Life Cycle Primary Energy and Carbon Analysis of Recovering Softwood Framing Lumber and Hardwood Flooring for Reuse

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Abstract

Recovering wood for reuse in a new house affects energy and greenhouse gas emissions. This paper finds the energy and emissions for recovering softwood framing lumber and hardwood flooring from an old house for installation in a new house. Recovering wood displaces primary production of new wood products and avoids the end-of-life (EOL) burdens for the old house. We used a cradle-to-gate life cycle analysis and examined the EOL burdens for the wood products when disposed of including the effect of biogenic CO2. Results showed that recovering softwood framing lumber and hardwood flooring for reuse consumed 320 and 761 MJ/m^3 while displacing primary production energy of 6,467 and 7,763 MJ/m^3, respectively. Burning wood for energy at EOL avoided coal power production. GWP increased by two to four times when including biogenic CO2. Recovering softwood framing lumber and hardwood flooring for reuse displaced a considerable amount of primary production energy.

Keywords: energy, carbon, life cycle, recovered wood products, end-of-life

Introduction

The role of carbon emissions in global climate change and its projected negative impact on ecosystem sustainability and the general health of our planet have never been more elevated in the public's consciousness.

Within the green building and sustainable construction fields, there is a growing movement to recover and reuse building materials in lieu of demolition and landfill disposal. In 2003 (latest figures), the United States produced about 164 million metric tons of construction and demolition (C&D) waste from building-related activities (EPA, 2009, 2011a). Of this, about 69 million metric tons comes from residential construction (primarily wood-framed). Because wood makes up about 25% to 40% of a C&D landfill (EPA, 1995; NWMOA, 2009), a significant amount of reusable wood building materials can potentially be diverted and reused. Not surprisingly, many end-of-life (EOL) studies indicate that increasing the reuse and recycling of C&D materials results in corresponding lower levels of landfilling. Additionally, reuse and recycling lowers the need for new product production, thus lowering overall energy consumption and environmental impacts (Blengini, 2009, Smith et al., 2001; Ericksson et al., 2005; 2005; Thorneloe et al., 2007). Recycling and reuse have different environmental impacts depending on types of materials recycled and reused, transportation distances, and the remanufacturing processes (Thorneloe et al., 2007).

Building materials reuse has several benefits, including reducing carbon footprint, conserving resources, extending landfill life, and minimizing pollution (Smith et al., 2001; Falk, 2002; Ericksson et al., 2005; Olofsson et al., 2005; Thorneloe et al., 2007). In spite of these benefits, there is currently no easy way to quantify the environmental impact of incorporating recovered wood building materials in new construction. However, life-cycle research can play an important role by examining various EOL scenarios for their environmental trade-offs (Borghi et al., 2009).

A previous study (Bergman et al., 2010) developed cradle-to-gate life cycle inventory (LCI) data for two recovered wood products—softwood framing lumber and hardwood flooring—and compared these data with corresponding cradle-to-gate LCI data of their new wood product counterparts (Puettmann and Wilson, 2005; Puettmann et al., 2010). The new wood products consumed more energy and emitted more greenhouse gases than did the recovered wood products. However, no EOL effects were included.

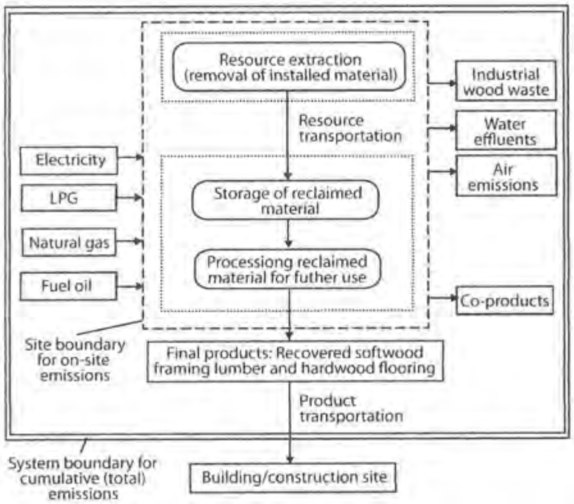
The objective of this study was to fmd the life cycle energy and emissions for recovering softwood framing lumber and hardwood flooring from an old house for installation in a new house. Recovering wood displaces primary production of new wood products and avoids the EOL burdens for the old house. Primary production includes harvesting (i.e. resource extraction), resource transportation, primary product production, and product transportation. The EOL burdens include demolition, waste transport, and processing of waste wood whether burning it for energy, mulching, or C&D landfilling.

