecified)	6.10E-01	1.19E+00	1.71E-01	3.34E-01
Phenol	1.92E-02	3.74E-02	1.92E-02	3.74E-02
Sulfur dioxide	5.05E+00	9.85E+00	5.58E-01	1.09E+00
VOC	1.04E+00	2.03E+00	9.99E-01	1.95E+00

[a] 0.885 m^3 per 1000 ft^2 (3/8 in. basis).
[b] Includes solid materials not incorporated into the product or co-products and leave the system boundary
[c] Solid waste is mostly boiler ash from burning wood. Boiler ash is either spread as a soil amendment or landfilled depending on the facility.

Material and energy resources consumed to manufacture 1 m^3 of prefinished engineered wood flooring are shown in Table 6.1. These input values are unallocated and were entered into SimaPro 7 to find the environmental burdens of manufacturing 1 m^3 of prefinished engineered wood flooring. Table 7.4 lists the onsite energy values unallocated and allocated to the planed dry lumber. Unallocated values were calculated from material and energy resources found in Table 6.1 and were the sum of all fuel and electricity inputs to the process. Allocated onsite energy use is roughly 57% of the total unallocated onsite use. Material and energy consumed at the mill for SimaPro 7 gave LCI outputs allocated to manufacturing prefinished engineered wood flooring, not to associated wood co-products. Using the total difference between the unallocated and allocated values, we calculated 4,700 MJ of energy used at the mill was allocated to the co-products.

Table 7-4 Fuel and electrical energy used on-site to produce a 1 m3 of prefinished engineered wood flooring.

	Energy use at mill Unallocated (MJ/m3)	Allocated (MJ/m3)
Fossil fuel[1]		
Natural gas	11.4	6.62
Propane	143	82.9
Electricity[2]		
Off-site generation	4,006	2,326
On-site transportation fuel[3]		
Off-road diesel	271	110
On-road diesel	165	66.9
Gasoline	19.9	8.09
Propane	167	67.9
Renewable fuel[4]		
On-site wood fuel	4,050	2,350
Purchased wood fuel	2,220	1,290
Total	11,000	6,300

[1] Energy values were determined using their higher heating values in MJ/kg: 43.3 for fuel oil #1 and #2.
[2] Conversion unit for electricity is 3.6 MJ/kWh.
[3] Energy values were determined using their higher heating values in MJ/l: 38.7 for off-road diesel, 26.6 for propane, and 34.8 for gasoline.
[4] Values given in oven-dried weights (20.9 MJ/OD kg).

8 Carbon Balance

Carbon emissions are playing an increasingly important role in policy decision making in the United States and throughout the world. The impact of carbon was determined by estimating values of carbon found in wood and bark as described from previous studies, such as Skog and Nicholson (1998), using a mixture of hardwood roundwood values for the eastern United States. We used a mixed hardwood factor of 305.1 kg/m^3 of wood material and a carbon content of 51.7% with an incoming log wood mass of 1,255 OD kg/m^3 prefinished engineered wood flooring to calculate the carbon balance. Resins and coating processes are not included. Total carbon input and output of 831 and 872 kg/m^3 prefinished engineered wood flooring are found (Table 8.1) resulting in a difference of 4.4 %. Contribution to the carbon balance from air emissions are shown in Table 8.2. A cubic meter of prefinished engineered wood flooring stores 1,096 kg CO_2-equivalents[8] as a final product.

Table 8-1 Tracking of wood-based carbon inputs and outputs for prefinished engineered wood flooring

	Elemental carbon	
Substance[a]	(kg/m^3)	(lb/thousand ft^2)[b]
Input		
Logs	649	1,265
Bark[c]	35	67.4
Purchased dry veneers	92	179
Purchased wood fuel	55	107
Sum carbon in	831	1,618
Output		
Prefinished engineered wood flooring	299	582
Co-products[c]	376	733
Solid emissions	21	42
Air emissions	176	343
Sum carbon out	872	1,700

[a] Wood-related carbon and its emissions.
[b] 0.885 m^3 per 1000 ft^2 (3/8 in. basis).
[c] Bark leaves system both as wood fuel and as a co-product (mulch).

Table 8-2 Composition of wood-based air emissions related to carbon contribution

	Total[a]		Carbon[a]		
Substance	(kg/m^3)	(lb/thousand ft^2)[b]	(%)[c]	(kg/m^3)	(lb/thousand ft^2)[b]
Benzene	2.32E-03	4.53E-03	92.3%	2.14E-03	4.18E-03
Carbon dioxide, biogenic	6.23E+02	1.22E+03	27.3%	1.70E+02	3.32E+02
Carbon monoxide	5.57E+00	1.09E+01	42.9%	2.39E+00	4.66E+00
Formaldehyde	4.00E-02	7.80E-02	40.0%	1.60E-02	3.12E-02
Methane	2.65E+00	5.17E+00	75.0%	1.99E+00	3.88E+00
Naphthalene	6.99E-04	1.36E-03	93.7%	6.55E-04	1.28E-03
NMVOC, non-methane volatile organic compounds, unspecified origin	5.79E-01	1.13E+00	88.2%	5.11E-01	9.96E-01
Organic substances, unspecified	8.05E-02	1.57E-01	50.0%	4.02E-02	7.85E-02
Phenol	1.92E-02	3.74E-02	76.6%	1.47E-02	2.87E-02
VOC, volatile organic compounds	1.04E+00	2.03E+00	88.2%	9.20E-01	1.79E+00
Total	633	1236	27.7	176	343

[a] All values per unit of prefinished engineered wood flooring.
[b] 0.885 m^3 per 1000 ft^2 (3/8 in. basis).
[3] Percentage from Softwood Lumber LCI (Milota et al. 2004) and Softwood Plywood LCI (Wilson and Sakimoto 2004).

[8] Multiplying (mass of wood flooring) × (carbon content) × (carbon to carbon dioxide conversion) = 578 kg × 51.7% × 44/12 = 1,096 kg CO_2-equivalents.

9 Sensitivity Analysis

A sensitivity analysis was completed per ISO 14040 standards in SimaPro to model the effects of using different quantities of fuel sources for thermal energy generation. Sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in prefinished engineered wood flooring manufacturing, heat is used in several sub-processes, consuming a combination of wood, natural gas, and propane as fuel to generate the heat. Changing fuel sources, also referred to as fuel switching, can have a significant effect on the type and quantity of emissions. This sensitivity analysis compared the effects of the “base” fuel mix to using (1) all onsite generated wood fuel (mostly green hog fuel from the peeling and clipping process) and (2) using all propane as a fuel input. Propane is chosen because it burns cleaner than fuel oil and is abundantly available domestically.

