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Using Reclaimed Lumber and Wood Flooring in Construction: Measuring Environmental Impact Using Life-Cycle Inventory Analysis

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Abstract

With green building concepts becoming widespread in the construction field, building practices and materials are being examined for their environmental impact. Reusing building materials has a distinct advantage over using newly manufactured materials because these reclaimed materials avoid greenhouse gas emissions associated with new (virgin) material manufacturing. In a wood-framed building, building materials reclaimed during deconstructing (dismantling) may include framing lumber and wood flooring. This study quantified the energy impact of reusing these two wood materials in new construction or remodeling. This paper presents results of a deconstruction industry survey following Consortium for Research on Renewable Industrial Materials Research Guidelines. A life-cycle inventory approach was applied to track the energy consumption and emissions associated with reclaiming materials. This study showed how the material flowed through the various unit processes beginning at the deconstruction site and ending at a storage facility. We used weight-averaged material and energy production data to estimate the environmental impact of the two reclaimed materials. Results from this life-cycle inventory showed that cumulative energy consumed in producing virgin compared to reclaimed framing lumber and wood flooring was about 11 and 13 times greater, respectively. Global Warming Potential was about 3 and 5 times greater, respectively. These results indicate that reclaimed framing lumber and wood flooring have a significantly lower environmental impact than their two virgin alternatives.

Keywords Reclaimed building material, wood flooring, framing lumber, life-cycle inventory, LCI, life-cycle assessment, LCA, reuse

Introduction

Background

Within the green building and sustainable construction fields is a growing movement to salvage and reuse building materials from building deconstruction. Building materials reuse has several benefits including reducing carbon footprint, conserving resources, extending landfills, and minimizing pollution (Smith et al. 2001; Ericksson et al. 2005; Heilmann and Winkler 2005; Profu 2004; Thorneloe et al. 2007). In spite of these benefits, there is currently no easy way to quantify the carbon impact of incorporating reused and recycled wood products into building design.

Deconstruction (dismantling) is the selective disassembly of building components, specifically for re-use, recycling, and waste management, and it differs from demolition. During demolition, a site is cleared of its building by the quickest means (Winistorfer et al. 2005). The intent of deconstruction is to recover material for reuse. Buildings have a useful life span but deconstruction focuses on giving the reclaimed materials (i.e., building components) extracted a new useful life once the building as a whole reaches its end of life (Falk and Guy 2007; Kibert 2003).

Construction and Demolition Waste Management

The latest construction and demolition (C&D) waste data indicate that the United States produced 295 million metric tons of waste in 2003. Of this, building-related C&D materials comprise roughly 50% while the rest primarily comes from roads and bridges (EPA 2009a, EPA 2004). Reducing the volume of material disposed of in landfills has been critical to mitigating greenhouse gas (GHG) emissions such as methane released from landfills (EPA 2006).

Two recent events illustrate the importance of the need for better materials management. 1) The USEPA has declared carbon dioxide and other GHG emissions as air pollutants (EPA 2009b). 2) A requirement for 50% C&D waste diversion by 2015 for Federal agencies (Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance). Initial works on broad categories of waste disposal, including dimensional lumber, are being evaluated through the Waste Reduction Model (WARM) developed using a streamlined life-cycle assessment (LCA) approach (EPA 2010). WARM calculates GHG emissions of baseline and alternative waste management practices. Using WARM, some preliminary results on deconstructing military facilities were developed (Napier et al. 2007). However, WARM does not account for the energy consumed and material used in the deconstruction process, just the material itself when determining GHG emissions. Regardless of the limitations of WARM, the results from Napier and others (2007) are a good starting point for our approach on investigating the environmental impacts of substituting reclaimed for virgin material in building construction.

The USEPA has initiated programs such as Resource Conservation Challenge to aid the United States in moving toward materials management and away from solid waste disposal. Regarding this effort, life-cycle research plays a role by examining the various scenarios for their environmental trade-offs (Borghi et al. 2009). A critical point is that recycling and reuse have different environmental impacts depending on types of materials recycled, transportation distances, and the remanufacturing processes (Thorneloe et al. 2007).

