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Life-Cycle Energy and GHG Emissions for New and Recovered Softwood Framing Lumber and Hardwood Flooring Considering End-of-Life Scenarios

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Abstract

Within the green building fields is a growing movement to recover and reuse building materials in lieu of demolition and land fill disposal. However, they lack life-cycle data to help quantify environmental impacts. This study quantifies the primary energy and greenhouse gas (GHG) emissions released from the production of wood recovered from an old house and from new wood harvested from the forest and produced in a sawmill with both products ending up installed in a new house. In addition, the study quantifies the primary energy and GHG emissions released if the recovered wood is not reused but instead is either burned to replace coal or natural gas to generate electricity, landfilled with or without landfill gas capture equipment, ground into mulch, or some combination.

Keywords: energy, carbon emissions, reuse, softwood framing lumber, hardwood flooring, life-cycle, life-cycle inventory, LCI, end-of-life, EOL

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Contents

Conversion Table

English unit	Conversion factor	SI unit
board feet	0.0023597	m^3 (nominal)
mile (m)	1.6093	kilometer (km)
British thermal unit (Btu)	0.00105506	megajoule (MJ)

Life-Cycle Energy and GHG Emissions for New and Recovered Softwood Framing Lumber and Hardwood Flooring Considering End-of-Life Scenarios

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Executive Summary

Within the green building and sustainable construction fields is a growing movement to recover and reuse building materials in lieu of demolition and landfill disposal. Building materials reuse has several benefits including reducing carbon footprint, conserving resources, extending landfill life, and minimizing pollution. Additionally, recovering building materials for reuse in construction typically provides greater economic benefits than any alternative use. Building professionals including architects, materials specifiers, and contractors are more interested in mitigating the environmental impact of the buildings they create. However, they lack life-cycle data that will help quantify the environmental impact of the building materials they specify as well as the project's overall impact, including contribution to global climate change.

The goal of this study was to use life-cycle assessment (LCA) to quantify greenhouse gas (GHG) emissions and primary energy use of new and reused wood products with additional information on end-of-life (EOL) options. At the end, we compare the impact on GHG emissions for two alternatives: reusing old wood in recovered products or discarding old wood with the attendant end-of-life emissions and making new products. We use existing life-cycle inventory (LCI) data and develop new LCI data from reusing two recovered wood products, softwood framing lumber and solid-strip hardwood flooring, production of new wood products, and disposal of old wood products. Life-cycle stages for new products include harvesting (i.e., resource extraction or deconstruction), resource transportation, primary product production, and product transportation. For reusing recovered wood, the environmental burdens associated with recovery include decay of waste wood generated, transportation, production, and product transportation. For disposal of old wood, the EOL burdens include demolition, waste transport, and processing of waste wood whether burning it to replace fossil fuels for generation of electricity, mulching it, or landfilling it.

This study involved two parts. The first developed life-cycle data for the two recovered wood products and compared these data with life-cycle data for their new wood product counterparts. LCI data for new products are from forest cradle to installation in a new building. LCI data for recovered products includes the deconstruction process through to installation in a new building. The second part estimates emissions for various EOL scenarios when old wood is discarded from old structures (i.e., burning to generate electricity, grinding for mulch, landfilling without methane capture, and other disposal options for wood removed from old buildings). The second part also compared GHG emissions for cases where old wood is reused for products to cases in which old wood is discarded to various EOL dispositions and new products are produced.

The LCI for recovered wood excluded the environmental impacts associated with the previous product production of those products. The processes that were excluded from the initial product system include raw material extraction, resource transportation, product manufacturing, product transportation, construction, and use. The focus of this analysis was on comparing impacts of making new products compared with making recovered wood products.

The study methodology followed ISO 14040 and 14044 guidelines. The present study used allocated emissions using

an economic screen and mass allocation to assign emissions to wood products and waste co-products. Emissions were allocated on the basis of mass to primary products and co-products if they each had some economic value (as is the case for new products). If the waste has no economic value, then all emissions are assigned to the primary products (as is the case for recovered/reused products). Primary (annual production) data for reused products were collected on the residential sector from 13 deconstruction companies spread across the United States in 2009. Using production weight-averaged survey data, our study estimated emissions per functional unit, which was 1 m^3 of final product at the construction site where the reused product was installed.

Evaluation of the emissions associated with discarding old wood products used a base case EOL scenario and five alternate scenarios. The base case approximates current practice and was comprised of burning the wood for energy to replace coal power (30%), grinding for mulch (10%), and disposal in a construction and demolition landfill (C&D) without methane capture (60%). In landfills, wood breaks down anaerobically into biogenic methane and biogenic carbon dioxide. C&D landfills, unlike municipal solid waste (MSW) landfills, typically do not have methane capture technology installed. Biogenic methane, a potent GHG if captured from landfills, avoids the necessity of producing natural gas, although not all biogenic CH_4 that is generated can be captured. In the present study, the captured landfill methane was burned to generate electricity to replace natural gas. The Global Warming Potential (GWP) for EOL GHG emissions was calculated using the International Panel on Climate Change (IPCC) 2007 100-year time horizon.

LCI data for recovered wood products includes cumulative cradle-to-gate energy use and emissions obtained from the survey of demolition/reuse businesses and from the U.S. LCI Database. Fossil energy used to recover softwood framing lumber and hardwood flooring was 418 and 859 MJ/m^3, respectively. Crude oil was the largest energy component due mostly to resource and product transportation with values of 178 and 437 MJ/m^3, respectively. No biomass energy was used to make recovered products.

Comparison of Processes to Make New Wood Products and Recovered Products

Fossil and biomass energy used to make new softwood framing lumber and hardwood flooring was 6,440 and 7,750 MJ/m^3, about 15 and 9 times, respectively, the amount used to make recovered wood products. One-half or more of the energy used to make new softwood framing lumber and hardwood flooring was from biomass: 4,360 and 3,880 MJ/m^3, respectively.

Of the life cycle stages examined for both new and recovered wood products, the highest energy consumed was associated with new wood product production. Most energy for new wood products came from burning of on-site biomass (i.e., mill residues) to generate thermal energy. Burning biomass such as mill residues emits biogenic CO_2.

Fossil CO_2 emitted for new framing lumber and new hardwood flooring were about four times greater than for recovered softwood framing lumber (109 vs 23.9 kg/m^3) and recovered hardwood flooring (228 vs 49.7 kg/m^3). Primary drivers for the higher fossil CO_2 emissions for new products were from new wood product production and transportation. New wood products typically travel much further to their markets, urban centers, than recovered wood products. Recovered wood products are primarily produced in urban centers and have low transportation environmental burdens. When biogenic CO_2 emissions are added to fossil emissions, the total new products' CO_2 emissions were 8 to 10 times the emissions for the recovered products.

When estimating GWP, it is standard protocol not to include biogenic CO_2 emissions, as they are assumed to be recovered by forest carbon sequestration over time. GWP without biogenic CO_2 emissions is lower for recovered wood products than for the new wood products. GWP without biogenic CO_2 emissions is also lower for recovered products if disposal of wood waste during deconstruction is not considered.

Energy and Emissions for Discarded Old Wood Products at Their End-of-Life

EOL scenarios for old wood products can result in large negative energy use and fossil CO_2 emissions if discarded wood is used to displace coal or natural gas in producing electric power. In the base case EOL scenario, where 30% of the discarded wood replaces coal power, the displaced coal energy consumption was –2,300 and –2,920 MJ/m^3 for the discarded softwood framing lumber and hardwood flooring, respectively. To put this into perspective, this negative energy amount would offset 53% (2,300/4,360) and 75% (2,920/3,880) of biomass energy consumed to make the new softwood framing lumber and hardwood flooring.

Five other EOL scenarios that examined various alternatives included 1) burning wood as a replacement for natural gas to generate electricity, 2) turning 100% wood waste into mulch, 3) disposing 100% to construction, and 4) demolition landfills with or 5) without methane capture and energy recovery into electricity. When 100% of wood replaces natural gas to generate electricity, energy use and GWP were also negative but less negative than when offsetting coal. All other EOL scenarios result in positive energy and GWP values.

For the base case EOL scenario (approximate current practice) where we assumed making new products would require discard of old wood to the current mix of proportions to energy, landfills, and mulch, the reuse of both softwood lumber and hardwood flooring produces less GWP than making new products. The GWP benefit is greatest for reusing hardwood flooring instead of making of new flooring.

This is true for GWP estimates that either exclude or include biogenic CO_2 emission. However, if we consider GWP that excludes biogenic CO_2 emissions (standard LCA practice), reuse could be notably worse (higher GWP) than new wood if all old wood could be burned to offset coal or natural gas in making electric power. Reuse could be slightly worse than new for softwood lumber if all old wood could be used as mulch (unlikely if wood is contaminated). So a key point is that if wood cannot be reused for products, the next best step is to keep it out of landfills and use it for either energy (top priority) or mulch (lower priority). There is a greater benefit from keeping hardwood out of landfills than keeping softwood out of landfills.

Introduction

The role of carbon emissions on global climate and the projected negative impact on ecosystem sustainability and the general health of our planet have never been more elevated in the public's consciousness. This awareness is particularly evident in the building construction field where *green building* concepts are becoming more prevalent. Green building is defined as the practice of increasing the efficiency with which buildings use resources—energy, water, and materials—while reducing building impacts on human health and the environment. This is done through better siting, design, material selection, construction, operation, maintenance, and removal throughout the complete building life cycle. Building professionals, including architects, materials specifiers, and contractors, are more interested in mitigating the environmental impact of the buildings they create. However, they lack life-cycle data that will help quantify the environmental impact of the building materials they specify and a given project's contribution to global climate change.

Within the green building and sustainable construction fields is a growing movement to recover and reuse building materials in lieu of demolition and landfill disposal. Building materials reuse has several benefits including reducing carbon footprint, conserving resources, extending landfill life, and minimizing pollution (Smith and others 2001, Falk 2002, Ericksson and others 2005, Heilmann and Winkler 2005, Olofsson and others 2005, Thorneloe and others 2007). In spite of these benefits, there is currently no easy way for building professionals to quantify the environmental impact of incorporating reused building materials in new building or remodeling construction.

The goal of this study was to use life-cycle analysis to quantify greenhouse gas (GHG) emissions and primary energy use of new and reused wood products with additional information on end-of-life (EOL) options or scenarios. Incorporating existing and developed life-cycle inventory (LCI) data, the environmental consequences of reusing two recovered wood products—softwood framing lumber and solid-strip hardwood flooring—relative to the virgin counterparts were evaluated. A study by Bergman and others (2010) developed cradle-to-gate LCI data for these two recovered wood products and compared these data with corresponding cradle-to-gate LCI data of their new wood product counterparts (Puettmann and Wilson 2005, Puettmann and others 2010). These studies found that the new wood products consumed more energy and emitted more GHGs than did the recovered wood products; however, those results considered neither product transportation for the new wood from the manufacturing facility to the construction site nor transportation of the recovered wood from the resale facility to the construction site.

The results presented here include new wood product transportation to the construction site. In addition, various EOL scenarios (i.e., burning for energy, grinding for mulch, and other disposal options) for the two wood products removed from old buildings were studied to evaluate the impact on global warming potential (GWP).

Background

The recovery and reuse of building materials from wood-framed building removal is becoming more widely recognized as a positive environmental alternative to demolition and landfilling. Using "deconstruction," or dismantlement, a building can be selectively dismantled and usable materials recovered for reuse in construction (Falk 2002, Falk and Guy 2007, Kibert 2003). This deconstruction and reuse strategy is consistent with resource conservation efforts, waste reduction, and green building certification programs. Examples of such programs are United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED), and the Green Globe Green Building Initiative (GBI).

Using conventional demolition, the wood-framed building is cleared from the site by the most expedient means possible, typically using a "track-hoe" or other heavy machinery to reduce the building to the smallest pieces possible for easy loading and transport to a construction and demolition (C&D) landfill. This process is by its nature destructive to the building materials and typically results in nearly all of the building ending up as unusable for reuse in new construction.

As for deconstruction, two approaches are typically used in salvaging building materials. At its simplest level, a nonstructural approach is taken (also known as "soft-stripping") and focuses on the recovery of easier to remove components, such as finish flooring, wall finishes, doors, windows, and other finish materials. A more involved approach, often called "full deconstruction," involves the dismantling of the structural components of a building. As a result, it is more time intensive. The material recovered typically includes roof, wall, and floor framing, sheathing, and other building frame components. Unusable wood material goes typically to a local C&D landfill.

Construction and Demolition Waste Management

In 2003 (latest figures), the United States produced about 164 million metric tons of C&D waste from building-related activities (EPA 2009a, 2012a). Of this, about 69 million metric tons comes from residential construction (primarily wood framed). Because wood contributes between 25% and 40% of a C&D landfill (EPA 1995, NWMOA 2009, Falk and McKeever 2012), potentially a significant amount of reusable wood building materials can be diverted and reused. Better materials management strategies for C&D waste would result in conservation of natural resources, reduced landfill requirements and associated pollution, and GHG emissions that result from such facilities. In the United States, landfills are the third largest source of methane behind intestinal fermentation and natural gas systems (EPA 2011).

Three recent events illustrate the importance of the need for such strategies:

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 (EO) 13514, Federal Leadership in Environmental, Energy, and Economic Performance).

3) A requirement for Federal agencies to set goals in the areas of energy efficiency, acquisition, renewable energy, toxics reductions, recycling, sustainable buildings, electronics managements, fleets, and water conservation (EO 13423 Strengthening Federal Environmental, Energy, and Transportation Management).

Not surprisingly, many studies indicate that increasing the reuse and recycling of C&D materials results in corresponding lower levels of landfilling. Additionally, this utilization lowers the need for new product production, lowering overall energy consumption and environmental impact (Blengini 2009, Smith and others 2001, Eriksson and others 2005, Heilmann and Winkler 2005, Sunberg and others 2004, Thorneloe and others 2007).

Reusing, or otherwise diverting, building materials fated for landfills can help reduce energy use and mitigate GHG emissions (e.g., biogenic methane) released from landfills (EPA 2011). Thorneloe and others (2007) indicates that for a typical U.S. landfill accumulating 437,000 tonnes/y with a recycling rate of 40% saved almost 8.44 million GJ (8,000 trillion (10^{12}) Btu (TBTU)) of energy compared to a recycling rate of 30%, which saved about 2.11 million GJ (2,000 TBTU) of energy. This effect seems counter-intuitive. Nevertheless, improving the recycling rate affects materials that may be more difficult to remove but require more energy to produce as new. As a result, higher recycling rates create higher energy savings per percentage increase.

Recycling and reuse have different environmental impacts depending on types of materials recycled and reused, transportation distances, and the remanufacturing processes (Thorneloe and others 2007). Life-cycle research can play an important role by examining various scenarios for their environmental trade-offs (Borghi and others 2009).

Life-Cycle Assessment

Life-cycle assessment (LCA) is comprised of four stages (phases) as defined by the International Organization for Standardization (ISO). These are 1) goal and scope definition, 2) inventory analysis, 3) impact assessment, and 4) interpretation (Fig. 1). A LCA study includes all stages but a LCI study does not include stage 3, the impact assessment (SAIC 2006, ISO 2006a,b).