9.1 Alternative Fuel Sources

The “base” fuel mix in this study included three fuel sources, with wood fuel and propane supplying the majority of the energy. Natural gas contributed less than 1%. Based on survey data, the original model assumed that 97.6% of the fuel used was in the form of wood fuel (63.1% produced onsite and the remainder purchased) and 2.2% as propane. Most mills use only one or two types of fuel, whereas the base case resulted in a weight-averaged composite model incorporating different fuel sources taken from primary mill data for the five veneer mills and four flooring plants. In this sensitivity analysis, two alternative fuel-use scenarios were created for comparison to the “composite mill” or “base” scenario. One alternative assumed consumption of only onsite (generated) wood fuel used for all thermal energy by increasing the initial base value of 194 to 307 OD kg for this “100% onsite wood fuel” case to generate 6,418 MJ/m^3 (5.38 million Btu/thousand ft^2) of prefinished engineered wood flooring. The second alternative fuel-use scenarios, “100% propane,” had propane use increase from the base value of 5.4 to 241 L to provide all necessary heat for the facility.

9.2 Three Fuel Source Scenarios

This sensitivity analysis examined three scenarios for heat generation using the base fuel mix, 100% propane, and 100% onsite (generated) wood fuel cases. All three scenarios include emissions from the cradle-to-gate resource requirements (production and delivery) of grid electricity. The following three scenarios were modeled using SimaPro to find the differences in emissions: (1) comparing 100% propane case to the “base” hardwood lumber fuel mix that used both propane and wood fuel, (2) comparing 100% onsite (generated) wood fuel to the “base” hardwood lumber fuel mix that again had no fuel changes, and (3) comparing 100% propane to 100% onsite (generated) wood fuel cases.

9.3 Sensitivity Analysis Results

Table 9.1 presents the summary of the three fuel use scenarios, with a partial list of air emissions for the eastern region. In scenarios 1 and 2, a negative percentage difference number indicated that the alternative fuel source released fewer emissions than did the base model. A positive percentage difference means that the base or original model released fewer emissions. Scenario 1 indicated that less particulate (PM10), solid waste, acetaldehyde, and biogenic CO_2, but more fossil CO_2, non-methane VOC, and NOx, were produced when burning 100% propane than in the base fuel mix (original). Scenario 2 showed more biogenic CO_2, both types of particulate, acetaldehyde, benzene, naphthalene, and phenol, but less fossil CO_2 and NOx were produced when burning 100% wood fuel than in the base fuel mix (original). In scenario 3, a negative number indicates that the all-propane case released fewer emissions than the all-onsite produced wood fuel case, and a positive percentage number means that all onsite produced wood fuel models released fewer emissions. Scenario 3 highlighted the increase of fossil CO_2, non-methane VOC, and NOx produced along with less particulate (PM10) and biogenic CO_2 produced compared with scenario 1. For all three scenarios, the amount of VOC produced was similar regardless of the fuel used because most VOC originated in the actual drying of the veneer and during panel making and prefinishing.

Table 9-1 Sensitivity analysis for manufacturing prefinished engineered wood flooring

	Fuel Distribution (kg per cubic meter planed dry lumber)			Difference (%)		
Substance	100% propane	100% wood fuel[a]	Original (base)	Scenario 1—100% propane to original	Scenario 2—100% wood fuel to original	Scenario 3—100% propane to 100% wood fuel
Acetaldehyde	2.15E-01	2.18E-01	2.17E-01	-1.2%	0.5%	-1.7%
Benzene	1.41E-03	2.44E-03	2.40E-03	-51.9%	1.7%	-53.5%
CO_2 (biogenic)	5.59E+01	6.41E+02	6.24E+02	-167.1%	2.7%	-167.9%
CO_2 (fossil)	1.45E+03	1.06E+03	1.06E+03	30.6%	0.1%	30.4%
CO	3.61E+00	5.73E+00	4.39E+00	-19.4%	26.6%	-45.4%
Formaldehyde	3.80E-02	4.02E-02	4.00E-02	-5.1%	0.5%	-5.6%
Methane	2.20E+00	1.72E+00	2.67E+00	-19.5%	-43.4%	24.3%
Naphthalene	5.00E-05	7.18E-04	6.99E-04	-173.3%	2.7%	-174.0%
Nitrogen oxides	4.10E+00	3.79E+00	3.80E+00	7.5%	-0.5%	7.9%
Non-methane, VOC	8.22E-01	5.85E-01	5.87E-01	33.3%	-0.3%	33.6%
Organic substances, unspecified	3.55E-02	8.18E-02	8.05E-02	-77.5%	1.7%	-78.9%
Particulate (PM10)	9.19E-02	1.40E-01	1.38E-01	-40.3%	1.1%	-41.4%
Particulate (unspecified)	6.31E-01	6.19E-01	6.10E-01	3.3%	1.4%	2.0%
Phenol	8.31E-03	1.95E-02	1.92E-02	-79.1%	1.8%	-80.6%
Sulfur dioxide	2.16E+00	5.15E+00	5.11E+00	-81.2%	0.8%	-81.9%
VOC	1.06E+00	1.05E+00	1.04E+00	1.3%	0.4%	0.9%
Solid waste	1.67E+01	4.18E+01	4.14E+01	-84.8%	1.1%	-85.7%

[a] All wood fuel used was generated on-site.

10 Study Summary

A rigorous material and energy balance was completed on five veneer mills and four flooring plants located in the eastern United States. A weight-averaged process energy (unallocated) of 6,418 MJ/m^3 of prefinished engineered wood flooring (5.38 million Btu/thousand ft^2) was found with 1,521 MJ for block conditioning, 3,773 MJ for veneer drying, 723 MJ for lay up, and 401 MJ for stain drying. Total electrical energy consumption of 1,113 kWh/m^3 of prefinished engineered wood flooring (985 kWh/thousand ft^2) was also determined. Results showed a cumulative allocated value for manufacturing prefinished engineered wood flooring from the forest road to the final product leaving the flooring plant of 22,990 MJ/m^3 (19.3 million Btu/thousand ft^2)[9]. Unfinished engineered wood flooring showed a cumulative allocated value of 13,600 MJ/m^3 (11.4 million Btu/thousand ft^2).

Table 10.1 showed the difference by type of wood flooring for cumulative energy (allocated). Prefinished consumes more energy compared to unfinished engineered wood flooring, roughly 60%. Much of this increase in energy resulted from electrical consumption in the emission control devices to prevent the release of VOCs. These devices consumed approximately 30% of total electricity (335 kWh/m^3 (296 kWh/thousand ft^2)) needed for the entire manufacturing process. Resin usage also increased the environmental impact as noted when comparing unfinished engineered to unfinished solid strip wood flooring. Unfinished solid strip flooring cumulative energy showed a consumption rate of only 6,498 MJ/m^3, roughly half of unfinished engineered wood flooring.