Life-Cycle assessment

Life-cycle assessment is a method for evaluating the environmental impacts of processes and products. Performing an LCA of a product is a detailed, data-intensive process. Life-cycle inventories (LCIs) are part of an LCA or may be completed as a separate study. LCIs track all the inputs and outputs including emissions of a single life-cycle stage such as harvesting or product manufacturing across the system boundary (ISO 2006a). For example, Figures 1 and 2 highlight the system boundaries for a cradle-to-gate LCI for virgin framing lumber and solid strip hardwood flooring, respectively (Puettmann and Wilson 2005, Puettmann et al. 2010). Within each system boundary, the individual unit processes are identified for greater transparency. In Figure 1, unit processes for producing framing lumber include transportation, log yard, sawing, drying, and planing.

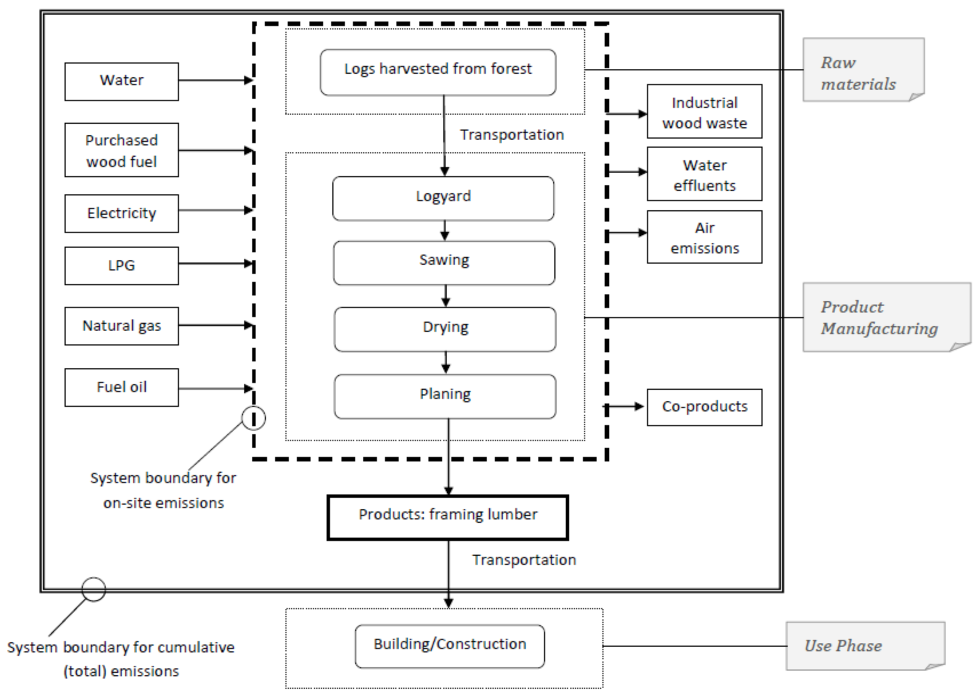

Figure 1. Cradle-to-gate system boundaries for virgin framing lumber (cradle-to-gate)