LCA is a well-established method for evaluating the environmental impacts of processes and products. Among other attributes of environmental performance, LCA quantifies the carbon impact of products. Performing a unit process based LCA of a product is a detailed, data-intensive process. A LCA is composed of life-cycle stages. Life-cycle stages for building products include resource extraction, transportation, product manufacturing, construction, use, and final disposition (i.e., EOL) (Fig. 2).

Each life-cycle stage is evaluated by conducting LCIs. LCIs quantify the material and energy inputs as well as the environmental burdens within carefully defined system boundaries for a given product, process, or service in relation to a functional unit (ISO 2006a,b). 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). While LCAs have typically been

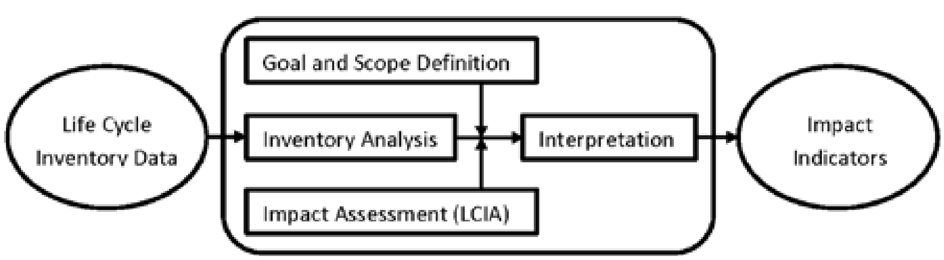

Figure 1. Life-cycle assessment phases.

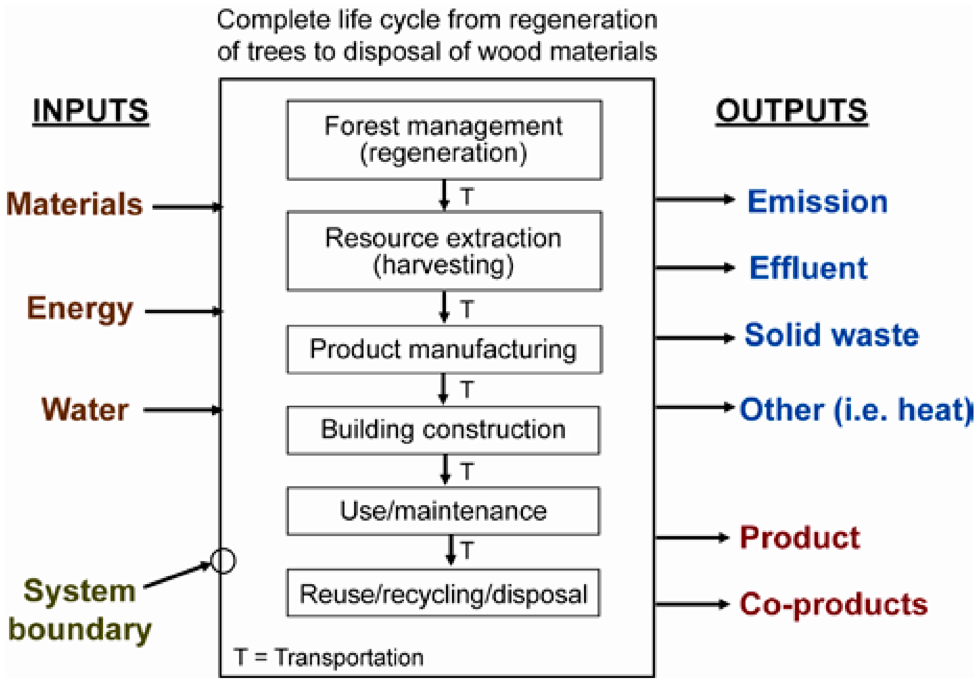

Figure 2. Complete life-cycle from regeneration of trees to disposal of wood materials (based on Fava and others (1994)).

used to evaluate the environmental impact of producing virgin materials, they can also be used to evaluate the environmental impacts of reusing recovered materials. For example, a study by Blengini (2009) indicated that the total energy and GHG emissions associated with the reuse of recovered building materials from a residential building shell located in Italy are 29% and 18%, respectively, of the environmental burdens of similar virgin materials.

Environmental Assessment Tools

Research on assessing the environmental impact of final product disposition for wood products draws on and must integrate diverse literature, available U.S. LCI data for virgin wood products, and analysis of various disposal scenarios.

For LCA practitioners, obtaining transparent and consistent U.S. LCI datasets on wood products was difficult until the mid-2000s. As part of an on-going effort, the National Renewable Energy Laboratory (NREL) working with LCA experts manages a publically available LCI database called the U.S. LCI Database. To aid in populating the U.S. LCI Database, the Consortium for Research on Renewable Industrial Materials (CORRIM) is developing critically reviewed LCI datasets on forestry and forest products for the U.S. LCI database (CORRIM 2010, USDA 2013).

In the various geographical regions of the United States, CORRIM has constructed cradle-to-gate LCI data based on individual gate-to-gate LCIs for many new wood products (Puettmann and Wilson 2005, Puettmann and others 2010). The U.S. LCI Database has become a repository of many wood building materials. Other environmental tools, such as the U.S. Environmental Protection Agency's (EPA) Waste Reduction Model (WARM) are available to evaluate materials for their carbon emissions and energy use.

Initial work on broad categories of waste disposal, including dimensional lumber, are being evaluated through WARM that was developed using a streamlined LCA approach (EPA 2012b). WARM's streamlined LCA is limited to an inventory of GHG emissions, carbon sinks, and energy impacts. The model does not evaluate human health impacts or air, water, or other environmental burdens that do not have a direct impact on climate change. In addition, WARM simplifies the determination of emissions from life-cycle stages that occur before a material reaches its end-of-life (EPA 2010). WARM calculates GHG emissions and energy benefits of baseline and alternative waste management practices. Another LCA tool for building products, the ATHENA Impact Estimator (IE, Athena 2012), includes evaluation of several LCA impact categories including primary energy consumption, air pollution index, water pollution index, and GWP.

Napier and others (2007) used both the WARM and ATHENA IE tools in a study to evaluate the GHG impact of recovering wood products from deconstructed military facilities. Results were limited to the effects of diverting materials from landfills and did not include end-of-life effects. Results indicated that 15,000 tonnes of recovered dimensional lumber that was reused instead of being landfilled reduced carbon emissions by 3,257 tonnes of CO_2 equivalents and reduces energy use by approximately 8,750 GJ. As for the ATEHNA IE, results did indicate significant reduction for all six impact categories when recovering framing lumber for reuse. These results suggested that a comparative assessment of the environmental impacts of substituting recovered wood for new wood building material in construction could be made. This could include not only GHG effects of the manufacturing process and transportation but EOL effects as well.

Methodology

The first step in this study was to develop cradle-to-gate unit process life-cycle data for the two recovered wood products and compare these data with cradle-to-gate life-cycle data of their new wood product counterparts. No burdens of the previous life for the recovered wood products were assigned. For recovered wood, the old building from which the lumber was recovered was the cradle, whereas the forest was the cradle for new wood products. Therefore, the location from where the wood products are extracted is a critical distinction between products because the old building from which reused wood was removed was once built with new wood harvested from forests. To further emphasize that the LCI data developed was modular in nature, this study assigned impacts to each product as they happened, not for any future impacts. The gate is defined as the installation at the construction site for both new wood and recovered wood. For recovered wood products, a transportation distance of 25 miles was assumed between the deconstruction site and the resale facility. For new wood products, data from the United States Department of Transportation (USDOT) were used to calculate an average transportation distance from a manufacturing facility to a local wholesale facility. For both new products, the transportation from the sale facility to the construction site was assumed to be 24 km (15 miles).

The second part of this study evaluated various EOL scenarios of old wood products discarded from old buildings (i.e., burning to generate electricity, grinding for mulch, and other disposal options) and their environmental impacts.

Emission profiles per functional unit of products were estimated using SimaPro 7 modeling software. Input data averages from the survey of demolition and recovery businesses were production weighted and additional secondary data used from U.S. LCI Database (PRé Consultants 2013, USDA 2013). The modeling software provided a list of raw materials consumed during the cradle-to-gate production (i.e., LCI flows) that was used to calculate cumulative (primary) energy consumption. The study estimated the GWP in kg CO_2 equivalent using the IPCC 2007 100-year Method (PRé Consultants 2013, IPCC 2007). Calculating values for GWP typically does not include biogenic CO_2 emissions, as they are part of the natural carbon cycle and thus are excluded as standard LCA practice. However, new wood production burns wood waste (i.e., mill residue), a byproduct of making new wood products, thus emitting biogenic CO_2. Therefore, GWP with and without biogenic CO_2 was calculated to provide insight on overall CO_2 emissions in relation to new and recovered wood products.

Part 1—Cradle-to-Gate LCIs

New Softwood Framing Lumber and Hardwood Flooring

An analysis of the energy consumption and associated emissions of new wood products was made by using the LCA framework from cradle-to-gate and existing information from the U.S. LCI Database and other resources. The two products were evaluated for their environmental impact from harvesting through manufacturing to product transportation to the construction site.

Figure 3 highlights the system boundaries for a cradle-to-gate LCI for new framing lumber and hardwood flooring, respectively. Within each system boundary, the individual unit processes were identified for greater transparency and identifying environmental “hot spots.” Unit processes for producing softwood framing lumber include log yard, sawing, drying, and planing operations (Milota and others 2005, Bergman and Bowe 2010).

Assumptions of this analysis include that new wood material transport from the manufacturing site to a wholesale location occurs by rail and truck. Because wood products production is regionally located in the United States, and new lumber must be transported long distances to local markets, an average distance of travel from manufacturer to wholesaler based on data from USDOT (2010) for softwood framing lumber (NAICS 321) and hardwood flooring (NAICS 337) was calculated. Table 1 shows transportation data for moving the new product from the manufacturing site to wholesaler to the construction site. For product transportation, we assumed a distance of 24 km (15 miles) from wholesaler to construction site for the new lumber and the same distance for moving the recovered wood products from the resale facility to the construction site.

Recovered Softwood Framing Lumber and Hardwood Flooring

An analysis analogous to the new wood products was performed for the recovered products, however, because LCI information did not exist for the recovery process, a survey of the deconstruction industry was performed to collect necessary primary data (Appendix 1—Survey Instrument). The resultant survey data were weight-averaged before entering into the LCA modeling software for estimating the emission profile and raw material usage for the recovered material deconstruction process.

Figure 4 shows system boundaries for recovered softwood framing lumber and hardwood flooring cradle-to-gate LCI.

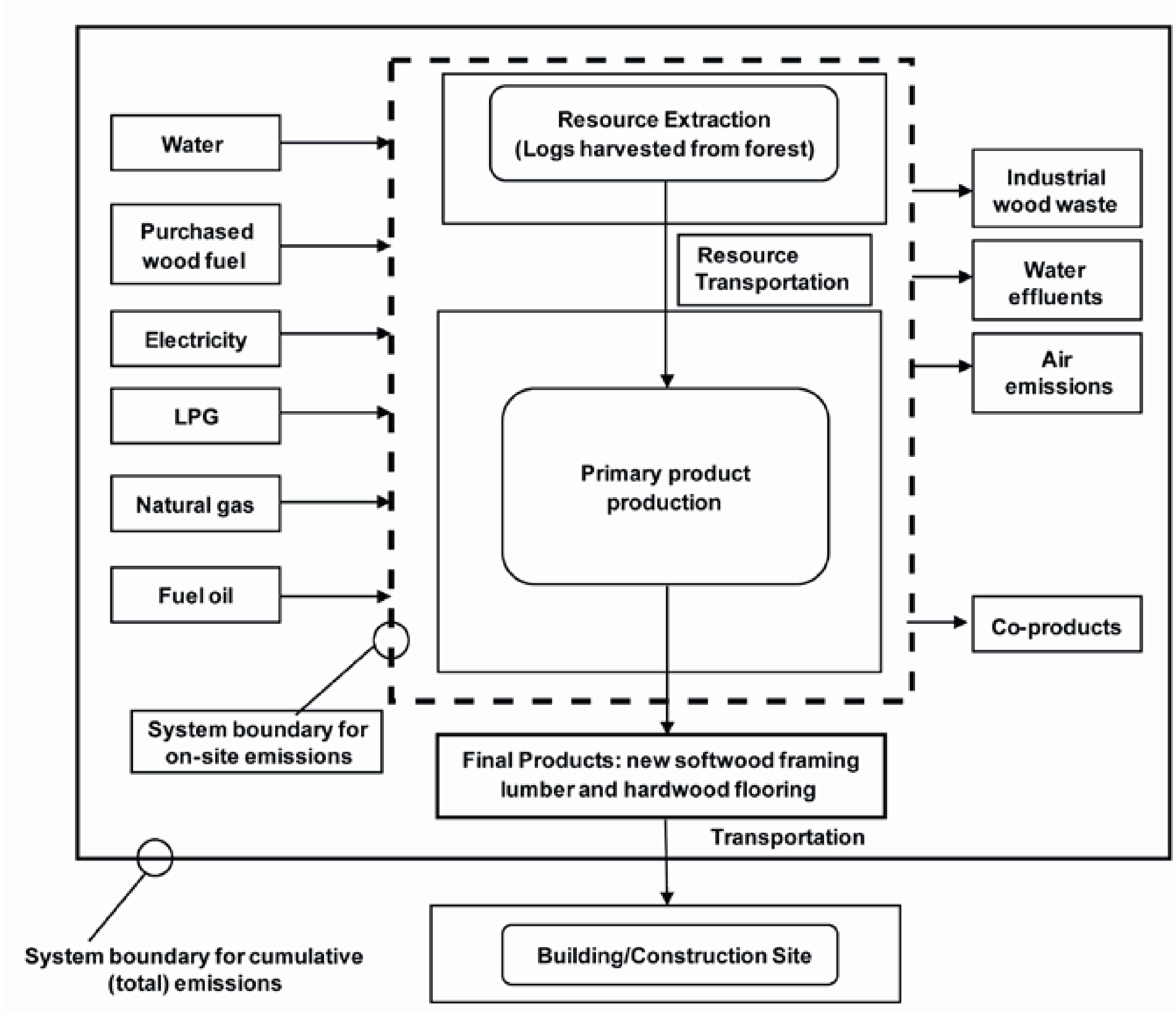

Figure 3. Cradle-to-gate system boundaries for new softwood framing lumber and hardwood flooring.

The process begins with extraction of the installed material (the raw material) from a building (i.e., the cradle), and includes transportation of the recovered material to storage and processing if necessary (product refurbishing) as well as transportation of the final product to the construction site (i.e., the gate). This cradle-to-gate analysis included everything within the "system boundary" that covers raw material extraction and product manufacturing (refurbishing) with the associated transportation up to but not including the use phase. Unit processes upstream of extraction such as storage of the recovered material were included in this analysis and the storage LCI data were the same for storing new material.

For recovered wood, survey data provided the basis for transporting the material from storage facility to construction site along with secondary sources (see Table 11 for new wood products) and expert opinion assuming recovered material reused locally. Surveying 13 U.S. building deconstruction companies that regularly recover lumber and wood flooring provided the primary (2009 annual production) data. LCA modeling software using weight-averaged production data along with secondary data from the U.S. LCI Database estimated emissions and raw material usage. Survey data included information as a basis for calculating materials transportation from extraction (deconstruction site) to resale location. The distance from resale location to construction site was assumed to be the same as for new wood products. In addition, because the deconstruction process generated wood waste, estimated material lost were 17% and 11% for softwood framing lumber and hardwood flooring, respectively. The deconstruction wood waste (i.e., unusable wood) was transported to a C&D landfill with no methane capture.