[9] Cumulative allocated value considers electrical efficiency of grid power provided.

Table 10-1 Cumulative energy (HHV) consumed during production of prefinished engineered wood flooring compared to unfinished engineered and solid strip wood flooring—cumulative, allocated gate-to-gate LCI values (SimaPro output values). Includes fuel used for electricity production and for log and purchased wood fuel transportation (allocated).

Fuel[1] (MJ/m^3)	Unfinished Solid Strip Flooring[2]	Engineered wood flooring	
		Unfinished	Prefinished
Biomass	4,195	1,724	2,195
Coal	748	4,992	9,222
Natural Gas	934	2,930	4,113
Crude Oil	557	2,580	3,403
Hydro	9	4	13
Uranium	48	1,363	4,039
Energy, unspecified	7	1	1
Total	6,498	13,595	22,986

[1] based on HHV; Energy values were found using their higher heating values (HHV) in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.
[2] Puettmann et al. (2010)

From a Swedish perspective, Potting and Blok (1995) conducted a life-cycle assessment on different flooring materials including linoleum and cushioned vinyl. Linoleum is comprised of linseed oil (27%), limestone (10%), ground wood (10%), ground cork (10%), colophonium (8%), and pigment (5%). Cushioned vinyl is comprised of polyvinyl chloride (50%, plasticizer (30%), limestone (15%), stabilizers (3%), and pigments (0.3%), and a few other additives. Each compound contributes to the overall amount of process energy required to produce the final product. Total percentage of components does not equal 100% for unknown reasons.

From Potting and Blok's study, we calculated the cumulative energy per kilogram of flooring for linoleum and cushioned vinyl. For linoleum with a density of 600 kg/m^{3}and ignoring material transportation, a value of 35.5 MJ/kg linoleum was calculated (Table 10.2). For cushioned vinyl with a density of 590 kg/m^3 and ignoring material transportation, a value of 70.0 MJ/kg was calculated. Caution is necessary because no allocation method was selected and no statement on whether higher or lower heating values was used.

Table 10.3 shows how wood and non-wood flooring material compare based on cumulative energy values. Unfinished solid strip flooring in the United States has the lowest cumulative energy value with 9.89 MJ/kg, about 14% of cushioned vinyl. Prefinished engineered wood flooring is similar in energy values to linoleum. Converting to MJ/m^2 (functional unit) indicates that wood material has higher cumulative energy values than the non-wood alternatives. However, no biomass energy was consumed during production of linoleum and cushioned vinyl. Furthermore, significant amounts of biomass energy were consumed during production of the different types of wood flooring. For example, nearly 98% of the process (thermal) energy for prefinished engineered wood flooring in the United States came from biomass. Contrarily, natural gas was the primary fuel for production of linoleum and cushioned vinyl (Potting and Blok 1995). In addition, Potting and Blok (1995) indicated that wood flooring products would typically last 50 years, about three and six times longer than linoleum and cushioned vinyl flooring would, respectively.

Table 10-2 Cumulative energy consumed during production of linoleum and cushioned vinyl—cumulative values. Transportation fuel data not included.

Linoleum			Cushioned vinyl		
Substance	(%)	(MJ/kg)	Substance	(%)	(MJ/kg)
Fertilizer		2.64	Polyvinyl chloride	50	77.9
Linseed oil[a] (27%)	27	0.54	Plasticizer	30	75.3
Limestone (10%)	10	0.08	Limestone	15	0.08
Ground wood (10%)	10	3.24	Stabilizers	3	-----
Ground cork (10%)	10	1.62	Pigments	0.3	70
Colophonium[b] (8%)	8	---------	Glass Fibre	3.2	5.9
Pigment (5%)	5	70.0	Process energy		8
Jute	11	0.96			
Acrylate dispersion layer	0.35	----			
Process energy		10.6			
Electricity		18.0			
Total		35.5	Total		70.0

[a] Fertilizing (Reaping (0.65MJ/kg); Extracting linseed oil (0.54MJ/kg)
[a] No data available
[b] Conversion for units of electricity is 3.6 MJ/kWh; assume 30% overall electrical efficiency; 1.5kWh/m^2

Table 10-3 Cumulative energy consumed production of wood and non-wood flooring.

Type	Density[a] (kg/m^3)	Energy (MJ/kg)	Weight (kg/m^2)	Energy (MJ/m^2)
Prefinished engineered wood[b]	656	35.0	6.56	230
Unfinished engineered wood[b]	643	21.1	6.43	136
Unfinished solid strip (US)[c]	657	9.89	12.5	123
Linoleum[d]	600	35.5	2.0	71
Cushioned vinyl[d]	590	70.0	1.7	119
Wood floor boards (Germany)[e]	---	19.8	10.71	212

[a] Oven dried
[b] Wood material had 9.5 mm thickness
[c] Hubbard and Bowe (2010); 19 mm thickness
[d] Transportation fuel data not included in the total
[e] Nebel et al. (2006); 212 MJ/m^2; 8kg/m^2; air dried to 17%MC; mass allocation

11 Discussion

Our data show that engineered wood flooring has two significant advantages over non-wood substitutes: biomass fuel is used instead of fossil fuel during manufacturing and and carbon can be sequestered (captured and stored) in the wood product. Burning biomass for energy does not contribute to increasing atmospheric CO_2, provided forests are regrowing and reabsorbing the emitted CO_2 on a sustainable basis. Other non-wood products typically do not have the benefits of a renewable product to use both as a fuel and a finished product. The carbon stored in the final product equates to the fossil CO_2 released during manufacturing. In addition, decreasing energy consumption would be of great benefit to the mills in terms of its both financial benefits (cost reduction) and environmental burden benefits, especially in veneer drying, lay up and prefinishing.

A trade-off occurs for prefinishing the engineered wood floor onsite. Additional electricity for emission controls of the VOCs emitted during prefinishing has a large environmental impact up-front. However, the environmental impact of prefinishing onsite compared to finishing engineered wood flooring once installed would likely show a positive environmental influence overall. This is due to controlling emissions at the flooring plants instead of finishing the installed engineered wood floor at a residential or commercial building that would likely allow uncontrolled release of VOCs.

12 Conclusions and Recommendations

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

- The amount of carbon stored in prefinished engineered wood flooring exceeds the fossil carbon emissions by about 4%. Therefore, as long as prefinished engineered wood flooring and its carbon stay in products held in end uses, the carbon stored will exceed the fossil carbon emitted in manufacturing.

