Journal of Transportation Technologies, 2013, 3, 58-67
http://dx.doi.org/10.4236/jtts.2013.31007 Published Online January 2013 (http://www.scirp.org/journal/jtts)

Life Cycle Assessment of CCA-Treated Wood Highway Guard Rail Posts in the US with Comparisons to Galvanized Steel Guard Rail Posts

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Received November 6, 2012; revised December 7, 2012; accepted December 18, 2012

ABSTRACT

A cradle-to-grave life cycle assessment is done to identify the environmental impacts of chromated copper arsenate (CCA)-treated timber used for highway guard rail posts, to understand the processes that contribute to the total impacts, and to determine how the impacts compare to the primary alternative product, galvanized steel posts. Guard rail posts are the supporting structures for highway guard rails. Transportation engineers, as well as public and regulatory interests, have increasing need to understand the environmental implications of guard rail post selection, in addition to factors such as costs and service performance. This study uses a life cycle inventory (LCI) to catalogue the input and output data from guard rail post manufacture, service life, and disposition, and a life cycle impact assessment (LCIA) to assess anthropogenic and net greenhouse gas (GHG), acidification, smog, ecotoxicity, and eutrophication potentially resulting from life cycle air emissions. Other indicators of interest also are tracked, such as fossil fuel and water use. Comparisons of guard rail post products are made at a functional unit of one post per year of service. This life cycle assessment (LCA) finds that the manufacture, use, and disposition of CCA-treated wood guard rails offers lower fossil fuel use and lower anthropogenic and net GHG emissions, acidification, smog potential, and ecotoxicity environmental impacts than impact indicator values for galvanized steel posts. Water use and eutrophication impact indicator values for CCA-treated guard rail posts are greater than impact indicator values for galvanized steel guard rail posts.

Keywords: Life Cycle Assessment; LCA; LCI; Environmental Impact; Treated Wood; Chromated Copper Arsenate; CCA; Guard Rail Post; Greenhouse Gas; GHG; Galvanized Steel

1. Introduction

A highway department's selection of a guard rail system and its materials primarily is based on safety; however factors such as cost, aesthetics, and environmental acceptance play a role in decisions made. While most highway guard rails are made of W-beam galvanized steel, the supporting posts are mostly either preserved wood or galvanized steel; The feasibility of composite materials as guard rail posts, has been studied [1], but the current use does not represent a significant portion of the guard rail post market.

While wood products are susceptible to degradation when left untreated, wood preservative treatments can extend the useful life of a wood product by 20 to 40 times that of untreated wood [2] when used in weather exposed or wet environments subject to microbial or insect attack. Chromated copper arsenate (CCA) was introduced in the 1930s and subsequently adopted throughout the United States for many exterior and marine uses. CCA has a long history of proven performance in transportation systems [3]. While alternative copper-based water-borne preservatives such as alkaline copper quaternary (ACQ) and copper azoles became popular in the early 2000s, CCA is approved for industrial uses [4] and remains the waterborne preservative of choice for many demanding, commercial applications, including guard rail systems. CCA is a mixture of chromic acid, cupric oxide, and arsenic pentoxide. Because CCA fixes strongly to wood, it provides wood with excellent protection from decay in a variety of environments. Wood post products fulfill the same function as galvanized steel posts and both products have advantages and disadvantages.

Consumer and regulatory agency concern about environmental impacts resulting from the manufacture, use, and disposal of infrastructure products, such as highway guard rail posts, has resulted in increased scrutiny during selection of transportation construction products. In

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many cases, products such as CCA-treated wood guard rail posts are replaced with galvanized steel guard rail posts based on perception rather than scientific consideration of potential environmental concerns. This study provides a basis for understanding the environmental impacts associated with the production, use, and final disposition of CCA-treated guard rail posts with comparison to galvanized steel posts.

2. Goal and Scope

The goal of this study is to provide a comprehensive, scientifically-based, fair, and accurate understanding of environmental burdens associated with the manufacture, use, and disposition of CCA-treated wood guard rail posts using primary data collected at U.S. treating plants. Other studies [5,6], discuss material performance. This study only includes performance as an estimate of service life.