Many laboratory and field studies have focused on decomposition of wood (i.e., biomass) disposed in a landfill.

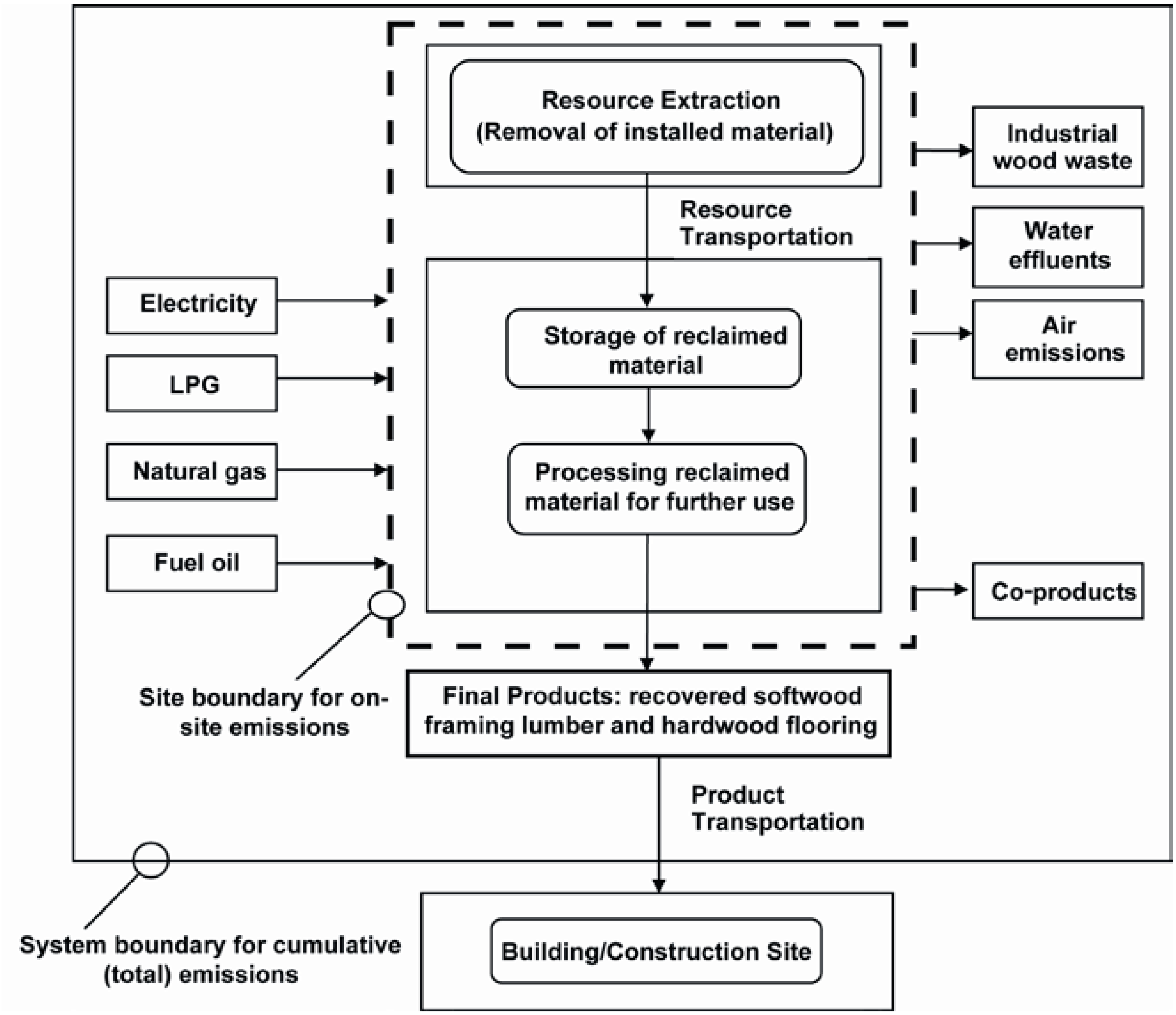

Figure 4. System boundaries for recovered framing lumber and hardwood flooring.

The question pertains to what percentage of wood actually breaks down to generate biogenic CO_2 and biogenic CH_4. The IPCC (2006) recommends a carbon loss for wood products of 0.5 in a landfill. Wang and others (2011) reported a range of 0%–19.9% wood decomposition for a laboratory study conducted on solid wood and engineered wood products. An Australian study (Ximenes and others 2008) indicated that after 46 years, hardwoods and softwoods under different waste management schemes lose on average about 18% and 17%, respectively, of their original carbon content. A study by Skog (2008) states an average 23% carbon loss for wood products disposed of in the landfill and is the basis for this study. A portion (23%) of this waste wood was assumed to decompose anaerobically (in the absence of oxygen) and be released as landfill gas in the LCI analysis whereas the remaining wood remained in the landfill as is. This study assumed that both types of landfills examined (MSW and C&D) passed through the four typical phases of a landfill over time but spent the vast majority of time in phase IV where biogenic methane and biogenic carbon dioxide are produced. Anaerobic conditions prevent the full decomposition of wood, unlike aerobic conditions. Wood material completely breaks down in aerobic conditions such as the forest floor and generates biogenic carbon dioxide and water as a result (ATSDR 2001, Staley and Barlaz 2009)). Future work will evaluate this phenomenon. In addition, we assumed that landfills captured the biogenic methane during decomposition and avoided natural gas production on 1:1 energy basis and was used to generate electricity. Biogenic methane is a GHG included in calculating GWP because it is human-made.

Deconstruction (extraction of recovered materials)—This unit process begins with installed softwood framing lumber (structural deconstruction) and installed hardwood flooring

Table 1. New wood product transportation data

	Wood products[a]			
	Softwood framing lumber		Hardwood flooring	
Transportation	tkm/m^3 [b]	tm/Mbf[c]	tkm/m^3 [b]	tm/Mbf[c]
Gate to wholesaler, by diesel truck	233	258	813	1,314
Gate to wholesaler, by rail	96	107	4	6
Wholesaler to construction site, by diesel truck	14	16	17	26

[a]Softwood framing lumber and solid strip hardwood flooring are 1.63 and 2.36 m^3/thousand board feet (Mbf), respectively.

[b]tkm/m^3 is tonne-kilometer per cubic meter of wood.

[c]tm/Mbf is ton-mile per thousand board feet of wood.

Figure 5. Hardwood flooring boards being removed during deconstruction.

(non-structural deconstruction) and includes the following operations:

Recovered softwood framing lumber unit processes

- Transporting workers to the deconstruction site.
- Transporting forklifts, bobcats, or other energy-consuming equipment to the jobsite.
- Removing surface materials such as roofing, drywall, subflooring, and insulation that would interfere with removal of framing lumber, either by hand or with machinery.
- Removing actual framing.
- Denailing framing, either by hand or pneumatic tool (i.e., denailer).
- Loading framing onto trucks, either by hand or with equipment.
- Transporting framing to a storage facility (i.e., resale facility).
- Unloading and storing the material until sold.

Recovered solid-strip hardwood flooring unit processes

- Transporting workers to the deconstruction site.
- Removing any furniture or other materials such as moulding that would interfere with the removal of the flooring.
- Sawing floor to ease removal.
- Removing the wood flooring board by board (Fig. 5)
- Denailing the flooring, either by hand or pneumatic tool (i.e., denailer).
- Loading the wood flooring onto trucks, either by hand or with equipment.
- Transporting the wood flooring to a retail facility.
- Unloading and storing the material until sold

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 framing lumber and flooring, and fuel to run heavy equipment used for structural deconstruction and unloading material at storage facility. Outputs include recovered softwood framing lumber and recovered hardwood flooring. Emissions include solid (wood) waste produced during the removal process, air emissions from grid electricity, on-site generators, and other equipment, and non-wood waste such as nails and drywall. Solid waste was transported to a C&D landfill.

Part 2—End-of-Life Scenarios

Various EOL strategies were also evaluated to assign the environmental burdens for cases where wood is not reused. EOL scenarios included burning wood for electric power production (decreases fossil emissions), grinding for mulch, and landfilling (without or with methane capture for energy production). A base-case scenario assumed that 30% of the wood not reused would be burned to replace coal to generate electricity, 10% would be ground for mulch, and the remaining 60% would be disposed of in a C&D landfill without methane capture. Additional scenarios were evaluated that extend the work done by Bergman and others (2012) and Winistorfor and others (2005).

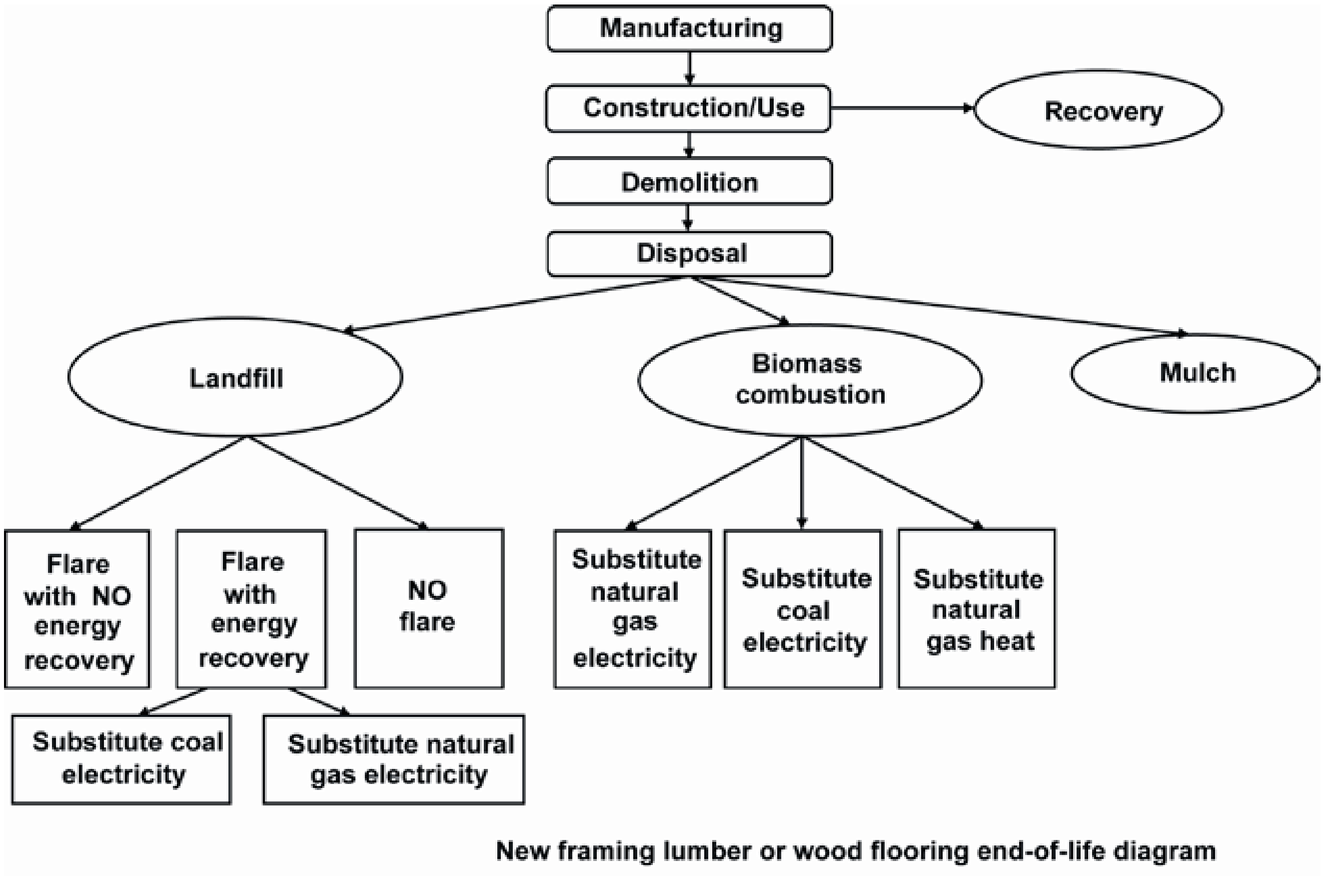

Figure 6. End-of-life disposal options for recovered wood materials.

Figure 6 indicates expected EOL scenarios for wood materials (Bergman and others 2012). Equations that estimate landfill emissions of biogenic CH_4 and biogenic CO_2 from anaerobic decomposition of wood are provided in Appendix 2—Landfill Equations.

The base case was comprised of burning the wood for coal power substitution (30%), grinding the wood into mulch (10%), and landfilling the wood without methane capture (60%). This distribution of wood to energy and landfills is in line with recent U.S. practices (Salazar and Meil 2009, Kaplan and others 2009, EPA 2011). Roughly 30% of C&D wood is burned for energy recovery: 11.2 million tons out of 39.4 million tons (EPA 2009c, EPA 2012b). C&D landfills contain much more wood than a MSW landfill on a volume basis (25% to 40% vs 6%), according to the EPA (2011). In addition, methane is not captured in C&D landfills. In alternate scenarios, we considered biogenic methane captured from C&D landfills and burning it to generate electricity to replace natural gas. Table 2 shows the base case scenario and the five alternatives scenarios.

Analysis Considerations

Reuse—This study evaluated the direct effects of reusing recovered wood products. Sathre and Gustavsson (2006) conducted a somewhat broader study that evaluated energy and carbon from a series of cascading uses where cascading wood is the sequential use (i.e., reuse) for different purposes and assumed that wood quality declines over time. In the present study, no decline in wood quality was assumed. This study also assumed that the lumber and flooring were used in the same application for which they were originally manufactured. We assume reused wood will be graded and this tends to assure that its performance will be the same as virgin wood that could have been used instead.

We assumed that carbon storage in recovered wood is the same as carbon stored in virgin wood. The benefits of reusing recovered wood relative to use of virgin wood include avoiding the environmental burdens associated with production of virgin wood and avoiding the generation of biogenic methane from the decay of discarded wood in landfills (Salazar and Meil 2009).

Forest Carbon Sequestration—We assumed that the use of wood harvested on a sustainable basis does not alter the carbon storage of forests in the long run. The USFS Forest Inventory Analysis indicates that forest area in the United States has been relatively constant since 1910 (USFS 2011, Oswalt and others 2009, Smith and others 2009). According to the International Panel on Climate Change (IPCC) GWP

Table 2. End-of-life scenarios by type and percentage

End-of-life scenarios	Base case (%)	Alt#1 (%)	Alt#2 (%)	Alt#3 (%)	Alt#4 (%)	Alt#5 (%)
Wood burned (substitute coal power)	30	100	0	0	0	0
Wood mulched	10	0	100	0	0	0
C&D landfill (no CH_4 capture)	60	0	0	100	0	0
Wood burned (substitute gas power)	0	0	0	0	100	0
C&D landfill (CH_4 capture)	0	0	0	0	0	100

method found in SimaPro 7.3 (PRé Consultants 2013, IPCC 2007), the characterization factor for biogenic CO_2 emissions was not assigned a value in the calculation for GWP. This approach also follows the ISO 14067 standard (ISO 2012). In addition, the issue of how to properly account for the carbon in harvested wood products has not been developed in a consensus-based standard. Therefore, the system boundary assumed for this study starts at the harvesting of the tree and extends to the time where new or reused material would be placed in a new use. This temporal end-point is assumed to include all EOL emissions for wood that is discarded when it is not reused.