- A trade-off exists between prefinished and unfinished engineered wood flooring. A large amount of electricity is consumed during the prefinishing unit process to control emissions from staining and coating the wood flooring. As a result, the environmental impact is significantly higher for prefinished engineered wood flooring than for unfinished engineered wood flooring. However, finishing the wood floor after installation in a residential or commercial building (an uncontrolled environment) would result in greater harm to the environment. This harm is caused by uncontrolled emissions released from the staining and coating process that are now captured or destroyed onsite at the flooring plant.

- Burning fuel for energy generates CO_2. Nearly all energy burned onsite for manufacturing prefinished engineered wood flooring comes from woody biomass. Burning biomass for energy does not contribute to increasing atmospheric CO_2 provided forests are regrowing and reabsorbing the emitted CO_2 on a sustainable basis.

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

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14 Appendix

14.1 LCI inputs

Logyard									
Products									
Roundwood, hardwood, green, at mill, US E	1255 kg			94.9%					
Bark, hardwood, green, at mill, US E	66.9 kg			5.1%					
Resources									
Water, well, in ground	851 l			30.0%	of total	2,838 l			
Water, process and cooling, surface	292 l			30.0%	of total	972 l			
Materials/fuels									
Roundwood, hardwood, at forest road, US NE-NC	1255 kg								
Bark, hardwood, at forest road, US NE-NC	66.9 kg								
Transport, combination truck, diesel powered	467 tkm	tkm=	1255	kg*	201	km*(1+	85.0%	MC)/1000	
Transport, combination truck, diesel powered	25 tkm	tkm=	66.9	kg*	201	km*(1+	85.0%	MC)/1000	
Diesel, combusted in industrial equipment	6.76 l			60%	of total	11.3 l			
Gasoline equipment (gal)	0.0 l			0%	of total	0.6 l			
Natural gas equipment (gal) - surrogate for propane	0.0 l			0%	of total	3.1 l			
Debarking and bucking									
Products									
Bucked log, hardwood, green, at veneer mill, US E	1255 kg			94.9%					
Bark, hardwood, green, at veneer mill, US E	60.9 kg			4.6%					
Fuel wood, hardwood, green, at veneer mill, US E	6.0 kg			0.5%					
Materials/fuels									
Roundwood, hardwood, at forest road, US E	1255 kg								
Bark, hardwood, at forest road, US E	66.9 kg								
Diesel, combusted in industrial equipment/US	1.13 l			10.0%	of total	11.3 l			
Gasoline, combusted in equipment/US	0.08 l			14.3%	of total	0.6 l			
Natural gas, combusted in industrial equipment/RNA	0.44 l			14.3%	of total	3.1 l			
Electricity/heat									
Electricity, at grid, Eastern US/US	319 MJ			8.0%	of total	4,006 MJ			
Final waste flows									
Dummy_Disposal, solid waste, unspecified, to inert material landfill	0.837 kg			9.44%	allocated to this stage				8.87
Dummy_Recycling, waste, unspecified	2.15 kg			7.21%	allocated to this stage				29.8
Block conditioning									
Products									
Conditioned log, hardwood, green, at veneer mill, US E	1255 kg								
Materials/fuels									
Bucked log, hardwood, green, at veneer mill, US E	1255 kg								
Diesel, combusted in industrial equipment/US	0.56 l			5.0%	of total	11.3 l			
Gasoline, combusted in equipment/US	0.08 l			14.3%	of total	0.6 l			
Natural gas, combusted in industrial equipment/RNA	0.44 l			14.3%	of total	3.1 l			
Electricity/heat									
Block conditiong, at veneer mill, US E	1,522 MJ			23.7%	of total	6,418 MJ			
Electricity, at grid, Eastern US/US	27 kWh			2.4%	of total	1,113 MJ			
Resources									
Water, well, in ground	1135 l			40.0%	of total	2,838 l			
Water, process and cooling, surface	389 l			40.0%	of total	972 l			
Peeling and clipping									
Products									
Veneer, hardwood, green, at veneer mill, US E	1 kg	43.26%							
Wood fuel, hardwood, green, at veneer mill, US E	0.330 kg	14.29%							
Wood chips, hardwood, green, at veneer mill, US E	0.981 kg	42.43%							
Peeler cores, hardwood, green, E, USA, U	0.00031 kg	0.01%							
Waste gate material, hardwood, green, E, USA, U	0.00027 kg	0.01%	2						
Materials/fuels									
Conditioned log, hardwood, green, at veneer mill, US E	2.31 kg	100%							
Diesel, combusted in industrial equipment/US	0.00104 l			5.0%	of total	11.3 l			
Gasoline, combusted in equipment/US	0.00015 l			14.3%	of total	0.6 l			
Natural gas, combusted in industrial equipment/RNA	0.00081 l			14.3%	of total	3.1 l			
Electricity/heat									
Electricity, at grid, Eastern US/US	0.245 kWh			11.95%	of total	1,113 kWh			
Veneer drying									
Products									
Veneer, hardwood, dry, at veneer mill, US E	1 kg	98.6%							
Wood fuel, hardwood, dry, at veneer mill, US E	0.009 kg	0.9%							
Clippings, hardwood, dry, at veneer mill, US E	0.006 kg	0.6%							
Materials/fuels									
Veneer, hardwood, green, at veneer mill, US E	1.015 kg								
Diesel, combusted in industrial equipment/US	0.00105 l			5.0%	of total	11.3 l			
Gasoline, combusted in equipment/US	0.00015 l			14.3%	of total	0.6 l			
Natural gas, combusted in industrial equipment/RNA	0.00083 l			14.3%	of total	3.1 l			
Electricity/heat									
Drying veneer, hardwood, , at veneer mill, US E	7.05 MJ			58.8%	of total	6,418 MJ			

