Life-Cycle Inventory Analysis of Manufacturing Redwood Decking

Richard D. Bergman[1] – Han-Sup Han[2] – Elaine Oneil[3]—Ivan L. Eastin[3]*

[1] Research Forest Product Technologist, U.S. Forest Service Forest Products Laboratory, Madison, Wisconsin, USA
* *Corresponding author*
rbergman@fs.fed.us
[2] Professor, Forest Operations and Engineering, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, USA
[3] Research Scientist and Executive Director (CORRIM), School of Forest Resources, University of Washington, Seattle, Washington, USA
[4] Professor and Director, Center for International Trade in Forest Products, University of Washington, Seattle, Washington, USA

Abstract

Green building has become increasingly important. Therefore, consumers and builders often take into account the environmental attributes of a building material. This study determined the environmental attributes associated with manufacturing 38-mm × 138-mm (nominal 2 × 6) redwood decking in northern California using the life-cycle inventory method. Primary data collected from four redwood mills represented over 83% of redwood lumber production. The primary data were then weight-averaged on a per-unit basis of one m^3 of planed redwood decking (380 oven dry (OD) kg/m^3) to calculate material flows and energy use. The cumulative unallocated energy consumption associated with manufacturing 1.0-m^3 planed redwood decking from 1.8 m^3 of incoming logs was found to be 1,500 MJ/m^3 with 14% of the energy provided by burning wood residues. Emission data produced through modeling the production process found that the estimated total biomass and fossil carbon dioxide emissions were 20.6 and 69.7 kg/m^3, respectively. Our analysis estimated that 38-mm × 138-mm redwood decking stores 697 kg CO_2-equivalents per m^3 of planed redwood decking assuming carbon content of wood of 50%. The amount of carbon stored in redwood decking exceeds the total carbon emissions during manufacturing by a factor of eight. Therefore, low carbon manufacturing emissions and redwood decking's ability to store carbon when in-use are positive environmental attributes when selecting a decking product.

***Keywords*:** Life-cycle inventory, LCI, redwood decking, manufacturing, environmental attributes.

Introduction

Categorizing building materials with positive environmental attributes is the result of the drive for green building. Green building is the practice of improving energy efficiency, construction, and operation of buildings while decreasing overall environmental burdens. By 2013, the green building market for new non-residential construction could triple to $96–140 billion from $42 billion in 2008 (MHC 2010). Creating a science-based green building policy for the building industry would aid in producing sustainable building practices. However, to create such a policy and to address environmental claims, scientific approaches such as life-cycle analysis will be required to assess building materials and practices for their environmental attributes.

The goal of this study was to document the life-cycle inventory (LCI) of redwood (*Sequoia sempervirens*) decking production from incoming logs to redwood decking in northern California. The present study listed material flow, energy consumption, and emissions for the redwood decking manufacturing process on a per-unit basis. Primary data collected by surveying redwood sawmills primarily used a questionnaire. Peer-reviewed literature provided secondary data per CORRIM guidelines (CORRIM 2010). Material balances constructed with a spreadsheet algorithm used data from primary and secondary sources. From material and energy inputs and reported emissions, SimaPro 7 software (PRé Consultants, Amersfoort, Netherlands) modeled the estimates for environmental outputs (PRé Consultants 2012).

Methodology

Scope. This study covered the manufacturing redwood logs leaving the forest landing to redwood decking leaving the sawmill according to ISO 14040 and 14044 standards (ISO 2006a,b). LCI data from this study will help conduct a comparative life-cycle assessment (LCA) for redwood decking to other non-wood decking materials. To construct a full LCA, this manufacturing LCI will be linked to forest resources (upstream) and product transportation (downstream). The LCI provided a gate-to-gate analysis of cumulative energy of manufacturing as well as transportation of raw materials. Analyses included redwood's contribution to cumulative energy consumption and emission data.

Four redwood mills representing over 83% of redwood lumber production provided 2010 primary data. In 2011, site visits were conducted at the four mills. The surveyed mills provided detail annual production data on their facilities including on-site energy consumption, electrical usage, log volumes, and decking production for 2010.