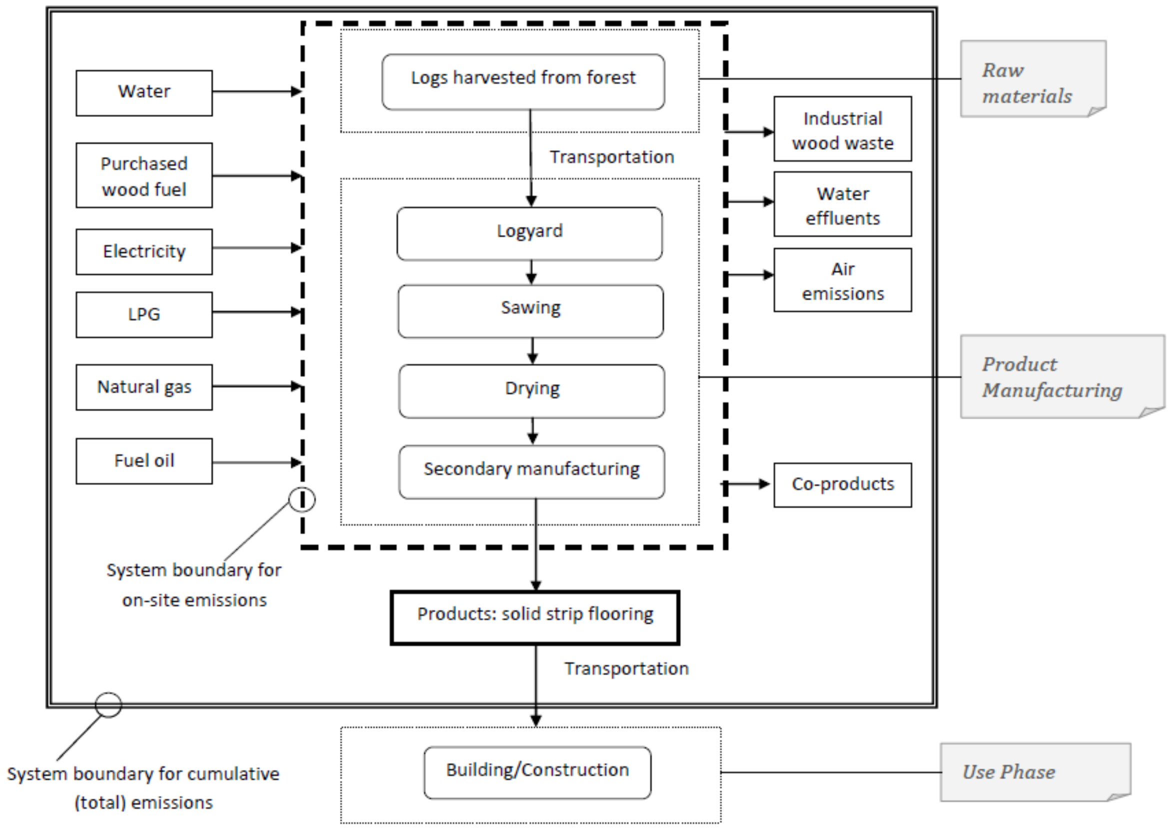

Figure 2. Cradle-to-gate system boundaries for virgin solid strip hardwood flooring

In the various geographical regions of the United States, cradle-to-gate LCI data for virgin wood products were developed using the LCA method by the Consortium for Research on Renewable Industrial Materials (CORRIM). This life-cycle work has shown that wood-framed housing has significant environmental advantages over both steel and concrete housing built in Minneapolis, Minnesota, and Atlanta, Georgia, respectively (Lippke 2004).

The goal of this project was to develop exploratory life-cycle data on reclaiming framing lumber and wood flooring for comparison to the virgin alternatives. We quantified the impact of reclaiming wood products for their cumulative energy consumption and associated emissions. This assessment followed the ISO 14040 (2006a) and 14044 (2006b) standards and CORRIM Research Guidelines (Briggs 2001). We incorporated existing LCI data from the US LCI Database (NREL 2010). These life-cycle data provide the ability to directly assess the environmental consequences (as measured by carbon and energy release) of selecting virgin or reclaimed building materials.

Method

The scope of the study was compare energy consumption and associated emissions of reclaimed and virgin wood products in the United States by using the LCA framework from cradle-to-gate. We chose mass allocation because the highest volume product had the highest economic value.