The scope of this study includes investigation of cradle-to-grave life cycle environmental impacts for CCA-treated wood guard rail posts for highway applications, using life cycle assessment (LCA) methodologies. The results of the CCA-treated guard rail post LCA are compared to LCA findings for galvanized steel guard rail posts. LCA is the tool of choice for evaluating the environmental impacts of a product from cradle to grave, and determining the environmental benefits one product might offer over its alternative(s) [7].

3. Methodology

The LCA methodologies used in this study are consistent with the principles and guidance provided by the International Organization for Standardization (ISO) in standards ISO 14040 [8] and 14044 [9]. The study includes the four phases of an LCA: 1) Goal and scope definition; 2) Inventory analysis; 3) Impact assessment; and 4) Interpretation. The environmental impacts of CCA-treated and galvanized steel highway guard rail posts are assessed throughout their life cycles, from the extraction of the raw materials through processing, transport, primary service life, reuse, and recycling or disposal of the product.

This LCA assumes CCA-treated and galvanized steel guard rail posts can be used interchangeably. CCA-treated and galvanized steel guard rail posts are produced by many different manufacturers and variations exist. Therefore, a “typical product” has been estimated for both guard rail post products.

The LCA for galvanized steel guard rail posts does not include independently developed manufacturing inventory data (primary data). Such data might improve the detailed comparison of these products. However, the data that are available, including data on production of steel shapes [10], provide a basis for general comparison of LCA impact indicators that is sufficient to understand how the guard rail post products compare.

4. Life Cycle Inventory Analysis

Life cycle inventory (LCI) data are collected at four main stages including raw material acquisition, manufacture, service life use, and disposition. LCI inputs and outputs are tallied and reported at a functional unit of one guard rail post per year of use.

4.1. CCA-Treated Guard Rail Post Inventory

LCI inputs and outputs for the CCA-treated wood guard rail post are quantified per 1000 cubic feet (Mcf). The cubic foot (cf) unit is a standard unit of measure for the U.S. guard rail post industry and is equivalent to 0.028 cubic meters (m^3). The cradle-to-grave life cycle stages considered in this LCI are illustrated in **Figure 1**.

This study builds on existing research for forestry resources and adds the treating (drying, CCA production, and pressure injection of preservative), service use, and disposition stages of CCA-treated wood highway guard rail posts. The previous studies, such as research conducted by the Consortium for Research on Renewable Industrial Materials (CORRIM), have investigated the environmental impacts of wood products. CORRIM’s efforts build on a report issued under the auspices of the National Academy of Science regarding the energy consumption of renewable materials during production processes [11]. CORRIM’s recent efforts [Johnson, *et al*. ([12-15]] have focused on an expanded list of environmental aspects necessary to bring wood products to market.

The main source of forest products LCI data used in this study are Johnson, *et al*. [12-14] and Milota, *et al*, [16]. Data include forestry practices applicable to rough cut southern pine softwood products grown on Southeastern U.S forest land with an average level of management intensity (*i.e.*, fertilization and thinning) and include the time frame from the sapling greenhouse (cradle) to the mill (gate). These data represent timber shipped to US wood preserving plants for treatment.

The data from Johnson *et al*. and Milota *et al*. are allocated for “typical” sawn and round guard rail posts. Sawn guard rail posts measure 5.5-inches (14 cm) wide by 7.25-inches (18 cm) deep by 6.0-feet (1.8 m) tall and have a volume of 1.66 cubic feet (ft^3) or 0.047 cubic meters (m^3). 1.0 Mcf of sawn timber posts is equivalent to 602 posts. Round posts measure 7.5-inches (19 cm) in diameter and are 6.0-feet tall and have a volume of 1.84 ft^3 (0.052 m^3). 1.0 Mcf of round posts equals 543 posts. Approximately 21% of guard rail posts are round and the rest are sawn rectangular shapes. Round posts are made of smaller diameter logs that only require peeling to remove bark and provide final shape and dimension. The