Method

The scope of the study was to calculate energy consumption and associated carbon emissions of recovered wood products for reuse in the United States by using a life cycle assessment framework. When assigning emissions to wood products and waste created when producing new products, we chose mass allocation because the highest volume product had the highest economic value. We collected primary (annual production) data on the residential sector from 13 deconstruction companies spread across the United States in 2009 and used production weight-averaged data to estimate the emissions. Carbon sequestration was not included in the study.

Cradle-to-gate LCI for recovered wood begins with extracting the installed material (the raw material) from a building and transporting the recovered 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 **(Figure 1).**

Figure 1 System boundaries for recovered framing lumber and solid strip wood flooring



For recovered wood, transportation from storage facility to construction site was based on secondary data collected from secondary sources and expert opinion with the underlying assumption that recovered material was reused locally. Because most deconstruction and building materials reuse is a local enterprise, we assumed the recovered materials traveled no further than 25 miles (40 km) from extraction (deconstruction site) to retail location.

Figure 2 highlights the system boundaries for a cradle-to-gate LCA for new framing lumber and hardwood flooring (Puettmann and Wilson 2005, Puettmann et al. 2010). System boundary includes resource extraction, resource transportation, primary product production, and product transportation. For reference in the rest of the paper, the wording "primary product production" will include the other processes listed above.

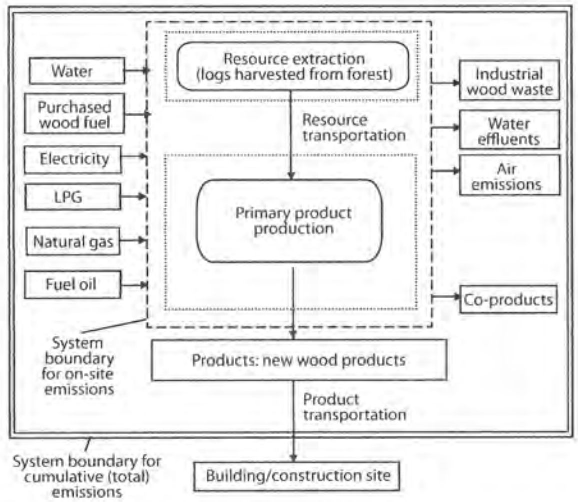


Figure 2 System boundaries for new framing lumber and solid strip wood flooring

We assumed that the wood products were transported from the manufacturing site to a wholesale location. Because wood products production is regionally located in the US, we assumed an average distance of travel from manufacturer to wholesaler based on data from USDOT (2010) for framing lumber (NAICS 321) and solid strip wood flooring (NAICS 337). Table 1 shows the various transportation data for moving the final product from the gate to wholesaler to the construction site. We assumed 15 miles (24 kin) from wholesaler to construction site.

Table 1 Virgin wood product transportation data

	Softwood framing lumber (tkm/m^3)	Hardwood flooring (tkm/m^3)
Gate to wholesaler[1]	202	753
Gate toPRéolesaler[2]	83	3
Wholesaler to site[1]	12	16

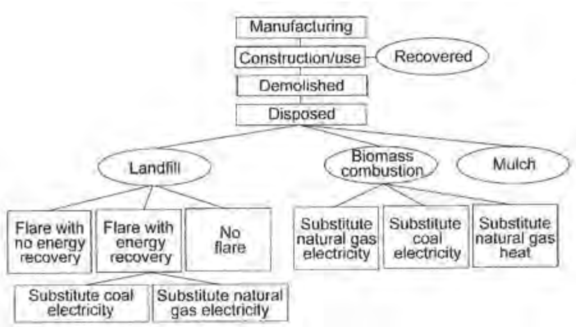
[1] by diesel truck
[2] by rail

We estimated the Global Warming Potential (GWP) in kg CO2-equivalent using the IPCC 2007 100a Method (PRe Consultants, 2011).

Biogenic CO2, a part of the natural carbon cycle, is not typically considered in calculating GWP. However, new wood production burns wood waste (i.e. mill residue), a by-product of making new wood products, thus emitting biogenic CO2. We will calculate GWP with and without biogenic CO2. LCI flows provided the necessary information to calculate cumulative energy.