Functional unit. Delineating system boundaries determined the unit processes to include and standardized material flows, energy use, and emission data. The present study selected a functional unit of one m^3 of decking material with 38-mm thickness and assumed no spacing between deck boards. Based on U.S. industry measures, converted green and dry wood decking using the following conversions: 2.36 m^3 and 1.62 m^3 per thousand board feet (bf), respectively, since wood shrinks as it dries from its green state to its final dry state and is planed (Bergman 2010). For dry redwood decking, 10 m^2 at 38-mm thickness equals 0.38 m^3 (231 bf). Results were reported per m^3 of planed redwood decking.

Unit processes. Five main unit processes were identified in manufacturing redwood decking. These included resource transport, log yard, sawing, drying, and planing with energy generation considered an auxiliary process. All emissions (i.e., environmental outputs) and energy consumed were assigned to the redwood decking and none to the co-products (i.e., redwood decking residue). The present study was consistent with the Mahalle and O'Connor (2009) LCA study on western redcedar (*Thuja plicata*) where the price for decking is much higher than the co-products is (10 to 1. Therefore, no primary energy and environmental outputs were allocated to the mill residues. Green wood residues included sawdust, chips, hog fuel, and bark. Some mills ground all wood residues into hog fuel. Diesel logging trucks transported the redwood logs from the forest landing to the log yard. Logs in the log yard were wetted to maintain log quality and prevent checking or splitting depending on the season and the mill. Log stackers or front-end loaders transported logs from the yard to the sawmill. Sawing the logs produced rough green redwood decking. The sawing process (less the bark) produces rough green decking (59.9%), wood chips (22.7%), sawdust (9.5%), hog fuel (5.0%), and shavings (1.9%). The three processing options for rough green decking include 1) planing on all four sides and selling as green decking (7.6%), 2) selling as-is (28.4%), or 3) drying, planing and selling as dry decking (64%). Drying rough green decking occurs mostly by air-drying with minimal kiln-drying to reach the desired moisture content (MC). After drying, the rough dry decking was planed on all four sides producing shavings.

System boundary. Boundary selection helps track the material and energy flows crossing the boundary precisely. To track flows tied to redwood decking production, two system boundaries were considered. One—the cumulative system boundary—is shown by the solid line in Figure 1 and includes both on- and off-site emissions for all material and energy consumed. Fuel resources used for the cradle-to-gate production of energy and electricity were included within the cumulative system boundary. The on-site system boundary (dotted line in Figure 1) covered emissions occurring only at the mill from the four unit processes involved: log yard, sawing, drying, and planing. Off-site emissions include grid electricity production, transportation of logs to the mill, and fuels produced off-site but consumed onsite. Ancillary material data such as motor oil, paint, and hydraulic fluid were collected and were part of the analysis.

Results and Discussion

By surveying four redwood mills in northern California in 2010, detailed primary data on mass flow, energy consumption, and fuel types provided life-cycle information including air emission data. SimaPro 7 modeled weight-averaged survey data to estimate non-wood raw material use and emission data on a 1-m^3 unit basis.

To confirm the data quality, a mass balance was performed and the results are summarized in Table 1. In performing the mass balance for redwood decking, all of unit processes located within the site system boundary were considered. Using a weight-averaged approach, 648 OD kg (1.8 m^3) of incoming redwood logs with a green density (127% MC) of 803 kg/m^3 produced 1.0 m^3 (380 OD kg) of planed redwood decking. The sawing process yielded 388 kg of rough green decking with no loss of wood substance occurring during the drying process. Planing the rough lumber into a surfaced decking product reduced the 388 OD kg of rough dry decking to 380 OD kg of planed dry redwood decking, for a 2% reduction in mass. Some wood waste was converted on-site to thermal energy in a boiler; boilers burned all 8 OD kg of dry shavings produced onsite for thermal process energy. Overall, an average redwood log was reduced to 58.6% (380/648) of its original mass during its conversion to planed dry redwood decking.