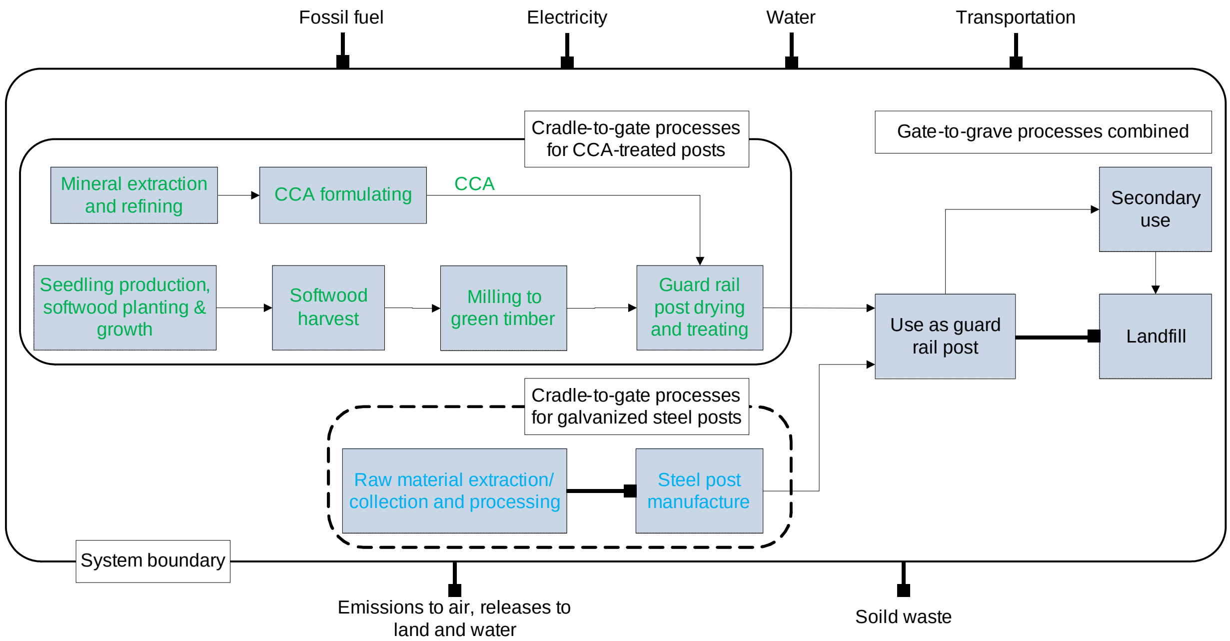


Figure 1. Life cycle stages of CCA-treated guard rail posts.

inputs and outputs of all guard rail posts are modeled in this LCA assuming that data for rough-cut, green lumber are applicable, acknowledging that rough cutting isn't required for round posts.

Six CCA treating plants in the U.S. provided the primary data responses covering operations at their respective treating plant in either 2007 or 2008. The total volume of CCA-treated guard rail posts reported in the surveys is approximately 0.8 million ft^3 (800 Mcf) of product. Vlosky [17] estimates US industry total CCA highway construction material treatment in 2007 at approximately 2200 Mcf. Therefore, the primary data used in this study represents approximately 36% of the US highway construction material treating industry.

Southern pine species green timbers are calculated to have an average density of approximately 61.1 pounds per cubic foot (pcf), using USDA [18] wood property factors. Timber posts are dried prior to treatment by either air drying or heat applied processes, reducing the timber density to 39.7 pcf (25% moisture content). Surveyed treaters report that 35% of the total guard rail posts manufactured are dried with heat and 65% are air dried. Half of the respondents report using biomass for at least part of the heat energy needs.