We collected US primary (annual production) data from 13 deconstruction companies in 2009 and modeled the weight-averaged production data to estimate the emissions. We compared the exploratory cradle-to-gate LCI data developed on reclaiming solid strip hardwood flooring and framing lumber to the virgin wood counterpart on a functional unit of 1 m^3. A typical cradle-to-gate LCI model provides an analysis of the cumulative environmental impacts of extraction, manufacturing, and shipping industrial products. This analysis included each wood product's contribution to energy consumption and climate change. We examined each material for its environmental impact up to but not including the energy to transport the materials to a storage facility. We estimated the Global Warming Potential (GWP) using carbon dioxide (CO_2) and methane (CH_4) over a 100-year time horizon (EPA 2010). To complete this study, we evaluated and selected a reuse (recycling) method to assign the environmental burdens properly for the reclaimed wood material.

Cut-off method

The choice of the reuse (recycling) methods can be the consequence of the particular goal of an LCI/LCA study. Some goals may promote the reuse of materials or support design for recycling. We focused on the fact that the wood industry manufactures virgin wood building materials with no expectation of being recycled or reused. Therefore, this study uses the cut-off method. This method accounts for the environmental impacts at the time they occur, not for any potential future use or reuse (Frischknecht 2007, ISO 2000, Gaudreault et al. 2010). Consequently, using reclaimed wood products avoids primary production and landfill emissions.

Reclaimed building materials

Cradle-to-gate LCI for reclaimed wood begins with extracting installed material from a building (the raw material) and transporting the material to storage and processing if necessary (product refurbishing) and transporting the final product to the construction site (the use phase). This cradle-to-gate analysis included everything within the "system boundary" that covers raw material extraction and product manufacturing (refurbishing) with the associated transportation but does not include the use phase. However, unit processes upstream of extraction such as storage of reclaimed material were not included in this analysis. Narrowing the scope of this project allowed for the proper comparison on reclaiming and new manufacturing of building materials. In addition, LCI data on storing virgin material were not available. Figure 3 shows the boundary conditions that correspond to both reclaimed framing lumber and solid strip hardwood flooring.