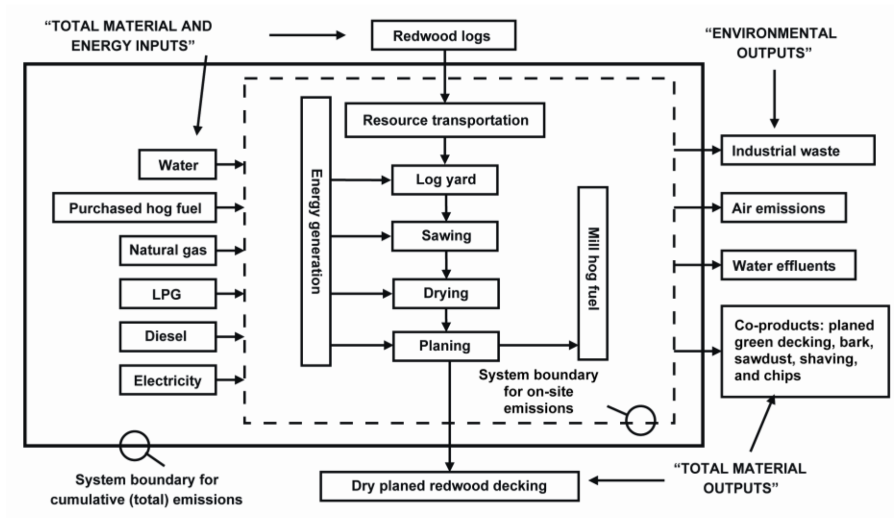

Figure1: System boundaries for redwood decking manufacturing

Table 1: Mass balance of redwood decking

Material (OD kg)	Sawing process In	Sawing process Out	Boiler process In	Dryer process In	Dryer process Out	Planer process In	Planer process Out	All process combined In	All process combined Out	All process combined Diff
Green logs (wood)	648	-	-	-	-	-	-	648	0	–648
Green logs (bark)	71	-	-	-	-	-	-	71	0	–71
Green chips	-	147	-	-	-	-	-	0	147	147
Green sawdust	-	68	-	-	-	-	-	0	68	68
Green bark	-	71	-	-	-	-	-	0	71	71
Green shaving	-	12	-	-	-	-	-	0	12	12
Green hog fuel	-	32	-	-	-	-	-	0	32	32
Rough green decking	-	388	-	388	-	-	-	388	388	0
Rough dry decking	-	-	-	-	388	388	-	388	388	0
Planed dry decking	-	-	-	-	-	-	380	0	380	380
Dry shavings	-	-	8	-	-	-	8	8	8	0
Sum	719	719	8	388	388	388	388	1503	1495	-8

Redwood decking in service stores carbon. Carbon content for wood products is assumed to be 50% by mass of oven-dried (OD) wood. Therefore, the carbon stored in one m^3 (380 OD kg) of redwood decking is equivalent to 697 kg CO_2.

Table 2 shows the cumulative unallocated energy consumption for a cubic meter of planed dry redwood decking. Cumulative energy consumption for manufacturing redwood decking was 1,500 MJ/m^3 with wood fuel comprising about 14%. Coal (33.2%), natural gas (20.0%), and crude oil (17.4%) were the three highest energy resources consumed during product production. Coal makes up about 35% of the grid in the western United States. Therefore, coal has the highest energy consumption because the mills use grid electricity. Because of the minimal kiln-drying that occurs during the production of redwood decking, less than 10 kg of wood fuel was burned in boilers on-site for energy per cubic meter of redwood decking made. Usually, most energy for processing wood products comes from wood fuel generated on-site and burned on-site (Puettmann et al. 2010). However, redwood decking is not the only wood product to have a low energy consumption profile. Douglas-fir (*Pseudotsuga menziesii*) used for structural lumber is usually not kiln-dried, and therefore, is installed green and dries in place. Thus, the energy profile for green Douglas fir looks similar to redwood decking (Milota et al. 2005; Puettmann and Wilson 2005).

Table 2: Cumulative energy (higher heating values (HHV)) consumed during production of planed (surfaced) redwood decking—cumulative, unallocated gate-to-gate LCI values[a]

Fuel[b,c]	(kg/m^3)	(MJ/m^3)	(%)
Wood fuel/wood waste	9.95	208	13.8%
Coal[d]	19.1	499	33.2%
Natural gas[d]	5.52	301	20.0%
Crude oil[d]	5.77	263	17.4%
Hydro	0	95.8	6.4%
Uranium[d]	0.000357	136	9.0%
Energy, unspecified	0	2.27	0.2%
Total	—	1,500	100%

[a] Includes fuel used for electricity production and for log transportation (unallocated).
[b] Values are unallocated and cumulative and based on HHV.
[c] Energy values were found using their HHV in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.
[d] Materials as they exist in nature and have neither emissions nor energy consumption associated with them.