CCA preservative is produced to meet the AWPA Standard for Waterborne Preservatives P5-09 [19]. CCA-C is the formulation currently in use in the U.S. and the preservative modeled in this study. The AWPA Standards specify CCA guard rail post preservative retentions for Use Category 4A (0.4 pcf outer 1.0-inch) and 4B/4C (0.6 pcf outer 1.0-inch) for sawn southern pine posts and 4A (0.4 pcf outer 1.0-inch) and 4B/4C (0.5 pcf outer 1.0-inch) for round posts [20]. A calculation of theoretical guard rail post retention is made using minimum retentions and assumes the "inner" retention in the zone from 1.0-inch deep to center is at 75% of the minimum retention level, acknowledging that the inner zone includes a heartwood section that accepts very little preservative. The calculated average retention for sawn timber posts (in their entirety) at UC4A is 0.35 pcf, for sawn timber posts at UC4B/4C is 0.53 pcf, and for round posts at UC4B/4C is 0.43 pcf. It is assumed that posts are treated at an average 15% over minimum AWPA standards to minimize retreating. The weighted average of these with 15% over-minimum treatment is 0.57 pcf. This theoretical guard rail post retention level compares well to the survey reported preservative use of 0.56 pcf.

Surveyed treaters report that wood treating facilities use a mix of both fossil and biogenic fuel for process heat necessary in facility processes such as kiln drying of posts. The survey respondents report approximately 2.2 tons of wood biomass and 8,500 cubic feet of natural gas per Mcf of guard rail post is used for kiln drying.

Posts are assumed to be installed with spacing of six-foot 3-inches on centers [21]. Service life is a function of quality and species of wood, quality and type of treatment, soil and climatic conditions at the installation location, and use factors. Often, posts are removed from service for other than quality reasons, such as for accident repair, road widening, or following repaving (so guards must be reinstalled higher). A 40-year average service life for CCA-treated guard rail posts is modeled in this LCI. Maintenance applications of preservative to an installed guard rail post are considered rare and are not included in this LCA. Other components of a highway guard rail installation, such as the rails and attachment hardware, are considered equivalent for use with wood and alternative post material and thus, not included within the system boundaries of this LCA.

At the end of useful life, this study assumes removal from service with 90% disposed in a solid waste landfill and 10% reused as fence posts or landscape timbers, or other applications that extend the use of the wood product.

Removed CCA-treated guard rail posts disposed in landfills are modeled as if decayed to a point where 17% of the carbon is released as carbon dioxide, 6% is released as methane, and 77% [21] of the wood carbon and 100% of the preservative remain in long-term storage in the landfill, following the primary phase of anaerobic degradation. Methane capture efficiencies are modeled based on landfill type. Of the captured methane, a portion is used to generate electricity, and applied as an energy credit, and the remainder is assumed to be destroyed by combustion (flaring), so that all the recovered methane is converted to carbon dioxide. Inputs and outputs related to landfill construction and closure are apportioned on a mass disposed basis using data from Menard *et al*. [22].

Transportation-related inputs and outputs are quantified for each life cycle process. Distances and transport modes for preservative supply to treaters, inbound untreated guard rail posts, and outbound treated guard rail posts are based on weighted averages of primary data.

4.2. Galvanized Steel Highway Guard Rail Posts Inventory

This LCA includes an LCI of galvanized steel guard rail posts. The "representative" galvanized steel guard rail post is an I-Beam (W6 × 8.5, W6 × 9, or W9 × 9) with a web width of approximately 6 inches (15 cm), a weight of approximately 8.5 or 9.0 pounds (3.9 to 4.1 kilograms) per foot and 6.0 feet in length and spaced at 6-foot 3-inches on centers [23]. The steel post is hot-dip galvanized to limit corrosion, assuming ASTM A123 standards of 2.0 ounces per 1 square foot of steel [24] or 1.7 pounds of zinc per guard rail post are met. Energy and resources needed to galvanize the steel I-Beams are modeled in the LCI.

Steel source is estimated as a mix of domestic and international sources. As with CCA-treated guard rail posts, transportation-related inputs and outputs are quantified for each life cycle process. Because there are fewer steel post manufacturing facilities than CCA-treating facilities, distances are assumed at least as great as the data received as part of surveyed CCA treaters; thus, the CCA-treated post and galvanized steel distribution distances are the same. Disposition transport to recycle sites is included in the model.