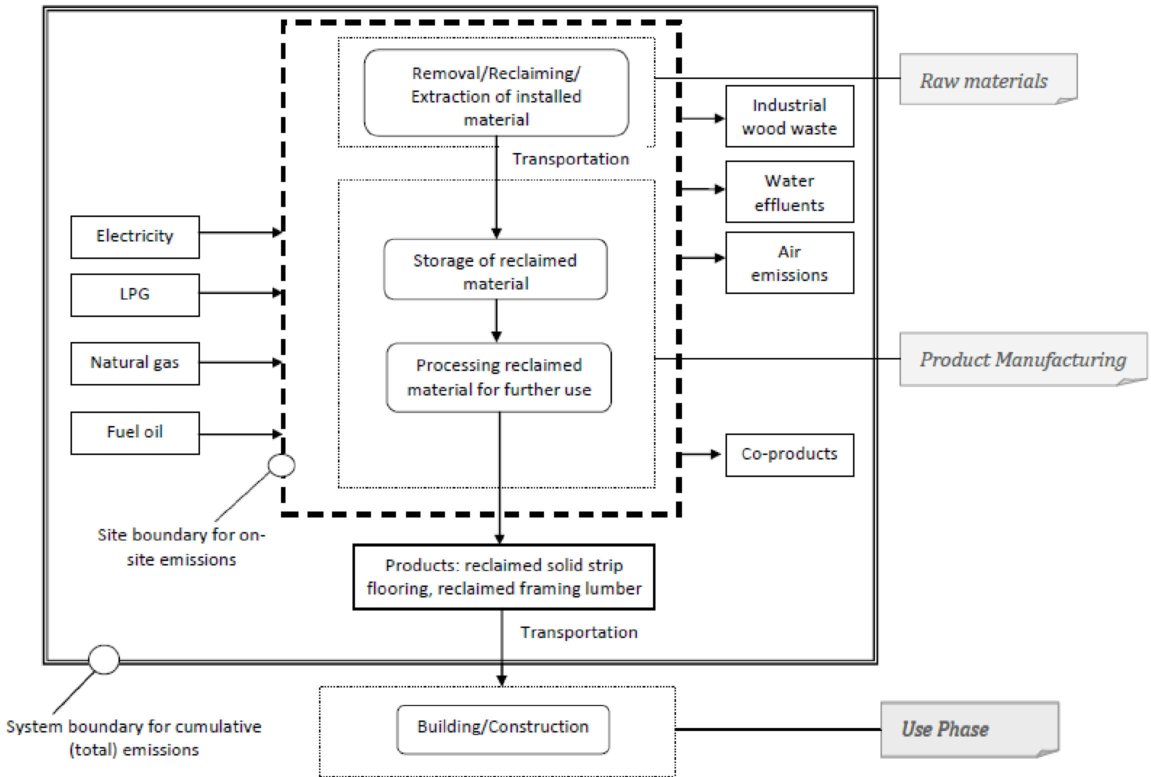

Figure 3. System boundaries for reclaimed framing lumber and solid strip hardwood flooring

Deconstruction (extraction of reclaimed material)

This unit process begins with installed solid strip hardwood flooring (non-structural deconstruction) and framing lumber (structural deconstruction) and includes the following operations:

Non-structural deconstruction

- Transporting workers to the deconstruction site
- Removing any furniture or other materials such as moulding that would interfere with the removal of the flooring
- Removing the flooring board by board
- Denailing the flooring, either by hand or nail kicker
- Loading the flooring onto trucks, either by hand or with equipment
- Transporting the wood flooring to a storage facility

Structural deconstruction

- Transporting workers to the deconstruction site
- Transporting forklifts, bobcats, or other energy-consuming equipment to the jobsite

- Removing surface materials such as roofing, drywall, subfloors, and insulation that would interfere with removal of framing lumber
- Removing actual framing
- Denailing framing, either by hand or nail kicker
- Loading framing onto trucks, either by hand or with equipment
- Transporting framing to a storage facility

Inputs include transportation fuel for worker vehicles and for material, fuel to run generators providing on-site electricity and/or grid electricity for tools to remove flooring and framing lumber, and fuel to run heavy equipment used for structural deconstruction. Outputs include reclaimed framing lumber and reclaimed wood flooring. Emissions include solid (wood) waste produced during the removal process (assumed to be 10% of installed product), air emissions from grid electricity, on-site generators, and other equipment, and non-wood waste such as nails and drywall.

Results and Conclusions

The following tables provided summarized life-cycle data for cumulative cradle-to-gate energy and emissions generated from SimaPro modeling of reclaimed building materials and their virgin alternatives. LCI data came from the virgin alternatives manufactured in the Pacific Northwest (PNW) and the Southeast (SE) (NREL 2010). The total energy required to produce 1-m^3 framing lumber from virgin wood materials is about 11 times on average greater than the energy required to reclaim materials from a deconstruction site (Table 1).

Table 1. Cradle-to-gate cumulative energy requirements by fuel source allocated to 1m^3 lumber

Planed dry softwood lumber					Reclaimed framing lumber		
	PNW		SE			Removal	
	MJ/m^3	%	MJ/m^3	%		MJ/m^3	%
Coal	92	2.5	356	10.2	Coal	120	35.1
Crude oil	361	9.7	337	9.7	Crude oil	141	41.4
Natural gas	1447	39.1	279	8.0	Natural gas	38	11.3
Uranium	7	0.2	35	1.0	Uranium	41	12.2
Biomass	1595	43.0	2473	70.8	Biomass	0.00	0.0
Hydropower	200	5.4	4	0.1	Hydropower	0.00	0.0
Electricity, other	3	0.1	8	0.2	Electricity, other	0.00	0.0
Total	3705	100	3492	100	Total	340	100

The percentage of difference for fossil carbon dioxide (CO_2) emissions to air for manufacturing 1 m^3 of new framing lumber is 310% higher on average compared to reclaiming framing lumber from a deconstructed building (Table 2).