Electricity, at grid, Eastern US/US	0.0248	kWh			1.2%	of total	1,113	kWh		
Emissions control, at veneer mill, US E	0.0911	kWh			4.4%	of total	1,113	kWh		
Air emissions										
Acetaldehyde	0.0001869	kg			2 of 5 mills reporting					
Acetone	0.0000477	kg								
Carbon monoxide	0.0001007	kg								
Formaldehyde	0.0000071	kg								
Methanol	0.0000579	kg								
Particulates	0.0003271	kg								
Phenol	0.0000028	kg								
VOC, volatile organic compounds	0.0005607	kg								
Hydrocarbons, unspecified	0.0007944	kg								
Layup										
Products										
Pressed raw panels, hardwood, at engineered wood flooring plant, US E	1	kg								
Resources										
Water, well, in ground	0.4761	l			10.0%	of total	2,838	l		
Water, process and cooling, surface	0.1630	l			10.0%	of total	972	l		
Materials/fuels			1							
Dry hardwood veneer, at veneer mill, US E	0.8984	kg								
Polyvinyl acetate, hardwood, panel making, US	0.1113	kg			65%	NVS				
Urea formaldehyde resin, liquid,65% non-volatile solids, USA, U	0.0583	kg			52.40%	NVS				
Diesel, combusted in industrial equipment/US	0.000945	l			5.0%	of total	11.3	l		
Gasoline, combusted in equipment/US	0.000137	l			14.3%	of total	0.6	l		
Natural gas, combusted in industrial equipment/RNA	0.000742	l			14.3%	of total	3.1	l		
Transport, combination truck, diesel powered	0.0810	tkm		Resin	tkm=	0.1697	kg*		477	km/1000
Transport, combination truck, diesel powered	0.9368	tkm		Dry veneer	tkm=	0.8984	kg*		1,043	km/1000
Electricity/heat										
Pressing panels, hardwood, at engineered wood flooring plant, US E	1.21	MJ			11.26%	of total	6,418	MJ		
Electricity, at grid, Eastern US/US	0.337	kWh			18.05%	of total	1,113	kWh		
Air emissions										
VOC, volatile organic compounds	0.0005537	kg								
Acetaldehyde	0.0001678	kg								
Methanol	0.0000839	kg								
Formaldehyde	0.0000503	kg								
Acetone	0.0000210	kg								
4-Methyl-2-pentanone	0.0000048	kg								
Hydrocarbons, unspecified	0.0000461	kg								
Phenol	0.0000092	kg								
Layup										
Products										
Pressed raw panels **(purchased veneer)**, hardwood, at engineered wood flooring plant, US E	1	kg								
Resources										
Water, well, in ground	0.476	l			10.0%	of total	2,838	l		
Water, process and cooling, surface	0.163	l			10.0%	of total	972	l		
Materials/fuels			1							
Veneer, hardwood, dry, at veneer mill, US E	0.8984	kg								
Polyvinyl acetate, hardwood, panel making, US	0.1113	kg			65.0%	NVS				
Urea formaldehyde resin, liquid,65% non-volatile solids, USA, U	0.0583	kg			52.4%	NVS				
Diesel, combusted in industrial equipment/US	0.00095	l			5.0%	of total	0.0	l		
Gasoline, combusted in equipment/US	0.00014	l			14.3%	of total	0.6	l		
Natural gas, combusted in industrial equipment/RNA	0.00074	l			14.3%	of total	3.1	l		
Transport, combination truck, diesel powered	0.08099	tkm				0.170	kg*		477	km/1000
Transport, combination truck, diesel powered	0.50355	tkm				0.90	kg*		561	km/1000
Electricity/heat										
Pressing panels, hardwood, at engineered wood flooring plant, US E	1.21	MJ			11.26%	of total	6,418	MJ		
Electricity, at grid, Eastern US/US	0.337	kWh			18.1%	of total	1,113	kWh		
Air emissions										
VOC, volatile organic compounds	0.0005537	kg								
Acetaldehyde	0.0001678	kg								
Methanol	0.0000839	kg								
Formaldehyde	0.0000503	kg								
Acetone	0.0000210	kg								
4-Methyl-2-pentanone	0.0000048	kg								
Hydrocarbons, unspecified	0.0000461	kg								
Phenol	0.0000092	kg								
Trimming, sanding, sawing, and moulding										
Products										
Engineered flooring, hardwood, unfinished, US E	1.00	kg								
Wood fuel, hardwood, dry, at engineered wood flooring plant, US E	0.0065	kg								
Sawdust, hardwood, dry, at engineered wood flooring plant, US E	0.1781	kg								
Shavings, hardwood, dry, at engineered wood flooring plant, US E	0.0178	kg								
Sanding dust, hardwood, dry, at engineered wood flooring plant, US E	0.0003	kg								
Materials/fuels										
Pressed raw panels, hardwood, at engineered wood flooring plant, US E	0.927	kg								

Pressed raw panels (purchased veneer), hardwood, at engineered wood flooring plant, US E	0.276	kg					
Diesel, combusted in industrial equipment/US	0.000876	l	5.0%	of total	11.3	l	
Gasoline, combusted in equipment/US	0.000127	l	14.3%	of total	0.57	l	
Natural gas, combusted in industrial equipment/RNA	0.000688	l	14.3%	of total	3.1	l	
Electricity/heat							
Electricity, at grid, Eastern US/US	0.104	kWh	6.0%	of total	1,113	kWh	
Air emissions							
Particulates, < 10 um	0.000109	kg					
Prefinishing							
Products							
Prefinished engineered wood flooring, at engineered wood flooring plant, US E	1	kg					
Materials/fuels							
Engineered flooring, hardwood, unfinished, US E	0.980	kg					
Diesel, combusted in industrial equipment/US	0.000859	l	5.0%	of total	11.3	l	
Gasoline, combusted in equipment/US	0.000125	l	14.3%	of total	0.6	l	
Natural gas, combusted in industrial equipment/RNA	0.000674	l	14.3%	of total	3.1	l	
Alkyd resin, long oil, 70% in white spirit, at plant/RER with US electricity U	0.000369	kg	30%	%solids			
Epoxy resin, liquid, at plant/RER with US electricity U	0.002114	kg	100%	%solids		expoxy acrylic	
Acrylic varnish, 87.5% in H2O, at plant/RER U US	0.000660	kg	20%	%solids		urethane acrylic	
Acetone, liquid, at plant/RER with US electricity U	0.000796	kg	0%	%solids	40%		
Butyl acetate, at plant/RER with US electricity U	0.000199	kg	0%	%solids	10%		
Isopropanol, at plant/RER with US electricity U	0.000498	kg	0%	%solids	25%		
Isopropyl acetate, at plant/RER with US electricity U	0.000498	kg	0%	%solids	25%		
Transport, combination truck, diesel powered	0.00105	tkm	Stains	0.0051	kg*	205	km/1000
			0.00				
Polyurethane, rigid foam, at plant/RER with US electricity U	0.002779	kg	100%	%solids			
Alumina, at plant/US	0.000695	kg	100%	%solids			
Acrylic filler, at plant/RER U US	0.005101	kg	100%	%solids			
Polyurethane, rigid foam, at plant/RER with US electricity U	0.005080	kg	100%	%solids			
Acrylic filler, at plant/RER U US	0.003984	kg	100%	%solids			
Acetone, liquid, at plant/RER with US electricity U	0.000408	kg	0%	%solids		80%	
Isobutyl acetate, at plant/RER with US electricity U	0.000102	kg	0%	%solids		20%	
Transport, combination truck, diesel powered	0.00372	tkm	tkm=	0.0181	kg*	205	km/1000
Corrugated cardboard FAL	0.0615	kg	used to protect final product for shipping, not counted toward final weight of product				
Electricity/heat							
Electricity, at grid, Eastern US/US	0.102	kWh	6.0%	of total	1,113	kWh	
Emission control, at engineered wood flooring plant, US E	0.510	kWh	30.1%	of total	1,113	kWh	
Drying stain, at engineered wood flooring mill, US E	0.611	MJ	6.25%	of total	6,418	MJ	
Air emissions							
HAPs	0.019	kg					
VOCs	0.301	kg					
Final waste flows							
Material for recycling	0.0122	kg	90.56%	allocated to this stage		8.87	
Waste in inert lanfilled	0.0422	kg	92.79%	allocated to this stage		29.8	
Energy Generation (Franklin Boiler)							
Products							
Block conditioning, at veneer mill, E, USA, U	1,522	MJ	23.7%	of total	6,418	MJ	
Veneer drying, at veneer mill, Franklin Boiler, E, USA, U	3,773	MJ	58.8%	of total	6,418	MJ	
Pressing panels, hardwood, at engineered wood flooring plant, US E	723	MJ	11.3%	of total	6,418	MJ	
Drying stain, at engineered wood flooring mill, US E	401	MJ	6.2%	of total	6,418	MJ	
		MJ	100.0%				
		6,418					
Resources							
Water, well, in ground	568	l	20.0%	of total	2,838	l	
Water, process and cooling, surface	194	l	20.0%	of total	972	l	
Materials/fuels							
Wood into industrial boilers (generated on-site), engineered wood flooring, green and dry, E, USA, U	194	kg					
Wood into industrial boilers (purchased), engineered wood flooring, green and dry, E, USA, U	106	kg					
Transport, combination truck, diesel powered	23.7	tkm	tkm=	106	kg*	165	km*(1+ 35.8% MC)/1000
Natural gas, combusted in industrial boiler/US	0.30	m3					
Liquefied petroleum gas, combusted in industrial boiler/US	5.36	l					
Emission Controls							
Electricity/heat							
Grid Electricity, Veneer Mill Emission Control, Engineered Wood Flooring Region	49	kWh	4.4%	of total	1,113	kWh	
Grid Electricity, Flooring Plant Emission Control, Engineered Wood Flooring Region	335	kWh	30.1%	of total	1,113	kWh	