Data Collection and Treatment—Building material recovery and reuse data were collected for the United States only. Primary data of deconstruction companies were collected across the entire United States. Primary mill data for deconstruction and reuse businesses were production-weight-averaged as required by CORRIM research guidelines to maintain confidentiality of surveyed facilities (CORRIM 2010). The following tasks are part of a standard LCA research protocol.

Validation of Data—The reused wood materials considered in this study were tracked through the entire process to ensure validation of raw and LCI data. No physical changes occurred in the softwood framing lumber and hardwood flooring recovered for reuse in new construction.

Data Quality Statement—Primary data quality was high because of expert knowledge and complete responses obtained from the extensive and comprehensive survey of industry (Appendix 1—Survey Instrument). Annual production data were collected for the years 2008 and 2009 from deconstruction facilities across the United States that used average technologies and produced 362 m^3 (230,000 bf) of recovered softwood framing and 25.4 thousand m^2 (273 thousand ft^2) of recovered hardwood flooring. Statistics for total production of recovered softwood framing and hardwood flooring for the same time period were not available at the time of completion of this study.

Aggregation—Primary data on environmental burdens per unit of reused wood were weighted as in previous CORRIM reports (Milota and others 2004) using

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

where $\bar{P}_{\text{weighted}}$ is the weighted average of the survey values reported by the mills, P_i is the reported mill value, and x_i is the ratio of the mill's production to total production for all surveyed facilities.

Modeling Procedure Including Allocation—The weighted-average primary data on environmental burdens was estimated per functional unit using SimaPro LCA software (PRé Consultants 2013). A wood mass balance and energy consumption verification for the necessary unit processes were performed and the weighted-average data were linked together into SimaPro for each unit process. Secondary data found in the U.S. LCI Database within SimaPro software provided additional life-cycle data. The additional life-cycle data includes generation and delivery of electricity and fossil fuel use and emissions. LCI outputs from SimaPro included raw material consumption, solid waste, and emission to air, water, and land. The mass allocation method was used to allocate environmental burdens to the primary product and co-products.

The mass allocation method was chosen because the highest volume product had the highest economic value. Emissions were allocated based on mass to primary products and co-products if they each had some economic value (as is the case for new products). If the waste has no economic value, then all emissions are assigned to the primary products (as is the case for recovered/reused products). The cradle-to-gate LCI data for recovered hardwood flooring and softwood framing lumber were developed using a functional unit of 1 m^3, the same functional unit as new wood products.

Elementary Flows—Nearly all individual wood products flow through the system without changing shape. Softwood framing lumber and hardwood flooring that suffered physical damage during deconstruction were not reused and were sent as waste wood to a C&D landfill with no methane capture.

Assumptions—Assumptions and limitations associated with making the LCI estimates are provided in Appendix 3—Assumptions and Limitations.

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

	Softwood framing lumber		Hardwood flooring	
	MJ/m^3	%	MJ/m^3	%
Coal	462	7	816	11
Crude oil	826	13	1,980	26
Natural gas	592	9	790	10
Uranium	160	2	270	3
Biomass	4,360	68	3,880	50
Hydropower	37	1	12	0
Total	6,440	100	7,750	100

[a]Energy values were determined using their higher heating values in MJ/kg: 54.4 for natural gas, and 20.9 for oven-dried wood, 26.2 for coal, 45.5 for crude oil, and 381,000 for uranium.

Results and Discussion

Part 1—Cradle-to-Gate LCIs

LCI data for cumulative cradle-to-gate materials use, energy use, and emissions per cubic meter of newly made softwood framing lumber and hardwood flooring were generated using SimaPro modeling. Additional data were obtained on energy and emissions per cubic meter for product transportation to the construction site from literature. LCI data were estimated using primary data from surveys and secondary data found in the U.S. LCI Database and literature. The surveyed facilities provided detailed data on mass flow, and energy consumption and emissions by type of fuel. Data from surveys were weighted by facility production and were input into SimaPro 7 to estimate average non-wood raw material use and emissions. Input data collected by survey are listed in Appendix 4—SimaPro Inputs. The total energy to produce 1-m^3 framing lumber and hardwood flooring from new wood materials was 6,440 and 7,750 MJ/m^3, respectively (Table 3). Based on information obtained, at least 50% of the energy used to make new wood products came from woody biomass.

Table 4 shows the major GHG emitted in making new softwood framing lumber and hardwood flooring. Emissions were consistently greater per cubic meter to make hardwood flooring because of its higher density and greater energy requirements in product production (principally drying) than softwood framing lumber. Production of hardwood lumber emits about twice as much fossil CO_2 (228 kg/m^3) as does the production of softwood framing lumber (109 kg/m^3). Appendix 5—LCI Flows shows detailed LCI results for newly made and recovered softwood lumber and hardwood lumber including raw materials used, solid waste generated, and emissions to air, water, and soil.

Table 5 shows cradle-to-gate LCI energy use data for recovered softwood framing lumber and hardwood flooring per cubic meter of recovered wood and includes energy for product transportation to the construction site. Recovered softwood framing lumber and hardwood flooring consume 418 and 859 MJ/m^3 of energy, respectively. Included in the energy allocated to the recovered wood are those from wood lost during deconstruction process (i.e., waste wood) that was sent a C&D landfill with no methane capture. Crude oil was the largest energy component because of resource (i.e., raw material) and product transportation with values of 178 and 437 MJ/m^3, respectively. Coal consumption was next at 145 and 235 MJ/m^3. However, more energy was consumed during hardwood flooring recovery because the flooring was primarily stored in a closed, natural gas-heated building. No biomass was burned for energy in recovering old wood products for reuse.

Table 6 shows cradle-to-gate major GHG emissions for recovered softwood framing lumber and hardwood flooring. Recovered hardwood flooring production emitted more fossil CO_2 than recovered softwood framing lumber did. This was due to the higher wood density for hardwood versus softwood and because hardwood flooring was stored inside heated closed buildings unlike softwood framing lumber, which was stored covered outside. In addition, more biogenic CO_2 was emitted for softwood framing lumber (24.8 kg/m^3) than hardwood flooring (19.2 kg/m^3) because more lumber was lost during the recovery process for softwood framing lumber than flooring. Therefore, a higher percentage of removed softwood framing lumber later

Table 4. Cradle-to-gate major GHG emissions allocated to 1 m^3 new wood products

	Quantity emitted (kg/m^3)	
	Softwood framing lumber	Hardwood flooring
Carbon dioxide, fossil	109	228
Methane, fossil	0.303	0.459
Methane, biogenic	0	0
Nitrous oxide	3.32×10^{-3}	2.87×10^{-3}
Carbon dioxide, biogenic	365	390

Table 5. Cradle-to-gate cumulative energy requirements by fuel source allocated to 1 m³ recovered wood products[a]

	Softwood framing lumber		Hardwood flooring	
	MJ/m³	%	MJ/m³	%
Coal	145	35	235	27
Crude oil	178	43	437	51
Natural gas	47	11	109	13
Uranium	43	10	70	8
Biomass	0	0	0	0
Hydropower	5	1	8	1
Total	418	100	859	100

[a]Energy values were determined using their higher heating values in MJ/kg: 54.4 for natural gas and 20.9 for oven-dried wood, 26.2 for coal, 45.5 for crude oil, and 381,000 for uranium.

Table 6. Cradle-to-gate major GHG emissions allocated to 1 m³ recovered wood products

	Quantity emitted (kg/m³)	
	Softwood framing lumber	Hardwood flooring
Carbon dioxide, fossil	23.9	49.7
Methane, fossil	4.73×10^{-3}	9.94×10^{-3}
Methane, biogenic	7.31	5.59
Nitrous oxide	3.32×10^{-3}	7.99×10^{-3}
Carbon dioxide, biogenic	24.8	19.2

decomposed in a landfill. Biogenic methane has a much greater impact on climate change than carbon dioxide, 22 to 1 when calculating GWP (non-biogenic methane has a GWP characterization factor of 25 for the IPCC 2007 100-year time horizon) (PRé Consultants 2013, IPCC 2007). Bergman and others (2010) provided LCI data for recovered framing lumber and hardwood flooring without considering disposal of the unusable wood from deconstruction. Total methane production was 0.3 kg/m³ for both recovered wood products when the analysis did not include biogenic methane emissions generated after landfilling of unusable wood. Biogenic methane emissions from the decomposition of wood lost increased total methane emitted by a factor of 24 (7.31/0.3) and 19 (5.59/0.3), respectively, a huge increase in GWP. Survey results estimated wood lost during removal at 17% and 11% for recovered framing lumber and wood flooring, respectively. Wood decomposition in landfills was the source for all the biogenic CO_2 and biogenic CH_4 emitted in production of recovered wood products.

Tables 7 and 8 show that cradle-to-gate GWP including and excluding biogenic CO_2 for products and recovered products. For new products, GWP with biogenic CO_2 emissions included was two to four times greater than when biogenic CO_2 emissions were excluded. For recovered wood products, GWP was marginally greater when biogenic CO_2 emissions were included. Biogenic CO_2 emitted came from the decomposition in the landfilled wood lost during the recovery process for recovered wood products.

GWP for new products is substantially higher when biogenic CO_2 is included because production includes burning onsite biomass (i.e., mill residues) to provide thermal energy for drying wood. Considerably lower GWPs were indicated when biogenic CO_2 emissions were not considered (standard LCA practice).

Tables 7 and 8 show cumulative energy requirements for the new framing lumber and flooring were 15 and 9.0 times greater, respectively, than for the equivalent recovered wood products. The GWP ratio between new and recovered products is much lower because it includes, for recovered products, the landfill methane emissions generated from wood lost during the recovery.

When GWP excludes biogenic CO_2 emissions (standard LCA practice), then GWP for new hardwood flooring is greater than for recovered flooring (ratio is 1.4). However, GWP is less for new softwood lumber than for recovered softwood lumber (ratio is 0.6). GWP that includes biogenic CO_2 emissions is greater for new products than for recovered products by factors of 2.3 and 3.2 for softwood lumber and hardwood flooring, respectively. The doubling or more of GWP when including biogenic CO_2 indicates the importance of what emissions are included for wood products production.

Part 2—End-of-Life Scenarios

The second part of this study examined various EOL scenarios for the case where wood is not recovered and estimated the associated cumulative energy use and GHG emissions. This portion of the study is intended to answer the question, "If recovered wood were not reused in construction and had a different fate (e.g., burned to generate electricity, ground for mulch, or landfilled), what would the impact be on environmental burdens?" In addition, we answer the question, "When are GHG emissions less for reuse of old wood compared to discard of old wood under several EOL scenarios and associated production of new products?"

The base case EOL scenario assumes a mix of dispositions for discarded wood: burning wood for energy to replace coal power (30%), grinding for mulch with open air decay (10%), and disposal in a C&D landfill without methane capture (60%). All EOL analyses used data from the U.S. LCI Database. There are five alternate scenarios.

Table 9 shows that for the base case (current U.S. practice) cumulative EOL energy is negative because of decreased coal burning with increased wood burning. Wood burning allows for coal energy decreases of –2,300 and –2,920 MJ/m³ of softwood framing lumber and hardwood flooring, respectively. To put this into perspective,

Table 7. Summary environmental impact measures for producing softwood framing lumber

Environmental impact measures	(1) New framing lumber	(2) Recovered framing lumber	Ratio (1)/(2)
Cumulative energy (MJ/m^3)	6440	418	15
CO_2 total (kg/m^3)	474	48.9	9.7
CO_2 less biogenic (kg/m^3)	109	24.8	4.4
GWP including biogenic CO_2 (kg CO_2-e/m^3)[a]	483	211	2.3
GWP less biogenic CO_2 (kg CO_2-e/m^3)	118	186	0.6

[a]Global warming potential (GWP) when biogenic CO_2 is given a characterization factor of 1.

Table 8. Summary environmental impact measures for producing hardwood flooring

Environmental impact measures	(1) New hardwood flooring	(2) Recovered hardwood flooring	Ratio (1)/(2)
Cumulative energy (MJ/m^3)	7,750	859	9.0
CO_2 total (kg/m^3)	618	79.4	7.8
CO_2 less biogenic CO_2 (kg/m^3)	228	48.7	4.7
GWP including biogenic CO_2 (kg CO_2-e/m^3)[a]	630	195	3.2
GWP less biogenic CO_2 (kg CO_2-e/m^3)	240	175	1.4

[a]Global warming potential (GWP) when biogenic CO_2 is given a characterization factor of 1.

53% (2,300/4,360) and 75% (2,920/3880) of the biomass energy used in making new softwood framing lumber and hardwood flooring is displaced by burning the old wood at EOL to avoid coal power production. Wood burned for energy recovery at EOL has a considerable effect, although only 30% of the old wood is burned to replace coal.

Table 10 shows that for the base case, some major GHG emissions were positive overall. Positive GHG emissions occurred even though cumulative energy at EOL was negative (Table 9). Negative fossil CO_2 emissions correspond to negative energy consumption and result from the discarded wood being burned to displace coal to generate electricity. As a result, fossil CO_2 values were –156 kg/m^3 for softwood framing lumber and –193 kg/m^3 for hardwood flooring. However, some positive GHG emissions occurred because of the release of biogenic CO_2 and biogenic methane from wood burning and degradation. Wood degradation occurs from two sources: the spreading of mulch and the landfilling of the discarded wood. Biogenic CO_2 generated from burning wood, mulch, and landfills was large for softwood framing lumber (317 kg/m^3) and hardwood flooring (402 kg/m^3). Biogenic methane emissions from landfills were 21.5 and 27.2 kg for softwood framing lumber and hardwood flooring, respectively. The discarded wood burned to replace coal to generate electricity substantially offsets fossil CO_2 emissions but adds to biogenic CO_2 emissions.

Table 9. Cumulative end-of-life energy consumption by fuel source allocated to 1 m^3 wood products (base-case scenario[a,b])

	Softwood framing lumber		Hardwood flooring	
	MJ/m^3	%	MJ/m^3	%
Coal	–2,300	106	–2,920	110
Crude oil	65	–3	173	–7
Natural gas	31	–1	41	–2
Uranium	32	–1	38	–1
Biomass	0	0	0	0
Hydropower	5	0	7	0
Total	–2,170	100	–2,660	100

[a]30% of wood waste from old structures goes to replace coal to generate electricity, 10% gets ground into mulch, and the remaining 60% transported to a construction and demolition landfill with no methane capture.
[b]Energy values were determined using their higher heating values in MJ/kg: 54.4 for natural gas and 20.9 for oven-dried wood, 26.2 for coal, 45.5 for crude oil and 381,000 for uranium.