Most wood products consume more energy per cubic meter of final product during the manufacturing stage than redwood decking. For making hardwood lumber in the southeastern United States, cumulative allocated energy consumption for one m^3 of planed dry hardwood lumber is 5,860 MJ/m^3 with 66% from wood fuel (Bergman and Bowe 2012). The values listed in Puettmann et al. (2010) and Bergman and Bowe (2012) studies use mass allocation. The present study allocates all primary energy to redwood decking and none to its residues. Primary energy is energy embodied in the original resources such as crude oil and coal before conversion. However, cumulative unallocated energy for manufacturing redwood decking is still only 26% of southeastern hardwood lumber (Bergman and Bowe 2012). The low cumulative energy for redwood decking occurred because of minimal use of kiln drying, which is the most energy-intensive part of producing dry lumber products.

Table 3 lists the unallocated environmental outputs for manufacturing one m^3 of redwood decking for the cumulative and on-site system boundaries. The cumulative values included all emissions and were higher than the on-site emissions. For the cumulative system boundary, biogenic CO_2 and fossil CO_2 were 20.6 and 69.7 kg/m^3. Fossil CO_2 for the cumulative case was about eight (69.8/8.94) times the fossil CO_2 emitted for the on-site case. For on-site, the only sources of fossil CO_2 came from rolling stock such as front-end loaders moving logs and forklifts moving lumber around the mill. Additionally, mercury emissions to air dropped by a factor of 11 (0.176/0.0152) because emissions from grid electricity consumed at the mill were not included in the on-site case.

Table 3: Environmental outputs for manufacturing one m^3 of planed redwood decking

Substance	Cumulative (kg/m^3)	On-site (kg/m^3)
Water effluents		
BOD5 (Biological oxygen demand)	2.09E-01	1.69E-01
Chloride	1.71	0.389
COD (Chemical oxygen demand)	2.21E-02	1.02E-02
DOC (Dissolved organic carbon)	2.17E-03	1.87E-03
Oils, unspecified	3.14E-03	2.11E-03
Suspended solids, unspecified	7.07E-02	2.58E-02
Industrial waste[a]		
Waste in inert landfill	0.267	0.267
Waste to recycling	0.222	0.222
Solid waste[b]	0.111	0.092
Air emissions		
Acetaldehyde	1.19E-04	1.04E-04
Acrolein	4.06E-04	3.35E-04
Benzene	4.98E-04	3.92E-04
CO	0.239	4.97E-02
CO_2 (biomass (biogenic))	20.6	16.2
CO_2 (fossil)	69.8	8.94
CH_4	5.06E-04	4.16E-04
Formaldehyde	1.09E-06	3.08E-07
Mercury	0.176	1.52E-02
NO_x	6.15E-04	3.95E-05
Non-methane VOC	1.61E-02	8.41E-03
Particulate (PM10)	5.77E-02	4.55E-02
Particulate (unspecified)	2.67E-02	1.70E-03
Phenol	3.79E-07	3.68E-07
SO_x	0.399	0.0127
VOC	5.21E-02	5.14E-03

[a] Includes solid materials not incorporated into the product or co-products but left the system boundary.
[b] Solid waste was boiler ash from burning wood. Wood ash is typically

used a soil amendment or landfilled.

Coal power plants are major emitters of mercury in the United States (Pirrone et al. 2010). Sulfur dioxide is similar to mercury as its emissions follow coal power production. Biogenic (biomass) CO_2 decreased by about 21% because some wood fuel burned to provide thermal energy for the mills was burned off-site (outside the system boundary), and then the boiler steam was pumped to mills. Solid waste (wood boiler ash) follows wood fuel consumption.

Conclusions

The amount of carbon stored in redwood decking is about eight times the total carbon dioxide emissions released during manufacturing. Therefore, low carbon manufacturing emissions and redwood decking's ability to store carbon when in use similar to other wood products are positive environmental attributes when selecting a decking product.

Air-drying redwood decking dramatically lowers energy consumption during product production. Wood product production usually consumes more fossil and wood fuel than found for redwood decking manufacturing. The main reason is that most wood product manufacturing facilities especially when processing hardwoods kiln-dry their final product when it is freshly cut or green. An additional benefit, redwood decking can typically equilibrate to exterior conditions without any issues after installation.

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