14.2 Questionnaire

CONFIDENTIAL

Engineered Wood Flooring Analysis Project

Thank you for giving me the opportunity to work with you on a project involving the long-term viability and profitability of the U.S. wood products industry. Results from this project will be a good marketing tool for the U.S. engineered wood flooring industry particularly the green building industry. A growing demand for building projects that use environmentally friendly and energy-efficient materials has spurred a green movement in the construction industry. For 2006, an estimated $10 billion of "green buildings" were in the process of construction in the United States and the residential green building market share may increase to over $38 billion by 2010.

As a member of the U.S. forest products industry you know that using wood is a sensible choice because wood is renewable and often poses fewer burdens to the environment than substitute materials. Many consumers do not understand this. With your input we can test the theory that engineered 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.

This questionnaire focuses on annual production, annual energy use and generation, annual material inputs and outputs, and annual environmental emissions for engineered wood flooring manufactured in the United States. Regarding the questionnaire, our primary focus is on overall mill information because this data is vital for precise and accurate results. Details harder to report may be requested later. We realize that you may not have all the information requested, but the data you are able to provide will be appreciated. My final report will describe a gate-to-gate life cycle analysis of manufactured engineered wood flooring. **Strict confidentiality will be maintained for all companies that supply data for this project.** Please complete the following questionnaire by **August 8, 2008.**

Company Name: ____________________________________

Facility Address: ____________________________________

____

Contact Person: ____________________________________

Telephone: (   ) ______________ **Fax:** (   ) __________

Contact email: ____________________________________

Please direct questions and send complete questionnaires to:

Rick Bergman
University of Wisconsin-Wood Products Program
1630 Linden Drive
Madison, WI 53706
Phone (608) 231-9477 / Fax (608) 231-9200
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CONFIDENTIAL

ENGINEERED WOOD FLOORING ANALYSIS

Manufacturing engineered wood flooring is designed to be more dimensionally stable than solid strip wood flooring because it is less susceptible to changes in moisture. Engineered wood flooring as defined by the National Wood Flooring Association (NWFA) is composed of several sheets of solid wood (veneer) bonded together with an adhesive under heat and pressure. Although plies having 2, 3, 5, 7, or 9 sheets are available, 3 and 5 are most common. Also, the veneer plies may be produced from different species for the face, bottom, and core sections. Sheets are stacked on top of each other with the wood grain facing perpendicular to each subsequent sheet for dimensional stability. The flooring consists of random lengths with the final dimensions of width ranging from 2 ¼ to 7" and from ¼ to 9/16" in thickness. For this project, we need information on the total inputs and outputs from your company as a whole and then for some individual processes. Answer the questions as best you can. The questionnaire is organized as follows:

Part I: Basic description of facility operations

Part II: Information about facility total inputs and outputs

A. Veneer mill

B. Flooring plant

All responses you provide should be for the reporting year (annual basis). 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 Rick Bergman at (608) 231-9477 or rbergman@wisc.edu with any questions.**

PART I: OPERATION OVERVIEW

GENERAL INFORMATION **(Please provide responses for all requested information)**

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

2. **Type of operation (questionnaire split into main sections: veneer mill and flooring plant)**

   a. Veneer mill (please check one):

      i. ☐ Rotary veneer ______% production ________ thousand ft^2 3/8" basis/year
      ii. ☐ Sliced veneer ______% production ________ thousand ft^2 3/8" basis/year
      iii. ☐ Dry solid-sawn ______% production _______ thousand ft^2 3/8" basis/year (or bf)
      iv. Average log diameter if logs are processed _________ inches
      v. Average log length _________ inches
      vi. Average final core size if logs are rotary peeled _________ inches
      vii. Initial green veneer MC ________%MC
      viii. Final dry veneer MC ________%MC

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

      i. Volume of incoming veneer _____________ thousand ft^2 3/8" basis/year
      ii. Volume of incoming lumber _____________ thousand bf
      iii. Annual production of engineered wood flooring produced: ____________ sq. ft.
      iv. Percent of engineered wood flooring that is pre-finished: _________ %