Tables 11 and 12 show cumulative energy use and GWP for the base case and five alternative EOL scenarios. GWP_1 excludes biogenic CO_2, the method consistent with TRACI 2 Method (PRé Consultants 2013, Bare 2011). GWP_2 includes biogenic CO_2. Alternative scenario #1 (burn all the wood to replace coal to generate electricity) had the lowest levels of GWP_1 and GWP_2 across all the scenarios. Softwood framing

Table 10. Major GHG emissions for the end-of-life (base-case scenario[a])

GHG	Quantity emitted (kg/m^3) Softwood framing lumber	Hardwood flooring
Carbon dioxide, fossil	–156	–193
Methane, fossil	–0.286	–0.353
Methane, biogenic	21.5	27.2
Nitrous oxide	1.78×10^{-3}	2.40×10^{-3}
Carbon dioxide, biogenic	317	402

[a]30% of wood waste from old structures goes to replace coal to generate electricity, 10% gets ground into mulch, and the remaining 60% is transported to a construction and demolition landfill with no methane capture.

Table 11. Cumulative energy and GWP for the various end-of-life scenarios[a] for softwood framing lumber

Environmental impacts	Base case	Alt#1	Alt#2	Alt#3	Alt#4	Alt#5	Reuse	New
Cumulative energy (MJ/m^3)	–2,160	–8,100	471	329	–7,300	–1,420	418	6,440
GWP_1 (kgCO_2-e/m^3)[g]	310	–592	28	808	–379	199	186	118
GWP_2 (kgCO_2-e/m^3)[h]	627	–93	980	928	120	394	211	483

[a]Base case: 60% of wood waste into landfill with no methane capture/30% burned to replace coal power/10% ground into mulch; Alt#1: 100% wood waste burned to replace coal power; Alt#2: 100% wood waste ground into mulch; Alt#3: 100% wood waste into landfill with no methane capture; Alt#4: 100% wood waste burned to replace natural gas power; Alt#5: 100% wood waste into landfill with methane capture; Global warming potential (GWP) with biogenic CO_2 having a characterization factor of 1.

Table 12. Cumulative energy and GWP for the various end-of-life scenarios[a] for hardwood flooring

Environmental impacts	Base case	Alt#1	Alt#2	Alt#3	Alt#4	Alt#5	Reuse	New
Cumulative energy (MJ/m^3)	–2660	–10,100	676	497	–9,200	–1,720	859	7,750
GWP_1 (kgCO_2-e/m^3)[g]	397	–744	40	1030	–475	257	175	240
GWP_2 (kgCO_2-e/m^3)[h]	799	–113	1,250	1180	156	504	195	630

[a]Base case: 60% of wood waste into landfill with no methane capture/ 30% burned to replace coal power/ 10% ground into mulch; Alt#1: 100% wood waste burned to replace coal power; Alt#2: 100% wood waste ground into mulch; Alt#3: 100% wood waste into landfill with no methane capture; Alt#4: 100% wood waste burned to replace natural gas power; Alt#5: 100% wood waste into landfill with methane capture; Global warming potential (GWP) with biogenic CO_2 having a characterization factor of 1.

lumber and hardwood flooring had GWP_1 values of –592 and –744 kg/m^3, respectively. GWP_2 values were –93 and –113 kg/m^3, respectively.

Cumulative energy was negative and lowest for alternative scenario 1. Scenario 4 (burn wood to replace natural gas to generate electricity) followed closely behind the first alternative with values of –7,300 and –9,200 MJ/m^3 for softwood framing lumber and hardwood flooring, respectively. Scenario 5 was next lowest but significantly behind. In Scenario 5, all wood goes to landfills and a small part is emitted as biogenic methane (i.e., landfill gas). Seventy-five % of the biogenic methane generated in the landfill was captured and burned to generate electricity to replace natural gas. Burning landfill methane generates biogenic CO_2. The remaining 25% was considered fugitive emissions and was emitted to the atmosphere. These results are consistent with Kaplan and others (2009) who found burning wood for energy provides substantially lower (negative) GHG emissions than landfilling and burning the captured landfill methane for energy. When landfill methane is not burned as in Scenario 3, GHG emissions are much higher. For softwood lumber, the effect of not burning landfill methane for energy when all wood is landfilled was to increase GWP_1 by a factor of four, from 199 to 808 kg CO_2-equivalents/m^3. The effect was similar for hardwood flooring. Thus, methane capture is critical for wood products when stored in a landfill to lower their impact on climate change.

Tables 13 and 14 compare GWP for cases where 1) old wood products are discarded (six EOL cases) and new products are made or 2) old wood is reused to make products. For the base case EOL scenario where we assume making new products would require discard of old wood to the current mix of proportions to energy, landfills, and mulch, then the reuse of both softwood lumber and hardwood flooring produces less GWP than making new products. The benefit is greatest for reuse of hardwood flooring (1,429/195 vs 1,110/211). This is true for GWP estimates that either include or exclude biogenic CO_2 emission. However, if we

Table 13. Scenarios[a] of GWP comparison of new softwood framing lumber plus the various end-of-life scenarios to recovered softwood framing lumber

Environmental impacts	Base case[a]	Alt#1[b]	Alt#2[c]	Alt#3[d]	Alt#4[e]	Alt#5[f]	Reuse
GWP_1 ($kgCO_2$-e/m^3)[g]	427	–474	146	926	–262	317	186
GWP_2 ($kgCO_2$-e/m^3)[h]	1,110	390	1,463	1,411	603	877	211

[a]Base case: 60% of wood waste into landfill with no methane capture/ 30% burned to replace coal power/ 10% ground into mulch; Alt#1: 100% wood waste burned to replace coal power; Alt#2: 100% wood waste ground into mulch; Alt#3: 100% wood waste into landfill with no methane capture; Alt#4: 100% wood waste burned to replace natural gas power; Alt#5: 100% wood waste into landfill with methane capture; Global warming potential (GWP) with biogenic CO_2 having a characterization factor of 1.

Table 14. GWP comparison of new hardwood flooring plus the various EOL scenarios[a] to recovered hardwood flooring

Environmental impacts	Base case	Alt#1	Alt#2	Alt#3	Alt#4	Alt#5	Reuse
GWP_1 ($kgCO_2$-e/m^3)	637	–504	280	1,270	–235	497	175
GWP_2 ($kgCO_2$-e/m^3)	1,429	518	1,880	1,810	787	1,134	195

[a]Global warming potential (GWP) with biogenic CO_2 having a characterization factor of 1; Base case: 60% of wood waste into landfill with no methane capture/30% burned to replace coal power/10% ground into mulch; Alt#1: 100% wood waste burned to replace coal power; Alt#2: 100% wood waste ground into mulch; Alt#3: 100% wood waste into landfill with no methane capture; Alt#4: 100% wood waste burned to replace natural gas power; Alt#5: 100% wood waste into landfill with methane capture.

consider GWP that excludes biogenic CO_2 emissions (standard LCA practice) reuse could be notably worse (higher GWP) than new wood if all old wood could be burned to offset coal or natural gas in making electric power. Reuse could be slightly worse than new for softwood lumber if all old wood could be used as mulch (unlikely if wood is contaminated (186/146)). So a key point is that if wood cannot be reused for products the next best step is to keep it out of landfills and use it for either energy (top priority) or mulch (lower priority). There is a greater benefit from keeping hardwood out of landfills than keeping softwood out of landfills.

Conclusion

Recovering softwood framing lumber and hardwood flooring for reuse instead of making new products displaces a considerable amount of production energy use and avoids some GHG emissions, particularly biogenic CO_2. Reusing wood products for construction does not use biomass energy during its production, unlike new wood products. Including biogenic CO_2 from burning biomass for energy adds considerably to the estimate of GWP for new wood products. Adding biogenic CO_2 results in substantially higher GWP for new wood products because over 50% of its primary energy is from mill residues (i.e., wood). However, if biogenic CO_2 is not included, then the GWP values for new products are lower and reuse of wood does not avoid as much GWP as new product production.

GWP values change considerably for the different cases of discarding old wood (i.e., C&D waste). Standard GWP protocol excludes biogenic CO_2 emissions whether generated from burning wood, decaying mulch, decomposing wood in landfills, or burning landfill methane. Biogenic CO_2 emissions are assume to be balanced out by the carbon sequestration from trees over time as part of the natural carbon cycle. Standard U.S. waste disposal practice includes burning wood for energy to replace coal power (30%), grinding for mulch with open air decay (10%), and disposal in a C&D landfill without methane capture (60%). Therefore, the following hierarchy in this study shows the lowest to the highest GWP values for the six EOL scenarios investigated: 1) burning wood to generate electricity to replace coal, 2) burning wood to generate electricity to replace natural gas, 3) grinding wood into mulch, 4) installing methane capture equipment to capture most of the landfill methane and burning it to generate electricity to replace natural gas, 5) current U.S. practice, and 6) storing the wood in a landfill without methane capture. The two cases of burning old wood to replace fossil fuels have greater GHG benefits than the two cases of landfilling the discarded old wood with or without methane capture with mulching the old wood falling in between.

A downside to using C&D waste in energy generation to offset coal or natural gas emissions is that C&D waste typically contains contaminants unless the material is separated at the demolition or deconstruction site. Therefore, burning C&D waste can result in other air emissions and unknown materials that may require additional handling and associated energy consumption in the process than that already noted.

Greater environmental benefits tend to occur by keeping hardwoods out of landfills than keeping softwoods out of landfills. This is because hardwood flooring is produced from a dense wood species, and if kept out of landfills, could generate more energy per unit weight of wood than softwoods. Alternately, hardwoods that are kept out of landfills and are then reused will avoid production of new hardwood flooring, which requires more energy for drying to a lower moisture content to improve dimensional stability and to avoid degrade than softwood framing lumber does. This translates to greater environmental benefits of keeping hardwoods out of landfills and reusing for flooring or using it for energy than can be realized by recovery of softwood species for reuse.

Product transportation can be a critical component of the cradle-to-gate LCI. For new products, transportation often requires long distances. For example, new wood flooring is primarily produced in the eastern United States. Therefore, transportation by both truck and rail is typically required to deliver products to wholesale locations on the West Coast. For reused wood products, transport distance can be shorter because wood is recovered in large urban centers and can be reused locally.

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Appendix 1—Survey Instrument

Survey Instrument for Deconstruction Facility Operators and Managers

This questionnaire is comprised of two parts: 1. wood flooring and; 2. framing lumber. Some questions pertain to companies or individuals who do deconstruction/demolishing whereas some questions pertain to transportation to and around a resale facility. We are looking to evaluate your most current practices.

Part I—Wood Flooring

For this project, we are limiting our analysis to solid wood flooring, including tongue and groove (T&G) and plank flooring. We are not interested at this time in laminated (or engineered) wood flooring. The goal of this section is to determine all the energy inputs to remove, store, and sell the flooring. We are assuming that the following represents a typical sequence of flooring removal.

1. Transportation of workers to job-site.
2. Removal of any furniture or other materials such as molding that would interfere with removal of the flooring.
3. Removal flooring board by board.
4. Denailing of flooring either by hand or nail kicker.
5. Loading of flooring onto truck either by hand or with equipment.
6. Transport the flooring to storage facility
7. Unload the wood flooring either by hand or equipment.
8. Store the wood flooring in a facility until sold
9. Electricity and fuel used to keep facility lighted and heated.
10. Selling of wood flooring to customers

Part I—Wood Flooring (Soft-Strip)

1. What is the typical distance your crew travels to a jobsite to remove flooring? ________ miles
2. How many days do you typically stay on a deconstruction job to remove wood flooring? ____ days
3. How many hours per day spent removing flooring? _____ hours
4. How many miles are driven per day while at the jobsite? That is, driving to lunch, to the hardware store, picking up equipment, back and forth from office, etc. _______________ miles
5. Does your crew typically travel individually or as a group to the jobsite? Circle one: individual, group.
6. If a group, how many typically ride in each vehicle? ______persons
7. Estimate how many square feet of flooring each person can remove in an hour? _____sq.ft/hr/person
8. How many total sites (jobs) for wood floor removal are completed on annual basis?
9. List tools used to remove flooring?

If no tools use fuel or electricity, go to question 11, otherwise continue with question 10.

10. What tools do you use that require fuel or electricity, such as a Nail Kicker, electric saw/etc. in the flooring removal and denailing process?

    What do you typically use for a power source? Circle one: electrical outlet onsite or a jobsite generator

    If you use a jobsite generator, what fuel does the generator use and how much fuel does it use per hour of operation?
    ___________ gallons per hour gasoline
    ___________ gallons per hour fuel oil
    ___________ gallons per hour propane
11. Estimate how many square feet of flooring each person can denail and trim in an hour using the Nail Kicker or other electrical tools?____________ sq.ft./hr/person
12. If you use plug-in electricity for your tools, do you know how many Kw/hrs are used per square foot of flooring removed?
    ____________ kw-hr/sq.ft. flooring
13. On average, how much flooring do you recover per site? ____________ sq.ft.
14. Estimate how much flooring you lose in the removal and trimming process? 5, 10, 25, 50%? ____%
15. What percentage of recovered flooring is hardwood or softwood? _______% hardwood ________% softwood
16. Estimate how much flooring you recovered in the last year? Please give your answer in square feet.
17. What is the average distance you must move the recovered flooring to your resale facility? _______miles
18. Average number of trips to move the recovered flooring to resale facility per job? ____
19. Please indicate what type of truck is used? Circle one: pickup truck, box truck, semi, etc.

20. Estimate what percentage of the load (by weight) is flooring for a typical job? ______%

21. What type of fuel is used? Circle one: diesel or gas

22. We are trying to determine the energy costs associated with storing and selling the wood flooring you recovere. Can you estimate the holding costs (e.g., heating, lighting in BTU's/KWH's) associated with the retailing or wholesaling of wood flooring in your store?

a. Store size _____________ sq. ft.

b. Typically, how much wood flooring is stored at one time? ______________ sq. ft.

c. What would you estimate the percentage of wood flooring (by weight) is in your store compared to overall inventory _____%

d. Typically, how long is flooring stored before selling? ________days or weeks or months

e. Annual fuel consumption to heat store
___________ gallons heating oil
___________ gallons propane
___________1000 cubic feet natural gas
___________Kw-hr electricity

f. Annual electrical consumption for store (please provide at least two of the following items)
____________ kilowatt-hours
____________ cents/Kw-hr
____________ monthly electric bill

23. If you use equipment such as a forklift to move flooring around the facility, please list what type of equipment?

24. If the equipment uses fuel, what type of fuel? Circle one: gas, diesel, LP, or electric

25. Estimate how much fuel (or electricity) is used per year to move wood flooring around the facility and for loading onto a customer's vehicle? ____________ gallons fuel / _______ kw-hr

26. If you sell, average selling price of wood flooring? ___________$/sq.ft

Part II—Framing Lumber

Framing lumber is the structural support of a building, not the sheathing, trim, or other wood. In a house, it is usually 2 × 4s, 2 × 6s, 2 × 8s, and 2 × 10s. Once again, we are looking to see what energy goes into removing, transporting, and selling the framing lumber. However, if other re-useable material is also removed when removing the framing lumber, please indicate that. We expect that heavier equipment might be used. We are assuming that the following represents a typical sequence of framing removal.