Table 2. Cradle-to-gate cumulative air emissions to air allocated to 1-m^3 lumber

Planed dry softwood lumber					Reclaimed framing lumber		
	PNW		SE			Removal	Difference
	kg/m^3	%	kg/m^3	%		kg/m^3	(%)
CO	1.43	0.6	1.83	0.6	CO	0.5	230
CO_2 (biomass)	160	62.6	248	79.1	CO_2 (biomass)	1.9	11000
CO_2 (fossil)	92	36.0	62	19.8	CO_2 (fossil)	18.9	310
HAPS	0.01	0.0	0.01	0.0	HAPS	–	–
CH_4	0.19	0.1	0.1	0.0	CH_4	0.3	–52
Nitrogen oxides	0.67	0.3	0.64	0.2	Nitrogen oxides	0.2	230
Particulates	0.05	0.0	0.05	0.0	Particulates	<0.1	–
SO_2	1.03	0.4	0.43	0.1	SO_2	0.1	630
VOCs	0.08	0.0	0.49	0.2	VOCs	<0.1	–

The total energy required to produce 1 m^3 of wood flooring from virgin wood materials is about 13 times the energy required to use reclaimed flooring (Table 3). The percentage difference for fossil CO_2 emissions to air for manufacturing 1-m^3 wood flooring from virgin wood materials is 470% higher on average compared to reclaiming wood flooring from a deconstructed building (Table 4). Global Warming Potential for virgin framing lumber and wood flooring was about 3 and 5 times greater, respectively, than their reclaimed material counterparts. These results do not include biomass CO_2. In this study, biomass CO_2 is emitted from burning woody biomass for energy to dry wood during virgin wood product manufacturing. Including the biomass CO_2, the GWP ratio increased to 10 and 16 times, respectively. However, burning biomass for energy does not contribute to increasing atmospheric CO_2, provided forests are regrowing and reabsorbing the emitted CO_2.

Table 3. Cradle-to-gate cumulative energy requirements by fuel source allocated to 1-m^3 flooring

Solid strip hardwood flooring			Reclaimed wood flooring		
	Eastern US			Removal	
	MJ/m^3	%		MJ/m^3	%
Coal	748	11.1	Coal	157	31
Crude oil	768	11.4	Crude oil	245	48
Natural gas	934	13.9	Natural gas	53	10
Uranium	48	0.7	Uranium	54	11
Biomass	4195	62.5	Biomass	0	0.0
Hydropower	9	0.1	Hydropower	0	0.0
Electricity, other	7	0.1	Electricity, other	0	0.0
Total	6709	100	Total	509	100

Table 4. Cradle-to-gate cumulative air emissions allocated to 1-m^3 flooring

Solid strip hardwood flooring			Reclaimed wood flooring		
	Eastern US		Removal		Difference
	kg/m^3	%		kg/m^3	(%)
CO	3.49	0.58	CO	0.8	360
CO_2 (biomass)	431	71.44	CO_2 (biomass)	1.6	27,000
CO_2 (fossil)	164	27.18	CO_2 (fossil)	28.6	470
HAPS	0.02	0.00	HAPS	–	–
CH_4	0.25	0.04	CH_4	0.3	–17
Nitrogen oxides	1.44	0.24	Nitrogen oxides	–	–
NMVOC	0.38	0.06	NMVOC	<0.1	3,400
Particulates	0.2	0.03	Particulates	<0.1	1,600
SO_2	1.14	0.19	SO_2	0.1	1,000
VOCs	1.37	0.23	VOCs	<0.1	7,100

Reclaimed framing lumber and wood flooring have a significantly lower environmental impact than their two virgin alternatives. Significantly less fossil CO_2 was generated from reclaiming installed materials than producing the virgin materials. In addition, environmental burdens associated with storing and transporting the material to the construction site are expected to be higher for the virgin than the reclaimed material because buildings are diverse, whereas virgin wood manufacturing plants are centered. Therefore, we expect the GWP ratio to be similar once these life-cycle stages are included. In addition, although reclaimed wood materials emit significantly less GHGs than the virgin alternatives, the environmental performance of virgin wood is still better than non-wood building materials because of burning biomass for energy during manufacture of new wood products.

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