Figure 3 indicates some of the possible EOL scenarios for wood materials. To evaluate the consequence of not reusing a wood material and making new wood products or recovering wood for reuse, we analyzed the environmental consequence of several EOL alternatives to reuse according to ISO 14040 and 14044 standards (ISO, 2006a, **b).**

Figure 3: End-of-life options for wood materials



In this study, the fossil fuels were replaced by wood fuel whenever possible. We replaced bituminous coal burned for electricity with the wood not recovered for reuse because coal is used to generate the most power in the United States. A sensitivity analysis on other fossil fuels will be done in the future for comparison. Because landfill gas (LFG) after removing the CO2 has properties similar to those of natural gas, the resultant methane would be a good replacement for natural gas. In addition, as of July 2011, about 25% of municipal solid waste (MSW) landfills had operational LFG projects (EPA, 2011b). In addition, two-thirds of the LFG projects generate electricity.

We examined the wood waste generated during the recovery process for various scenarios. We estimated roughly 30% of C&D wood is burned for energy recovery, approximately 11.2 million tons out of 39.4 million tons of building-related C&D wood (McKeever, 2004; EPA, 2011a). According to the EPA (2010b), C&D landfills do not capture methane, in contrast to MSW landfills. For the wood not recovered for reuse, we selected burning the wood for fossil fuel substitution (30%), grinding wood waste into mulch (10%), and landfilling the wood waste without methane capture (60%) according to standard U.S. practices (Salazar and Meil, 2009; Kaplan et al., 2009; EPA, 2011a). Wood loss during the recovery process was sent to a MSW landfill with methane capture and energy recovery to replace natural gas. This study did not examine treated wood.

Results and Discussion

The following tables show summarized life-cycle data for the different life cycle stages on energy and emissions generated from SimaPro modeling **Table 2** provides cradle-to-gate LCI data on recovered softwood framing lumber and hardwood flooring that include product transportation to construction site. Recovered softwood framing lumber and hardwood flooring consumes 320 and 761 MJ/m^3, respectively. Crude oil was the largest energy component due mostly to resource and product transportation with values of 262 and 476 MJ/m^3, respectively.

Table 2 Cradle-to-gate cumulative energy requirements by fuel source allocated to 1 m^3 recovered wood products

	Softwood framing lumber		Hardwood flooring	
	MJ/m^3		MJ/m^3	
Coal	141	44	235	31
Crude oil	262	82	476	63
Natural gas	-131	-41	-28	-4
Uranium	42	13	70	9
Biomass	0	0	0	0
Hydropower	5	2	7	1
Total	320	100	761	100

In addition, wood lost when recovering wood products for reuse has an effect. We estimated wood lost during removal at 17% and 11% for recovered framing lumber and wood flooring, respectively. The lost material was sent to a MSW facility that captured methane for energy recovery. As shown in **Table 2,** for softwood framing lumber, the avoided natural gas (-131 MJ) offset the coal burned for power (141 MJ) almost one to one. However, recovered flooring had a smaller effect because the material was primarily stored in a closed, natural gas-heated building thus consumed more energy and less flooring was lost during recovery.

Table 3 provides cradle-to-gate LCI data on new softwood framing lumber and hardwood flooring that include product transportation. New softwood framing lumber and hardwood flooring consumes 6,467 and 7,763 MJ/m^3, respectively. At least 50% of the energy for new wood products comes from woody biomass whereas no biomass was consumed for the recovered wood products.

Table 3 Cradle-to-gate cumulative energy requirements by fuel source allocated to 1m^3 new wood products

	Softwood framing lumber		Hardwood flooring	
	MJ/m^3		MJ/m^3	
Coal	467	7	817	11
Crude oil	845	13	2001	26
Natural gas	594	9	790	10
Uranium	161	2	270	3
Biomass	4367	68	3884	50
Hydropower	34	1	2	0
Total	6467	100	7763	100

Table 4 provides EOL LCI data on softwood framing lumber and hardwood flooring. The results represented the point at where the wood products were removed from the old house to the point where the wood waste had been processed for final disposition. The significance of the portion of wood that ended up as fuel substitute for coal power (30%) was shown by the negative value listed for coal, -3581 and -4534 M.1 for softwood framing lumber and hardwood flooring, respectively. In addition, roughly as much coal with respect to energy content was displaced as what was burned as mill residues to make the original product **(Table 3).**