1. Transportation of workers to jobsite.
2. Transportation of forklift, bobcat, or other energy using equipment to jobsite.
3. Removal of surface materials such as roofing, drywall, subfloors, and insulation that would interfere with the removal of the framing lumber
4. Removal of actual framing.
5. Denailing of framing either by hand or nail kicker.
6. Loading of framing onto truck either by hand or with equipment.
7. Transport the framing to storage facility
8. Unload the wood framing either by hand or equipment.
9. Store the wood framing in a facility until sold
10. Electricity and fuel used to keep facility lighted and heated.
11. Selling of framing lumber to customer

Part II—Framing Lumber (Full Deconstruction)

What is the typical distance your crew travels to a jobsite to remove framing? ________ miles.

1. How many miles are driven per day while at the jobsite? That is, driving to lunch, to the hardware store, picking up equipment, back and forth from office, etc.
   ______________ miles
2. Does your crew typically travel individually or as a group to the jobsite? Circle one: individual, group.
3. If a group, how many typically ride in each vehicle?
   _____ persons
4. How many days do you typically stay on a deconstruction job to remove framing? _____days
5. How many hours per day spent removing framing?
   _____ hours
6. Estimate how many linear feet or board feet of framing each person can remove in an hour?
   ______ linear ft/hr/person or board ft/hr/person
7. How many total sites (jobs) for framing removal are completed on annual basis?
8. List tools used to remove flooring.

   If no tools use fuel or electricity, go to question 11, otherwise continue with question 10.
9. What tools do you use that require fuel or electricity, such as a power saw/etc. in the framing removal and denailing process?

   What do you typically use for a power source? Circle one: electrical outlet onsite or a jobsite generator

   If you use a jobsite generator, what fuel does the generator use and how much fuel does it use per hour of operation?
   ___________ gallons per hour gasoline
   ___________ gallons per hour fuel oil
   ___________ gallons per hour propane
10. Please estimate how many lineal feet, board ft. or tons of framing each person can denail and trim in an hour using the Nail Kicker or other electrical tools?
11. If you use plug-in electricity for your tools, do you know how many Kw/hrs are used per square foot of framing removed?
12. On average, how much framing do you recovere per site? ____________ board feet or lineal feet or tons

Can you estimate how much framing you loose in the removal and trimming process? 10% 25% 50%

13. Do you use heavy equipment to recovere and move framing, such as a telescoping forklift, Bob Cat, boom lift, or other equipment? If so, please indicate how many total hours you typically use each machine on each job and how much fuel it burns per hour.

Machine Type	Hours used	Fuel type	Fuel use per hour
Forklift			
Bobcat			

14. Can you estimate how much framing you recovered in the last year? Please give your answer in either board feet, lbs (tons), or lineal feet of each size.
15. What is the average distance you must move the recovered framing to your resale facility? _______miles
16. Average number of trips to move the framing lumber to resale facility per job? ____
17. Please indicate what type of truck is used? Circle one: pickup truck, box truck, semi, etc.
18. Estimate what percentage of the load (by weight) is framing for a typical job? _____%
19. What type of fuel is used in the truck? Circle one: diesel or gas
20. We are trying to determine the energy costs associated with storing and selling the wood framing you recovere. Can you estimate the holding costs (e.g., heating, lighting in BTU's/KWH's) associated with the retailing or wholesaling of wood framing in your store?
    a. Store size _____________ sq. ft.
    b. Typically, how much wood framing is stored at one time? ______________ sq. ft.
    c. Estimate the percentage of wood framing (by weight) is in your store compared to overall inventory _____%
    d. Typically, how long is framing stored before selling? ________days or weeks or months
    e. Annual fuel consumption to heat store
       ___________ gallons heating oil
       ___________ gallons propane
       ___________1000 cubic feet natural gas
       ___________kw-hr electricity
    f. Annual electrical consumption for store (please provide at least two of the following items)
       ____________ kilowatt-hours
       ____________ cents/kw-hr
       ____________ monthly electric bill
21. If you use equipment such as a forklift to move flooring around the facility, please list what type of equipment?
22. If the equipment uses fuel, what type of fuel? Circle one: gas, diesel, LP, or electric
23. Estimate how much fuel (or electricity) is used per year to move wood flooring around the facility and for loading onto a customer's vehicle? ____________ gallons fuel / _______ kw-hr
24. If you sell framing lumber, average selling price of material broken down by size if possible?

Size	Price ($ per bf)
2x4's	
2x6's	
2x8's	
2x10's	
2x12's	
3x3's	
3x4's	
4x4's	
6x6's	
Other __________________	
Other __________________	
Other __________________	
Other __________________	
Other __________________	

If you have more to add please make as many additional comments as necessary. We appreciate your time to help out on this important research project. Also, please call Rick Bergman (608) 231-9477 or email at rbergman@fs.fed.us if you have any questions.

Please send the complete questionnaire to:

Rick Bergman
Mail: Forest Products Laboratory
One Gifford Pinchot Dr.
Madison, WI 53704
Fax: (608) 231-9508 (fax)
Email: rbergman@wisc.edu

Appendix 2—Landfill Gas (LFG) Equations

Equation 1: Where GHG_{DE} is GHGs directly emitted to atmosphere (kg CO_2-eq):

$$GHG_{DE} = (W_{kg})(C)(C_{CO_2})(D)(1 - LFG_C)\left(\frac{44}{12}\right) + (W_{kg})(C)(C_{CH_4})(D)(1 - LFG_C)\left(GWP_{CH_4} \cdot \frac{16}{12}\right)$$

Equation 2: Where GHG_{LFGR} is GHG emitted from LFG energy recovery (kg CO_2-eq):

$$GHG_{LFGR} = (W_{kg})(C)(D)(LFG_C)(LFG_R)\left(\frac{44}{12}\right)$$

Equation 3: Where GHG_{LFGF} is GHG emitted from LFG flaring (kg CO_2-eq):

$$GHG_{LFGF} = (W_{kg})(C)(D)(LFG_C)(1 - LFG_R)\left(\frac{44}{12}\right)$$

Equation 4: EO_{LFGR} is the energy offset by LFG recovery (MJ/kg):

$$EO_{LFGR} = (LFG_{HHV})(W_{kg})(C)(D)(LFG_C)(LFG_R)\left[\left(\frac{44}{12}\right)(C_{CO_2}) + \left(\frac{16}{12}\right)(C_{CH_4})\right]$$

W_{kg}	wood mass (kg)
C	carbon montent of mood = 50%
D	decomposition of mood in mandfill = 23% (Skog 2008)
C_{CO2}	carbon content of wood converted to CO_2 at landfill surface= 55%
C_{CH4}	carbon content of wood converted to CH_4 at landfill surface= 45%
GWP_{CH4}	global warming potential of CH_4 = 25
LFG_C	landfill gas capture efficiency = 75%
LFG_R	landfill gas energy recovery efficiency = 70%
LFG_{HHV}	landfill gas higher heating value = 15.8 MJ/kg

Appendix 3—Assumptions and Limitations

- The oven-dried (OD) density of solid-strip hardwood flooring was assumed to be 657 kg/m^3 based on several hardwood species including hard maple, oak, cherry, ash, and beech (Hubbard and Bowe 2010).
- Based calculation for the OD density of recovered framing lumber on a Southeast (SE) and Pacific Northwest (PNW) softwood lumber study done by Milota and others (2005). Milota and others reported 774 OD kg wood per 1.623 m^3 planed dry western lumber and 883 OD kg per 1.623 m^3 planed dry southwestern lumber. In addition, Milota and others reported approximately 21 million cubic meters annual lumber production in the PNW for Douglas fir and western hemlock and 36 million cubic meters in southern pine dimension lumber. Density value for recovered framing lumber estimated using weighted-averages as following: $(774/1.623) \times (21/(21+36)) + (883/1.623)x(36/(21+36)) = 519$ kg/m^3
- Based calculation for onsite electricity use during the reclaiming process on the assumption that the on-site grid electricity has the same value as the electricity per volume reclaimed material produced from on-site generators. During a physical visit to a demolition site (7/7/2009 in Madison, WI), data collected included time and power of the generator powered by gasoline. Using run-time data, results estimated the electricity used from the grid per volume of material recovered. Results estimated 20.09 kWh/Msf of flooring and 27.08 kWh/Mbf of framing lumber recovered. Although removal of other materials such as wood doors, cast iron sink, etc. occurred during deconstruction, the study assigned all of the material and energy inputs to the old wood products.
- HHV represents the energy content of a fuel with the combustion products such as water vapor brought to 25º C (77º F), whereas lower heating value (LHV) ignores the energy produced by the combustion of hydrogen in fuel. HHV is the preferred method in the United States (EIA 2013).
- For transportation of workers and materials to/from the demolition site, survey results indicated transportation of five men during each building deconstruction daily with an average weight 86 kg per worker (Ogden and others 2004).
- During deconstruction, survey results estimated weighted average of 17% and 11% material loss for softwood framing lumber and solid-strip hardwood flooring, respectively.
- During the transportation, assumed the recovered materials had 8% MC to account for the water weight.
- U.S. LCI Database typically provided LCI data for materials and energy including electricity (USDA 2012).
- The study modified a sanitary landfill process in the U.S. Ecoinvent database to alter waste and emissions to waste treatment based on U.S. specific data, named specific for our project: Disposal, wood untreated, 20% water, to sanitary landfill/CH with U.S. electricity U – USLCI. To create a U.S.-specific process, removed all processes associated with burning of sludge from wastewater treatment of short-term leachate.
- Assumed 1kg of disposal wood produce 0.314 of LFG, and 45% of it was methane at the surface on a molar basis and the rest was CO_2. On a mass basis, the landfill emits 0.072 kg CH_4/kg and 0.242 kg CO_2/kg. In addition, assumed approximately 75% of methane captured leaving the landfill and the remainder emitted directly to the atmosphere. Of the LFG, collected, assumed 30% flared (without energy recovery) and 70% burned for energy recovery (Salazar and Meil 2009).
- Assumed landfill methane has the same characteristics as natural gas.
- Survey questionnaire collected primary data on an annual basis across the United States for 2009.
- Collected primary mill data through a critically reviewed questionnaire in accordance with ISO 14040 and 14044 standards (2006a,b). Missing values were not weighted-average for a particular process in accordance with ISO standards.
- Background information[1]: recycled maple floor can be sold for \$1.50/ft^2, Oak floor for \$1.00/ft^2, Birch for \$1.25/ft^2, and Douglas-fir for \$1.25/ft^2.
- Ideal reclaimed material cost is 50–75% of virgin materials.
- Size of the deconstruction industry is unknown.
- Changed wood conversion to electricity process in U.S. LCI Database because less electricity was produced from wood from steam turbine (standard U.S. practice) than gasification systems provided in the dataset. Estimations provided by actual wood power plants lowered the value from 2.17 to 1.14 kWh/kg OD wood, a more conservative but realistic value. Calculation assuming HHV of 20.9 MJ/kg OD wood and 20% conversion of wood to electricity confirmed the value of 1.14 kWh/OD kg wood.
- Assumed energy use to store the virgin and recover wood material the same on a per unit basis.
- The study derived new framing lumber and new wood flooring transportation data from USDOT (2010).

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[1] Frank Bryne, Madison Restore, July 20, 2009

Assumed transportation data on Wood product manufacturing (NAICS code 321) estimated virgin wood framing and Furniture and related product manufacturing (NAICS code 337) estimated new solid-strip hardwood flooring.

- Future work will examine regional effects because insufficient data were available.

Appendix 4— SimaPro Inputs

Recovered wood framing lumber

Composite Recovered Softwood Framing Lumber for the United States

Removal

Output	Amount	Unit	
Recovered softwoodframing lumber, at deconstruction site	519	kg	83%
Disposal, wood untreated, 20% water, to santitary lanfilled/CH with US electricty - US LCI	106	kg	17%

Input			
Installed softwood framing lumber, at deconstruction site	625	kg	
Transport, Single unit truck, gasoline powered/US	0.62	tkm	materials
Transport, Single unit truck, diesel powered/US	0.51	tkm	materials
Gasoline, combusted in equipment/US	1.53	liter	
Electricity, at grid, US/US	14.3	kWh	

Storage

Output	Amount	Unit	
Recovered softwood framing lumber, at storage facility	519	kg	

Input			
Recovered framing lumber, at deconstruction site	519	kg	
Transport, combination truck, gasoline powered/US	0.67	tkm	to storage facility
Transport, combination truck, diesel powered/US	0.55	tkm	to storage facility
Electricity, at grid, US/US	2.86	kWh	lighting
Residual fuel oil, combusted in industrial boiler/US	0.22	liter	heating
Natural gas, combusted in industrial boiler/US	9.0E-05	m^3	heating
Gasoline, combusted in equipment/US	1.44	liter	transporting on-site

Product Transportation

Output	Amount	Unit	
Recovered softwood framing lumber, at construction site	519	kg	

Input			
Recovered framing lumber, at storage facility	519	kg	
Transport, single unit truck, diesel powered/US	12.5	tkm	to construction site

New wood framing LCI Inputs

Composite Softwood Framing Lumber Mill for the United States

Output	Amount	Unit	
Surfaced dried lumber, at planer mill, US AVG, at mill	519	kg	

Input			
Surfaced dried lumber, at planer mill, US SE/kg/US - Modified	328	kg	63.2%
Surfaced dried lumber, at planer mill, US SE/kg/US - Modified	191	kg	36.8%

Storage

Output	Amount	Unit	
Surfaced dried lumber, at planer mill, US AVG, at storage facility	519	kg	

Input			
Surfaced dried lumber, at planer mill, US AVG, at mill	519	kg	
Transport, single unit truck, diesel powered/US	233	tkm	to storage facility
Transport, train, diesel powered/US	96	tkm	to storage facility
Electricity, at grid, US/US	2.86	kWh	lighting
Residual fuel oil, combusted in industrial boiler/US	0.22	liter	heating
Natural gas, combusted in industrial boiler/US	9.0E-05	m^3	heating
Gasoline, combusted in equipment/US	1.44	liter	transporting on-site

Product Transportation

Output	Amount	Unit	
Surfaced dried lumber, at planer mill, US AVG, at construction site	519	kg	

Input			
Surfaced dried lumber, at planer mill, US AVG, at storage facility	519	kg	
Transport, combination truck, diesel powered/US	14	tkm	to construction site

Recovered solid strip wood flooring

Composite Recovered Hardwood Flooring the United States

Removal

Output	Amount	Unit	
Recovered hardwood flooring, at deconstruction site	657	kg	89%
Disposal, wood untreated, 20% water, to santitary lanfilled/CH with US electricty - US LCI	81	kg	11%

Input			
Installed hardwood flooring, at deconstruction site	738	kg	
Transport, Single unit truck, gasoline powered/US	2.86	tkm	materials
Transport, Single unit truck, diesel powered/US	3.84	tkm	materials
Gasoline, combusted in equipment/US	4.57	liter	
Electricity, at grid, US/US	18.6	kWh	

Storage

Output	Amount	Unit	
Recovered hardwood flooring, at storage facility	657	kg	

Input			
Recovered hardwood flooring, at deconstruction site	657	kg	
Transport, combination truck, gasoline powered/US	2.86	tkm	to storage facility
Transport, combination truck, diesel powered/US	3.84	tkm	to storage facility
Electricity, at grid, US/US	1.17	kWh	heating
Residual fuel oil, combusted in industrial boiler/US	1.12	liter	heating
Natural gas, combusted in industrial boiler/US	0.659	m^3	heating
Liquefied petroleum gas, combusted in industrial boiler/US	0.831	liter	heating
Electricity, at grid, US/US	7.55	kWh	lighting
Electricity, at grid, US/US	0.558	kWh	transporting on-site
Gasoline, combusted in equipment/US	2.47	liter	transporting on-site