PART II: TOTAL MILL MATERIAL & ENERGY INPUTS & OUTPUTS

A. VENEER MILL (annual production for reporting year; if no veneer mill go to page 7)

1. **Log scale: Dolye, International, Scribner, Weight base (circle one)**
2. **Type of veneer dryer: Jet, Rotary (circle one)**

- Incoming hardwood logs ________________ thousand BF/year
- Incoming softwood logs (if any) ________________ thousand BF/year
- Incoming hardwood lumber (if any) ________________ thousand BF/year
- Incoming green veneer (if any) ________________ thousand ft^2 3/8" basis/year
- Veneer produced on-site ________________ thousand ft^2 3/8" basis/year
- Hardwood lumber produced on-site (if any) ________________ thousand BF/year
- Hardwood lumber kiln-dried on-site (if any) ________________ thousand BF/year
- Average moisture content into dryer __________%MC
- Average moisture content out of dryer __________%MC
- Percent of redry __________%

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

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

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

TOTAL WATER USE

- Ground (municipal/well) water ____________ gallons or ft^3 ________percent recycled
- Surface water ____________ gallons or ft^3 ________percent recycled

TOTAL TRANSPORTATION FUEL USE ON-SITE (includes all fuels for yard equipment, forklifts, and carriers)

Type	Units
On-road diesel (between facilities)	Gallons
Off-road diesel	Gallons
Fuel Oil #6	Gallons
Propane	Gallons
Gasoline	Gallons
Other	

TOTAL MILEAGE: (Raw materials delivered to your manufacturing facility)

By Truck _______% By Rail_______%

- Average one-way distance to deliver logs: _______________miles
- Average one-way distance to deliver lumber if any: _______________miles
- Average one-way distance to deliver green veneer if any: _______________miles

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

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

TOTAL (NON-TRANSPORTATION) FUEL USE (boilers, cogeneration units, etc.)

Circle all types of boiler used: wood fuel, natural gas, oil, or propane

- Wood
  - On-site wood boiler fuel _______________@_________%MC tons
  - Purchased wood boiler fuel _______________@_________%MC tons
- Fossil Fuel
  - Natural Gas ____________________ thousand cubic feet (ft^3)
  - Fuel oil #1(kerosene) ____________________ gallons
  - Fuel oil #2 (heating oil) ____________________ gallons
  - Fuel oil #6 ____________________ gallons
  - Propane ____________________ gallons
  - Other ____________________
  - Electricity for entire facility ____________________ kilowatt-hours (kWh)
  - Electricity for the following processes **(Estimation is ok)**

Process	kWh	% of total
1. Bucking & Debarking		
2.Block Conditioning		
3. Peeling & Clipping		

Process	kWh	% of total
4. Veneer Drying		
5. Energy Generation		
6. Emissions control		

TOTAL PRODUCT OUTPUT (DRIED VENEER)

Total volume of outgoing dried veneer ____________________ thousand ft^2 3/8" basis/year

- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year
- Wood species ____________________ / ____________________ thousand ft^2 3/8" basis/year

TOTAL WOOD CO-PRODUCT/BY-PRODUCT OUTPUT

For each material, please record the amount of wood residue for the reporting period that are sold (shipped) to other users, used internally (such as fuel), landfill, or inventoried for future use. Select whatever category best fits your mill's situation. Please state units if other than tons such as cubic yards. **Please indicate whether the wood residue is listed as wet or dry weights.**

Co-products and By-Products	MC	Wet or dry weights	Sold (Shipped)	Boiler Fuel	Other uses	Landfilled	Inventory	Total
	(%)		tons	tons	tons	tons	tons	tons
Bark, green								
Roundup wood, green								
Peeler cores, green								
Veneer clippings, green								
Trim, green								
Chips, green								
Hogged material								
Waste gate material								
Clippings, dry								
Other								

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

Type	Tons/Pounds	Percent Landfilled
Pallets (not re-used)		
General refuse (do not include above materials)		
Recycled material		

VENEER DRYER OR/AND ENTIRE MILL EMISSIONS: (Provide stack test if available)

	SOURCE	
Emission	**Veneer dryer**	**Entire veneer mill**
Dust	pounds	pounds
Particulate	pounds	pounds
PM10	pounds	pounds
Hazardous Air Pollutants (HAPS)	pounds	pounds
Volatile organic compounds (VOCs)	pounds	pounds
Nitrous oxide (N_20)	pounds	pounds
Nitrogen oxide (NO)	pounds	pounds
Sulfur oxides (SOx)	pounds	pounds
Carbon monoxide (CO)	pounds	pounds
Carbon dioxide (CO_2)	pounds	pounds
Others (please list all known):	units	units

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 (gas, liquid, solid)	Electrical Usage For Device kWh (annual basis)

B. ENGINEERED WOOD FLOORING PLANT

WOOD AND OTHER MATERIAL INPUTS

Total volume of incoming dry veneer ________________ thousand ft^2 3/8" basis/year

- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year
- Wood species ________________ / ________________ thousand ft^2 3/8" basis/year

- Total volume of cardboard ____________ cartons/year
- Total volume of sandpaper ____________ rolls/year

TOTAL WATER USE

- Ground (municipal/well) water __________ gallons or ft^3 ______percent recycled
- Surface water __________ gallons or ft^3 ______percent recycled

TOTAL TRANSPORTATION FUEL USE ON-SITE **(includes all fuels for yard equipment, forklifts, and carriers)**

Type	Units
On-road diesel (between facilities)	Gallons
Off-road diesel	Gallons
Fuel Oil #6	Gallons
Propane	Gallons
Gasoline	Gallons
Other	

ADHESIVE INPUTS (glues used for lay-up (hot pressing) veneer plies)

Spread rate (gross plywood) ______________ grams per squ. ft. or lbs per squ. ft. (circle one)

Mark type of glue/adhesive used in lay-up and give percent solids:

☐ Urea Formaldehyde (UF) _______________lbs or gallons /year / __________% solid

☐ Polyvinyl acetates (PVA) _______________lbs or gallons /year / __________% solid

☐ Phenol formaldehyde (PF) _______________lbs or gallons /year / __________% solid

☐ Melamine-urea-formaldehyde (MUF) _______lbs or gallons /year __________% solid

☐ Phenol resorcinol (PR) _______________lbs or gallons /year / __________% solid

☐ Phenol resorcinol formaldehyde (PFR) ______lbs or gallons /year / __________% solid

List name and amount of other materials used in adhesives (such as extenders/ fillers, water and other solvents, catalysts, hardener, stabilizers, etc.) : Composition of material used to prepare glue by percent or by weight

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

Name of material _________________/ Percent or weight ________________ / _______% solid

FINISHING INPUTS (used for staining and coating)

List weights and percent solids of all stains used:

Spread rate ______________ grams per squ. ft. or lbs per squ. ft. (circle one)

- Solvent-based ____________________lbs or gallons /year / _____% solid
    - Type of solvent _____________________/ ___________lbs or gallons /year
    - Type of solvent _____________________/ ___________lbs or gallons /year
    - Type of solvent _____________________/ ___________lbs or gallons /year
    - Type of solvent _____________________/ ___________lbs or gallons /year
    - Type of solvent _____________________/ ___________lbs or gallons /year
- Water-based ____________________lbs or gallons /year / _____% solid
- UV-cured ____________________lbs or gallons /year / _____% solid
- Other material (please specify) ____________________lbs or gallons /year / _____% solid
- Other material (please specify) ____________________lbs or gallons /year / _____% solid
- Other material (please specify) ____________________lbs or gallons /year / _____% solid
- Other material (please specify) ____________________lbs or gallons /year / _____% solid
- Other material (please specify) ____________________lbs or gallons /year / _____% solid

List weights and percent solids of materials used in coating

Spread rate (gross plywood) _____________ grams per squ. ft. or lbs per squ. ft. (circle one)

- Polyurethane lacquer _________________________lbs or gallons /year / _____% solid
- Acid-curing lacquer _________________________lbs or gallons /year / _____% solid
- UV-curing lacquer _________________________lbs or gallons /year / _____% solid
- Oil treatment _________________________lbs or gallons /year / _____% solid
- Melamine _________________________lbs or gallons /year / _____% solid
- Water-borne lacquer _________________________lbs or gallons /year / _____% solid
- Aluminum oxide _________________________lbs or gallons /year
- Name of filler _______________ / __________lbs or gallons /year / _____% solid
- Name of filler _______________ / __________lbs or gallons /year / _____% solid
- Other (please specify) ___________________ / ____________lbs or gallons /year / _____% solid
- Other (please specify) _________________________________lbs or gallons /year / _____% solid
- Other (please specify) _________________________________lbs or gallons /year / _____% solid
- Other (please specify) _________________________________lbs or gallons /year / _____% solid
- Other (please specify) _________________________________lbs or gallons /year / _____% solid

TOTAL (NON-TRANSPORTATION) FUEL USE

- Wood
  - On-site wood boiler fuel ______________ @ ________ %MC tons
  - Purchased wood boiler fuel ______________ @ ________ %MC tons
- Fossil Fuel
  - Natural Gas ______________ thousand cubic feet (ft^3)
  - Fuel oil #1(kerosene) ______________ gallons
  - Fuel oil #2 (heating oil) ______________ gallons
  - Fuel oil #6 ______________ gallons
  - Propane ______________ gallons
  - Other ______________
  - Electricity for entire facility ______________ kilowatt-hours (kWh)
  - Electricity for the following processes **(Estimation is ok)**

Process	kWh	% of total
6. Hot Pressing		
7. Trimming		
8. Pre-finishing		

Process	kWh	% of total
9. Sawing & Moulding		
10. Packaging		
11. Emissions control		

TOTAL MILEAGE: (Raw materials delivered to your manufacturing facility)

By Truck _______% By Rail_______%

Average one-way distance to deliver dry veneer: ___________miles

Average one-way distance to deliver lumber: ___________miles

Average one-way distance to deliver resin and associated products: ___________miles

Average one-way distance to deliver stains, coatings, and such: ___________miles

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

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

TOTAL WOOD CO-PRODUCT/BY-PRODUCT OUTPUT

For each material, please record the amount of wood residue for the reporting period that are sold (shipped) to other users, used internally (such as fuel), landfill, or inventoried for future use. Select whatever category best fits your mill's situation. Please state units if other than tons such as cubic yards. **Please indicate whether the wood residue is listed as wet or dry weights.**

Co-products and By-Products	MC	Wet or dry weights	Sold (Shipped)	Boiler Fuel	Other uses	Landfilled	Inventory	Total
	(%)		tons	tons	tons	tons	tons	tons
Clippings, dry								
Sawdust, dry								
Shavings, dry								
Sanding dust, dry								
Wood flour, dry								
Other								

TOTAL PRODUCT OUTPUT (for reporting year)

Please complete the table for the different species used to produce *engineered wood flooring* including surface, bottom, and core plies. Do *not* include parquet, cork, bamboo or hardwood flooring data in this table. *See example on first line. Please copy and fill out multiple sheets as needed*

Engineered Wood Flooring Annual Production	
Species¹	**For Each Species Please Write In:** **Square Feet Produced / Width (inches) / Thickness (inches)**
Example: White Oak	3,000,000 ft² / 3⅛"/ 3/8", 1,500,000 ft²/2¼"/ ½ ", 5,000,000 ft² / 3⅛"/ ½", & 500,000 ft²/3"/ ½", etc.
Red oak	
Hard maple	
Hickory/pecan	
White oak	
Cherry	
Birch	
Yellow poplar	
Walnut	
Beech	
Ash	
Soft maple	
Other (specify)	
Other (specify)	
Other (specify)	
Other (specify)	
TOTAL SQUARE FEET PRODUCED FOR ALL SPECIES ABOVE (do not worry about totals by widths and thickness)	___________**Square feet**

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

Type	Tons/Pounds	Percent Landfilled
Pallets (not re-used)		
Adhesive mixed with wood waste		
General refuse (do not include above materials)		
Recycled material		

FINISHING LINE OR/AND ENTIRE MILL EMISSIONS: (Provide stack test if available)

	SOURCE	
Emission	**Finishing line**	**Flooring Plant**
Dust	pounds	pounds
Particulate	pounds	pounds
PM10	pounds	pounds
Hazardous Air Pollutants (HAPS)	pounds	pounds
Volatile organic compounds (VOCs)	pounds	pounds
Nitrous oxide (N_20)	pounds	pounds
Methane	pounds	pounds
Nitrogen oxide (NO)	pounds	pounds
Sulfur oxides (SOx)	pounds	pounds
Carbon monoxide (CO)	pounds	pounds
Carbon dioxide (CO_2)	pounds	pounds
Others (please list all known):	units	units

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 are controlled (i.e. settling pond, city sewer, septic). 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 (gas, liquid, solid)	Electrical Usage For Device kWh (annual basis)

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.
VOCs: Volatile Organic Compounds- produced in incomplete combustion of carbon based compounds; does not include methane; examples are oil based paints and gasoline fumes.

Bergman, R; Bowe, Scott. 2011. Life-cycle inventory of manufacturing prefinished engineered wood flooring in the eastern United States. CORRIM Phase II Final Report. Module N University of Washington, Seattle, Wa. pp. 1-47; 2011