Table 4 End-of-life cumulative energy requirements by fuel source allocated to 1m^3 wood products

	Softwood framing lumber		Hardwood flooring	
	MJ/m^3		MJ/m^3	%
Coal	-3581	-105	-4534	-106
Crude oil	94	3	172	4
Natural gas	27	1	36	1
Uranium	26	1	33	1
Biomass	0	0	0	0
Hydropower	4	0	5	0
Total	-3430	-100	-4288	**-100**

In this study, replacing coal power with the waste wood results in a negative overall energy consumption. Therefore, avoiding EOL burdens concerning energy is not a positive attribute for this scenario. This effect may not be as dramatic if other EOL scenarios were examined such as 100% C&D landfill without methane capture. Therefore, future work is necessary.

Reusing wood products for reuse displaces primary product production and avoids EOL burdens. In this study, recovered softwood framing and hardwood flooring consumes 320 and 761 MJ/m^3 (Table 2) while displacing 6,467 and 7,763 MJ/m^3 of primary product production **(Table 3)** and avoiding -3,430 and -4,288 MJ/m^3 **(Table 4),** respectively.

Tables 5, 6, and **7** provide the major GHG emissions for calculating the GWP. Most values are consistent table by table with hardwood flooring typically emitting more because of its higher density and requiring more energy for production. **Table 5** shows fossil CO2 emitted for softwood framing lumber at 28.5 kg/m^3 is less than hardwood flooring at 51.9 kg/m^3. Whereas, fossil CO2 in Table 6 was about four times as large for the two wood products. The negative values for fossil CO2 in Table 7 indicated the fuel substitution of coal by wood.

Table 5 Major GHG emissions for recovered wood

	Softwood framing lumber	**Hardwood** flooring
	kg/m^3	
Carbon dioxide, fossil	28.5	51.9
Methane	1.91	1.52
Dinitrogen oxide	4.13E-04	9.00E-04
Carbon dioxide, biogenic	99.3	76.1

Table 6 Major GHG emissions for new wood

	Softwood framing lumber	Hardwood flooring
	kg/m^3	
Carbon dioxide, fossil	110	229
Methane	0.28	0.42
Dinitrogen oxide	3.35E-03	2.90E-03
Carbon dioxide, biogenic	365	390

Table 7 Major GHG emissions at EOL

	Softwood framing lumber	Hardwood flooring
	kg/m^3	
Carbon dioxide, fossil	-246	-308
Methane	22	28
Dinitrogen oxide	2.72E-03	3.56E-03
Carbon dioxide, biogenic	399	505

We calculated GWP for **Table 8** primarily from the major GHG listed in **Tables 5, 6, and 7.**

Table 8 GWP for the various life cycle stages with and without biogenic CO_2

		GWP (kg CO2-e)	GWP (biogenic CO2) (kg CO2-e)
	SFL	76.4	176
Recovered	1-1F[2]	90.0	166
	SFL	118	483
New	HF	241	631
	SFL	304	703
EOL Burdens	HF	389	894

[1] SFL: softwood framing lumber
2 hardwood flooring

As shown by Table 8, GWP calculated with biogenic CO2 increased by two to four times more than when not considering biogenic CO2. Biogenic CO2 emitted for recovered wood products came from the waste wood breakinHF2 n in the MSW landfill as well as from the burning of methane produced from the waste wood.

The largest increase in GWP for the different life cycles examined came from new wood products. Most of the energy for producing new wood products came from on-site biomass (i.e. mill residues). Therefore, not burning mill residues for energy during manufacturing would result in a considerably worse GWP.

Conclusion and Recommendation

Recovering softwood framing lumber and hardwood flooring for reuse displaces a considerable amount of primary production energy usage and greenhouse gas emissions. However, what happens at EOL is not as direct because EOL energy was negative value while the carbon emissions were larger than the primary product production values. Because of the effect of replacing coal power with wood power, if the wood material was not able to be reused as is, recovering the wood for energy instead of sending to a C&D landfill without methane capture would help reduce fossil fuel usage. In addition, future work will examine regional effects because insufficient data were available.

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