Product Transportation

Output	Amount	Unit	
Recovered hardwood flooring, at construction site	657	kg	

Input			
Recovered hardwood flooring, at storage facility	657	kg	
Transport, single unit truck, diesel powered/US	17	tkm	to construction site

New solid strip hardwood flooring

US Solid Strip Hardwood Flooring Composite

Storage

Output	Amount	Unit	
Solid strip and plank flooring, hardwood, US NE-NC, at storage facility	657	kg	

Input			
Solid strip and plank flooring, hardwood, US NE-NC, at mill	657	kg	
Transport, combination truck, diesel powered/US	813	tkm	to storage facility
Transport, train, diesel powered/US	4	tkm	to storage facility
Electricity, at grid, US/US	1.17	kWh	heating
Residual fuel oil, combusted in industrial boiler/US	1.12	liter	heating
Natural gas, combusted in industrial boiler/US	0.659	m^3	heating
Liquefied petroleum gas, combusted in industrial boiler/US	0.831	liter	heating
Electricity, at grid, US/US	7.55	kWh	lighting
Electricity, at grid, US/US	0.558	kWh	transporting on-site
Gasoline, combusted in equipment/US	2.47	liter	transporting on-site

Product Transportation

Output	Amount	Unit	
Solid strip and plank flooring, hardwood, US NE-NC, at construction site	657	kg	

Input			
Solid strip and plank flooring, hardwood, US NE-NC, at storage facility	657	kg	
Transport, combination truck, diesel powered/US	17	tkm	to construction site

Appendix 5—LCI Flows

No	Substance	Compartment	Unit	Reclaimed flooring, no EOL, at construction site	Solid strip and plank flooring, hardwood, US NE-NC, at construction site	Reclaimed framing lumber, no EOL, at construction site	Surfaced dried lumber, at planer mill, US AVG, at construction site
1	Carbon dioxide, in air	Raw	kg	0.394989242	1115.391423	0.243722696	2461.63328
2	Coal, 26.4 MJ per kg, in ground	Raw	kg	8.900009534	30.9100888	5.491160187	17.49535827
3	Energy, from hydro power	Raw	MJ	7.716753336	11.60133582	4.861951228	37.02101266
4	Gas, natural, 46.8 MJ per kg, in ground	Raw	kg	0.003127892	0.586299379	x	0.655641422
5	Gas, natural, in ground	Raw	m3	2.254683069	17.52841005	0.974065359	12.73090649
6	Iron ore, in ground	Raw	kg	x	0.000210417	x	x
7	Limestone, in ground	Raw	kg	4.40529E-05	21.40715507	x	24.06784967
8	Nickel	Raw	m3	0.545879263	2.002789587	0.224457368	1.66269518
9	Occupation, forest, intensive, normal	Raw	m2a	x	2400.896794	x	x
10	Oil, crude, 42 MJ per kg, in ground	Raw	kg	0.044943599	2.676549027	x	2.958685658
11	Oil, crude, in ground	Raw	kg	9.555540097	41.13096704	3.910362129	15.43115058
12	Oxygen, in air	Raw	kg	x	1.50374E-05	x	x
13	Uranium oxide, 332 GJ per kg, in ore	Raw	kg	0.000211681	0.000751922	0.000130615	0.000412281
14	Uranium, 2291 GJ per kg, in ground	Raw	kg	3.10718E-09	8.86132E-06	x	9.95911E-06
15	Water, process, well, in ground	Raw	kg	x	2.959882421	x	x
16	Water, unspecified natural origin/m3	Raw	m3	x	x	x	0.190482081
17	Water, well, in ground	Raw	m3	x	0.106907415	x	x
18	Wood and wood waste, 20.9 MJ per kg, ovendry basis	Raw	kg	x	185.6510361	x	208.7263515
19	Wood and wood waste, 9.5 MJ per kg	Raw	kg	3.21075E-05	3.21355E-05	x	x
20	Wood, soft, US SE, standing/m3	Raw	m3	x	x	x	1.056604878
21	2-Chloroacetophenone	Air	kg	1.3151E-11	4.56847E-11	8.11462E-12	4.64181E-11
22	5-methyl Chrysene	Air	kg	8.57664E-11	2.9567E-10	5.2921E-11	1.66486E-10
23	Acenaphthene	Air	kg	1.98817E-09	6.85399E-09	1.22677E-09	3.85934E-09
24	Acenaphthylene	Air	kg	9.74621E-10	3.3599E-09	6.01376E-10	1.89189E-09
25	Acetaldehyde	Air	kg	8.23735E-05	0.000728841	3.57812E-05	0.001719876
26	Acetophenone	Air	kg	2.81806E-11	9.78959E-11	1.73885E-11	9.94673E-11
27	Acrolein	Air	kg	1.10648E-05	0.000516431	5.01271E-06	0.007478123
28	Aldehydes, unspecified	Air	kg	0.000394706	0.001686594	0.000161184	0.000634206
29	Ammonia	Air	kg	0.000214002	0.000904373	9.15732E-05	0.000652492
30	Ammonium chloride	Air	kg	1.12352E-05	3.99092E-05	6.93253E-06	2.18823E-05
31	Anthracene	Air	kg	8.18683E-10	2.82232E-09	5.05157E-10	1.58919E-09
32	Antimony	Air	kg	7.03936E-08	1.22941E-06	4.32991E-08	1.48881E-05
33	Arsenic	Air	kg	1.86538E-06	2.41679E-05	1.06711E-06	4.44422E-05
34	Barium	Air	kg	x	0.000763005	x	x
35	Benzene	Air	kg	0.000105582	0.001295539	4.68139E-05	0.007918452
36	Benzene, chloro-	Air	kg	4.13316E-11	1.43581E-10	2.55031E-11	1.45885E-10
37	Benzene, ethyl-	Air	kg	1.76599E-10	6.93994E-10	1.08968E-10	6.23329E-10
38	Benzo(a)anthracene	Air	kg	3.11875E-10	1.07515E-09	1.92438E-10	6.05396E-10
39	Benzo(a)pyrene	Air	kg	1.48143E-10	5.10706E-10	9.14095E-11	2.87568E-10
40	Benzo(b,j,k)fluoranthene	Air	kg	4.28832E-10	1.47835E-09	2.64605E-10	8.32428E-10
41	Benzo(g,h,i)perylene	Air	kg	1.0526E-10	3.62872E-10	6.49492E-11	2.04326E-10
42	Benzyl chloride	Air	kg	1.3151E-09	4.56847E-09	8.11462E-10	4.64181E-09
43	Beryllium	Air	kg	9.21059E-08	5.22874E-07	5.48416E-08	2.2649E-06
44	Biphenyl	Air	kg	6.62746E-09	2.28474E-08	4.08938E-09	1.28649E-08
45	Bromoform	Air	kg	7.32697E-11	2.54529E-10	4.521E-11	2.58615E-10
46	BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	Air	kg	0.000689952	0.004811743	0.00029527	0.003546035
47	Butadiene	Air	kg	4.19929E-06	5.34675E-06	1.82407E-06	2.71223E-06
48	Cadmium	Air	kg	3.27987E-07	1.76423E-06	1.68075E-07	8.36955E-06
49	Carbon dioxide	Air	kg	x	x	x	0.387940417
50	Carbon dioxide, biogenic	Air	kg	19.18702515	389.9056033	24.8357227	365.0154064
51	Carbon dioxide, fossil	Air	kg	49.67036669	227.9076378	23.92201678	108.5247301
52	Carbon disulfide	Air	kg	2.44232E-10	8.48431E-10	1.507E-10	8.6205E-10
53	Carbon monoxide	Air	kg	0.027648663	2.498400905	2.24647E-05	1.162003941
54	Carbon monoxide, fossil	Air	kg	1.115974063	1.180377546	0.463712491	0.525031041
55	Chloride	Air	kg	3.02705E-10	1.05355E-09	1.8678E-10	6.78568E-10
56	Chlorine	Air	kg	8.97629E-09	0.001451336	x	0.001475193
57	Chloroform	Air	kg	1.10844E-10	3.85057E-10	6.83947E-11	3.91238E-10
58	Chromium	Air	kg	1.2409E-06	1.49109E-05	7.01312E-07	4.16248E-05
59	Chromium VI	Air	kg	3.07975E-07	1.06171E-06	1.90032E-07	5.97826E-07
60	Chrysene	Air	kg	3.89852E-10	1.34397E-09	2.40553E-10	7.56762E-10
61	Cobalt	Air	kg	1.5441E-06	4.31635E-06	5.78788E-07	1.36177E-05
62	Copper	Air	kg	8.76266E-09	1.7934E-07	5.10678E-09	9.22764E-08
63	Cumene	Air	kg	9.95716E-12	3.45899E-11	6.14393E-12	3.51451E-11
64	Cyanide	Air	kg	4.69677E-09	1.6316E-08	2.89808E-09	1.65779E-08
65	Dinitrogen monoxide	Air	kg	0.000798902	0.002866567	0.000326802	0.003324541
66	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	kg	5.80321E-12	2.08718E-07	2.64976E-12	3.11841E-06
67	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	kg	1.51906E-16	1.51906E-16	x	x
68	Ethane, 1,1,1-trichloro-, HCFC-140	Air	kg	9.33979E-10	3.98902E-09	3.90016E-10	1.58022E-09
69	Ethane, 1,2-dibromo-	Air	kg	2.25445E-12	7.83167E-12	1.39108E-12	7.95739E-12
70	Ethane, 1,2-dichloro-	Air	kg	7.51484E-11	2.61056E-10	4.63693E-11	2.65246E-10
71	Ethane, chloro-	Air	kg	7.89058E-11	2.74108E-10	4.86877E-11	2.78509E-10
72	Ethene, tetrachloro-	Air	kg	1.82195E-07	6.20452E-07	1.08039E-07	3.42634E-07
73	Ethene, trichloro-	Air	kg	2.62384E-11	2.71274E-11	x	x
74	Fluoranthene	Air	kg	2.76794E-09	9.54217E-09	1.70792E-09	5.373E-09
75	Fluorene	Air	kg	3.54755E-09	1.22298E-08	2.18897E-09	6.88633E-09
76	Fluoride	Air	kg	3.34582E-07	1.18848E-06	2.06449E-07	5.167E-06
77	Formaldehyde	Air	kg	0.000167358	0.001923641	5.88787E-05	0.008319854
78	Furan	Air	kg	1.77491E-11	6.31152E-11	1.09518E-11	3.61766E-11
79	Heat, waste	Air	MJ	0.39771	x	0.52046	x
80	Hexane	Air	kg	1.25874E-10	4.37268E-10	7.76685E-11	4.44287E-10
81	Hydrazine, methyl-	Air	kg	3.19381E-10	1.10949E-09	1.97069E-10	1.1273E-09
82	Hydrocarbons, unspecified	Air	kg	6.48455E-05	0.000230341	4.0012E-05	0.000126297
83	Hydrogen chloride	Air	kg	0.004818197	0.018896858	0.002929338	0.044715943
84	Hydrogen fluoride	Air	kg	0.000584709	0.002015663	0.000360775	0.001134831
85	Hydrogen sulfide	Air	kg	9.78444E-12	3.40544E-11	6.03736E-12	2.19336E-11
86	Indeno(1,2,3-cd)pyrene	Air	kg	2.37814E-10	8.19838E-10	1.4674E-10	4.61634E-10
87	Iron	Air	kg	x	0.000763005	x	x
88	Isophorone	Air	kg	1.08965E-09	3.78531E-09	6.72354E-10	3.84607E-09
89	Isoprene	Air	kg	0.009921691	0.034532074	0.006122043	0.022241254
90	Kerosene	Air	kg	5.38147E-06	1.91142E-05	3.32018E-06	1.048E-05
91	Lead	Air	kg	1.98363E-06	0.00022075	1.12535E-06	9.32676E-05
92	Magnesium	Air	kg	4.28832E-05	0.000147835	2.64605E-05	8.32428E-05
93	Manganese	Air	kg	2.50896E-06	0.001768589	1.35847E-06	0.002991965
94	Mercaptans, unspecified	Air	kg	3.81527E-07	1.35651E-06	2.35416E-07	1.41564E-06
95	Mercury	Air	kg	3.63339E-07	1.76988E-06	2.14805E-07	7.28671E-06
96	Metals, unspecified	Air	kg	1.45013E-08	0.005345182	6.92614E-13	0.079867914
97	Methane	Air	kg	0.08692436	0.421212633	0.041932457	0.278714432
98	Methane, biogenic	Air	kg	5.589	x	7.314	x
99	Methane, bromo-, Halon 1001	Air	kg	3.00594E-10	1.04422E-09	1.85477E-10	1.06098E-09

100 Methane, dichloro-, HCC-30	Air	kg	2.09877E-06	4.28123E-05	9.94679E-07	0.000544782
101 Methane, dichlorodifluoro-, CFC-12	Air	kg	1.10892E-09	4.77325E-09	4.53798E-10	1.79079E-09
102 Methane, fossil	Air	kg	0.012505587	0.037332056	0.005374387	0.024399024
103 Methane, monochloro-, R-40	Air	kg	9.95716E-10	3.45899E-09	6.14393E-10	3.51451E-09
104 Methane, tetrachloro-, CFC-10	Air	kg	2.21369E-10	5.6243E-06	4.53798E-11	8.40302E-05
105 Methanol	Air	kg	x	x	x	0.000199253
106 Methyl ethyl ketone	Air	kg	7.32697E-10	2.54529E-09	4.521E-10	2.58615E-09
107 Methyl methacrylate	Air	kg	3.75742E-11	1.30528E-10	2.31846E-11	1.32623E-10
108 N-Nitrodimethylamine	Air	kg	5.80007E-12	5.99872E-12	x	x
109 Naphthalene	Air	kg	2.9319E-07	0.000429068	1.05857E-07	0.000181492
110 Nickel	Air	kg	1.73382E-05	0.000135687	5.44088E-06	7.41356E-05
111 Nitrogen oxides	Air	kg	0.363888569	1.746210706	0.170237861	1.193315102
112 Nitrogen, total	Air	kg	x	x	x	8.76702E-05
113 NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kg	0.020800881	0.084952299	0.008191468	0.033816433
114 Organic acids	Air	kg	4.12865E-08	1.46656E-07	2.54753E-08	8.04118E-08
115 Organic substances, unspecified	Air	kg	2.6016E-05	0.028871248	1.49451E-05	4.70208E-05
116 PAH, polycyclic aromatic hydrocarbons	Air	kg	1.80433E-05	2.29731E-05	7.83758E-06	1.16535E-05
117 Particulates, < 10 um	Air	kg	4.46743E-05	0.0332225	x	x
118 Particulates, > 2.5 um, and < 10um	Air	kg	0.004557214	0.091028294	0.002277674	0.947526756
119 Particulates, unspecified	Air	kg	0.01519143	0.874807804	0.008906701	0.343247833
120 Phenanthrene	Air	kg	1.0526E-08	3.62872E-08	6.49492E-09	2.04326E-08
121 Phenol	Air	kg	7.20543E-10	0.006936408	1.85477E-11	2.06475E-05
122 Phenols, unspecified	Air	kg	7.91815E-07	8.6026E-06	2.62337E-07	9.61544E-05
123 Phosphate	Air	kg	x	x	x	2.00047E-06
124 Phthalate, dioctyl-	Air	kg	1.37146E-10	4.76427E-10	8.46239E-11	4.84074E-10
125 Potassium	Air	kg	x	0.135259945	x	x
126 Propanal	Air	kg	7.1391E-10	2.48003E-09	4.40508E-10	2.51984E-09
127 Propene	Air	kg	0.000277089	0.000352801	0.000120361	0.000178965
128 Propylene oxide	Air	kg	x	7.29658E-11	x	x
129 Pyrene	Air	kg	1.2865E-09	4.43505E-09	7.93815E-10	2.49728E-09
130 Radioactive species, unspecified	Air	Bq	220696.1287	760660.4401	136098.3141	428047.3597
131 Radionuclides (Including Radon)	Air	kg	0.000300902	0.001068848	0.000185667	0.000586052
132 Selenium	Air	kg	5.22194E-06	1.85198E-05	3.17861E-06	1.53823E-05
133 Sodium	Air	kg	x	0.003121383	x	x
134 Styrene	Air	kg	4.69677E-11	1.6316E-10	2.89808E-11	1.65779E-10
135 Sulfur dioxide	Air	kg	0.163796405	0.743235329	0.09183665	0.481662491
136 Sulfur oxides	Air	kg	0.040618974	0.172844458	0.016647482	0.108597679
137 Sulfuric acid, dimethyl ester	Air	kg	9.01781E-11	3.13267E-10	5.56431E-11	3.18295E-10
138 t-Butyl methyl ether	Air	kg	6.57548E-11	2.28424E-10	4.05731E-11	2.3209E-10
139 Tar	Air	kg	3.4046E-10	1.18496E-09	2.10076E-10	7.63202E-10
140 TOC, Total Organic Carbon	Air	kg	x	0.000511133	x	0.007637393
141 Toluene	Air	kg	4.39265E-05	5.59305E-05	1.90807E-05	2.83724E-05
142 Toluene, 2,4-dinitro-	Air	kg	5.26039E-13	1.82739E-12	3.24585E-13	1.85672E-12
143 Vinyl acetate	Air	kg	1.42782E-11	4.96006E-11	8.81016E-12	5.03968E-11
144 VOC, volatile organic compounds	Air	kg	0.026182848	1.231171265	0.011134295	0.376528589
145 Xylene	Air	kg	3.06087E-05	3.8973E-05	1.32957E-05	1.97698E-05
146 Zinc	Air	kg	5.84177E-09	0.000763124	3.40452E-09	1.6771E-06
147 2-Hexanone	Water	kg	2.79726E-07	1.35871E-06	1.15556E-07	6.55918E-07
148 4-Methyl-2-pentanone	Water	kg	1.80037E-07	8.74494E-07	7.4374E-08	4.22162E-07
149 Acetone	Water	kg	4.28395E-07	2.08085E-06	1.76972E-07	1.00453E-06
150 Acidity, unspecified	Water	kg	4.90244E-11	4.90365E-11	x	x
151 Acids, unspecified	Water	kg	6.35839E-09	2.21301E-08	3.92336E-09	1.42535E-08
152 Aluminium	Water	kg	0.003297335	0.014562978	0.001370755	0.00593024
153 Ammonia	Water	kg	0.000762179	0.003568032	0.000315077	0.001619134
154 Ammonia, as N	Water	kg	3.19325E-09	1.1114E-08	1.97035E-09	7.15824E-09
155 Ammonium, ion	Water	kg	2.40216E-06	6.61583E-06	1.48222E-06	4.67857E-06
156 Antimony	Water	kg	2.0029E-06	8.8875E-06	8.21503E-07	3.58594E-06
157 Arsenic, ion	Water	kg	1.14315E-05	5.4387E-05	4.73003E-06	2.91491E-05
158 Barium	Water	kg	0.044225109	0.197105639	0.018145317	0.080320868
159 Benzene	Water	kg	7.1867E-05	0.000349073	2.96886E-05	0.00016852
160 Benzene, 1-methyl-4-(1-methylethyl)-	Water	kg	4.28095E-09	2.07939E-08	1.76848E-09	1.00383E-08
161 Benzene, ethyl-	Water	kg	4.04269E-06	1.96366E-05	1.67005E-06	9.47963E-06
162 Benzene, pentamethyl-	Water	kg	3.21075E-09	1.55956E-08	1.32638E-09	7.52878E-09
163 Benzenes, alkylated, unspecified	Water	kg	1.75686E-06	7.79511E-06	7.20586E-07	3.14457E-06
164 Benzo(a)pyrene	Water	kg	x	8.71687E-10	x	x
165 Benzoic acid	Water	kg	4.3458E-05	0.00021109	1.79527E-05	0.000101904
166 Beryllium	Water	kg	6.15994E-07	2.88877E-06	2.53745E-07	1.30804E-06
167 Biphenyl	Water	kg	1.13749E-07	5.04701E-07	4.66549E-08	2.03599E-07
168 BOD5, Biological Oxygen Demand	Water	kg	0.007774409	0.28058594	0.003210139	3.648924516
169 Boron	Water	kg	0.000134624	0.000653275	5.55454E-05	0.000315288
170 Bromide	Water	kg	0.00917871	0.044585209	0.003791775	0.021524725
171 Cadmium, ion	Water	kg	1.717E-06	8.10037E-06	7.12535E-07	5.0297E-06
172 Calcium, ion	Water	kg	0.137634332	0.668566023	0.056857903	0.322781263
173 Chloride	Water	kg	1.547287631	7.515803026	0.639192781	3.628429016
174 Chromate	Water	kg	5.73102E-10	5.73873E-10	x	x
175 Chromium	Water	kg	8.12708E-05	0.000349797	3.32549E-05	0.000136857
176 Chromium VI	Water	kg	3.41926E-07	1.47179E-06	1.39924E-07	5.52173E-07
177 Chromium, ion	Water	kg	9.76081E-06	5.40097E-05	4.07854E-06	3.15997E-05
178 Cobalt	Water	kg	9.49108E-07	4.61012E-06	3.92081E-07	2.22555E-06
179 COD, Chemical Oxygen Demand	Water	kg	0.014454992	0.069017324	0.00596115	0.032331671
180 Copper, ion	Water	kg	1.33145E-05	5.88711E-05	5.925E-06	2.92382E-05
181 Cyanide	Water	kg	3.12277E-09	1.14769E-07	1.28952E-09	7.29457E-09
182 Decane	Water	kg	1.24877E-06	6.06568E-06	5.15874E-07	2.92821E-06
183 Detergent, oil	Water	kg	3.71296E-05	0.00018343	1.536E-05	9.113E-05
184 Dibenzofuran	Water	kg	8.14577E-09	3.95666E-08	3.36505E-09	1.91009E-08
185 Dibenzothiophene	Water	kg	6.95088E-09	3.36151E-08	2.8704E-09	1.61042E-08
186 DOC, Dissolved Organic Carbon	Water	kg	1.95244E-11	6.79539E-11	1.20473E-11	4.37674E-11
187 Docosane	Water	kg	4.58418E-08	2.22669E-07	1.89375E-08	1.07494E-07
188 Dodecane	Water	kg	2.36933E-06	1.15086E-05	9.78782E-07	5.55581E-06
189 Eicosane	Water	kg	6.52339E-07	3.16862E-06	2.69484E-07	1.52966E-06
190 Fluorene, 1-methyl-	Water	kg	4.87556E-09	2.36821E-08	2.01412E-09	1.14326E-08
191 Fluorenes, alkylated, unspecified	Water	kg	1.01814E-07	4.51746E-07	4.17597E-08	1.82236E-07
192 Fluoride	Water	kg	3.9076E-05	0.000138827	2.41098E-05	0.011203709
193 Fluorine	Water	kg	5.07316E-08	2.26643E-07	2.08187E-08	9.28492E-08
194 Hexadecane	Water	kg	2.58613E-06	1.25616E-05	1.06834E-06	6.06415E-06
195 Hexanoic acid	Water	kg	8.99973E-06	4.37146E-05	3.71783E-06	2.11033E-05
196 Hydrocarbons, unspecified	Water	kg	2.44297E-11	8.50267E-11	1.5074E-11	5.47636E-11
197 Iron	Water	kg	0.006751376	0.030279538	0.002814926	0.012788917
198 Lead	Water	kg	2.31121E-05	0.000106797	9.57503E-06	4.92358E-05
199 Lead-210/kg	Water	kg	4.45123E-15	2.1621E-14	1.83882E-15	1.04376E-14
200 Lithium, ion	Water	kg	0.009561175	0.066582562	0.004091097	0.049011523
201 m-Xylene	Water	kg	1.29796E-06	6.30462E-06	5.36193E-07	3.04359E-06
202 Magnesium	Water	kg	0.026906192	0.13069937	0.01111512	0.06310174
203 Manganese	Water	kg	0.000111269	0.000451528	5.98552E-05	0.000237695
204 Mercury	Water	kg	3.82188E-08	1.66821E-07	1.63188E-08	1.2516E-07

205	Metallic ions, unspecified	Water	kg	1.03602E-06	1.03702E-06	1.84046E-10	6.68634E-10
206	Methane, monochloro-, R-40	Water	kg	1.72433E-09	8.37564E-09	7.1233E-10	4.04336E-09
207	Methyl ethyl ketone	Water	kg	3.44855E-09	1.67507E-08	1.42461E-09	8.08642E-09
208	Molybdenum	Water	kg	9.84803E-07	4.7835E-06	4.06826E-07	2.30924E-06
209	n-Hexacosane	Water	kg	2.85994E-08	1.38916E-07	1.18146E-08	6.70621E-08
210	Naphthalene	Water	kg	7.80116E-07	3.78142E-06	3.22261E-07	1.82772E-06
211	Naphthalene, 2-methyl-	Water	kg	6.78563E-07	3.29599E-06	2.80317E-07	1.59115E-06
212	Naphthalenes, alkylated, unspecified	Water	kg	2.87887E-08	1.27734E-07	1.18078E-08	5.15285E-08
213	Nickel	Water	kg	1.08905E-05	5.10226E-05	4.48575E-06	2.49356E-05
214	Nickel, ion	Water	kg	x	2.31632E-10	x	x
215	Nitrate	Water	kg	2.3E-10	2.44338E-10	1.32066E-12	4.79792E-12
216	Nitrate compounds	Water	kg	8.61713E-11	2.99916E-10	5.31708E-11	1.93168E-10
217	Nitric acid	Water	kg	1.93286E-07	6.72724E-07	1.19264E-07	4.33285E-07
218	Nitrogen, total	Water	kg	5.97993E-06	2.13503E-05	3.68984E-06	1.16468E-05
219	o-Cresol	Water	kg	1.23239E-06	5.98613E-06	5.09107E-07	2.88982E-06
220	Octadecane	Water	kg	6.38901E-07	3.10335E-06	2.63933E-07	1.49815E-06
221	Oils, unspecified	Water	kg	0.000981118	0.004650683	0.00040586	0.00218248
222	Organic substances, unspecified	Water	kg	4.97148E-07	4.99635E-07	x	x
223	p-Cresol	Water	kg	1.32966E-06	6.4586E-06	5.49288E-07	3.11793E-06
224	Phenanthrene	Water	kg	1.0827E-08	4.96386E-08	4.45198E-09	2.14911E-08
225	Phenanthrenes, alkylated, unspecified	Water	kg	1.1937E-08	5.29639E-08	4.89601E-09	2.13658E-08
226	Phenol	Water	kg	1.51356E-05	6.51386E-05	6.19249E-06	2.44369E-05
227	Phenol, 2,4-dimethyl-	Water	kg	1.19997E-06	5.82865E-06	4.95714E-07	2.8138E-06
228	Phenols, unspecified	Water	kg	6.09505E-06	3.68337E-05	2.56861E-06	2.3834E-05
229	Phosphate	Water	kg	2.07145E-08	1.96866E-08	x	0.008376962
230	Phosphorus	Water	kg	x	2.19489E-09	x	x
231	Radioactive species, Nuclides, unspecified	Water	Bq	348.9136622	1239.39443	215.292391	679.5631383
232	Radium-226/kg	Water	kg	1.54861E-12	7.52204E-12	6.39736E-13	3.63126E-12
233	Radium-228/kg	Water	kg	7.92139E-15	3.84767E-14	3.27236E-15	1.85748E-14
234	Selenium	Water	kg	1.22962E-06	4.71283E-06	6.78303E-07	2.33496E-06
235	Silver	Water	kg	8.99456E-05	0.000436795	3.71562E-05	0.000210781
236	Sodium, ion	Water	kg	0.436307313	2.11937221	0.180242611	1.023216853
237	Solids, inorganic	Water	kg	4.91424E-10	1.71038E-09	3.03226E-10	1.10161E-09
238	Solved solids	Water	kg	1.908660079	9.270560665	0.788398128	4.47564447
239	Strontium	Water	kg	0.002335453	0.011344004	0.000964786	0.005476322
240	Sulfate	Water	kg	0.007997099	0.03248363	0.004294245	0.016827245
241	Sulfide	Water	kg	1.75587E-06	7.8514E-06	7.18554E-07	2.83556E-06
242	Sulfur	Water	kg	0.000113501	0.000551312	4.6888E-05	0.000266148
243	Sulfuric acid	Water	kg	4.07386E-08	4.13776E-08	x	x
244	Suspended solids, unspecified	Water	kg	0.1001116	0.445249952	0.041257201	0.181847715
245	Tar	Water	kg	4.87021E-12	1.69506E-11	3.00509E-12	1.09174E-11
246	Tetradecane	Water	kg	1.03839E-06	5.04377E-06	4.28962E-07	2.43489E-06
247	Thallium	Water	kg	4.221E-07	1.87317E-06	1.73129E-07	7.55954E-07
248	Tin	Water	kg	8.61387E-06	3.96856E-05	3.54331E-06	1.73537E-05
249	Titanium, ion	Water	kg	3.07602E-05	0.000136499	1.26166E-05	5.50799E-05
250	Toluene	Water	kg	6.78984E-05	0.000329804	2.80491E-05	0.000159214
251	Vanadium	Water	kg	1.1633E-06	5.65052E-06	4.80564E-07	2.7278E-06
252	Water	Water	kg	x	0.006119306	x	x
253	Xylene	Water	kg	3.62544E-05	0.000175529	1.49728E-05	8.42605E-05
254	Yttrium	Water	kg	2.88705E-07	1.40232E-06	1.19265E-07	6.76972E-07
255	Zinc	Water	kg	7.8296E-05	0.000345884	3.29023E-05	0.000143119
256	Zinc, ion	Water	kg	3.79766E-09	-6.34299E-09	x	x
257	Waste, solid	Waste	kg	0.000780247	0.000780247	x	x
258	Bark	Soil	kg	x	x	x	4.836418555
259	Cost, Total	Non mat.	$US	x	6.236109334	x	x