The estimated average life of galvanized steel guard rail posts is assumed to be the same as for wood posts, acknowledging that some steel posts will be installed in regions of high corrosivity and some will be removed due to highway work. When removed from service, it is assumed that 100% are recycled as steel scrap.

New steel posts are assumed to be produced from typical blast furnaces using a combination of iron ore and approximately 29% recycled steel [26]. All steel posts are assumed to be recycled after service. The LCA allows for 5% loss in recycling [10]. Since the inputs needed to melt and shape the steel shapes cannot be recovered in recycling, the input of electric energy to melt and form steel in an electric arc mini-mill process is "taken back" from the recycle benefit. Thus, as steel recycling reaches 100% nationally, the lowest possible energy input for shapes from recycled steel is that required to process steel in an electric arc furnace since that is required in every cycle.

A summary of selected inventory inputs and outputs for CCA-treated and galvanized steel guard rail posts is provided in **Table 1**.

5. Life Cycle Impact Assessment

5.1. Selection of the Impact Indicators

The impact assessment phase of the LCA uses the LCI results to calculate impact indicators of interest. The LCIA environmental impact indicators are considered at "mid-point" rather than at "end-point". For example, the amount of greenhouse gas (GHG) emission in pounds of carbon dioxide equivalent (CO_2-eq) at mid-point is provided rather than estimating end-points of global temperature or sea level increases. The LCIA is performed using USEPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) [25,26] to assess GHG, acidification, ecotoxicity, eutrophication, and smog impacts potentially resulting from life cycle air emissions. Other indicators of interest also are tracked, such as fossil fuel use and water use.

5.2. Impact Indicators Considered But Not Presented

The TRACI model, a product of USEPA, and the USEtox model [27] a product of the Life Cycle Initiative (a joint program of the United Nations Environmental Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC)), offer several additional impact indicators that were considered during the development of the LCIA, including, but not limited to, human health impacts and impacts to various impact indicators from releases to soil and water. The decision was made

Table 1. CCA-Treated and galvanized steel highway Guard Rail (GR) post life cycle inventory summary (cradle-to-gate per post and cradle-to-grave per post).

		CCA-treated post (per post)		Galvanized steel post (per post)	
Infrastructure process	Units	Cradle-to-gate	Cradle-to-grave	Cradle-to-gate	Cradle-to-grave
Inputs from technosphere					
Electricity-avg. of US grid	kWh	8.5	18	0.071	65
Natural gas (feedstock)	ft3	19	36	0.11	118
Natural gas, combusted in boiler	ft3	26	27	11	18
Diesel fuel, at plant (feedstock)	gal	0	0	0	0
Diesel fuel, combusted in boiler	gal	0.010	0.015	0.00011	0.040
LPG, combusted in equipment	gal	0.00099	0.0010	0	0
Residual oil, processed (feedstock)	gal	0.0043	0.0043	0	0
Residual oil, combusted in boiler	gal	0.0084	0.0090	0.000050	0.0045
Diesel fuel, combusted in equipment	gal	0.14	0.14	0	0
Gasoline, combusted in equipment	gal	0.0051	0.0057	0.000046	0.0043
Hog fuel/biomass (50%MC)	lb	11	11	0.0016	1.8
Coal-bit. & sub. combusted in boiler	lb	0.0070	0.010	0.000016	0.018
Coal-feedstock	lb	0.0020	0.0020	0	0
Energy (unspecified)	Btu	77	77	0	0
Truck transport	ton-miles	56	59	0.042	25
Rail transport	ton-miles	3.4	5.1	7.1	19
Barge transport	ton-miles	0.20	0.41	0.0013	1.5
Ship transport	ton-miles	19	19	26	27
Diesel use for transportation	gal	0.59	0.63	0.018	0.31
Residual oil use for transportation	gal	0.036	0.037	0.048	0.048
Limestone from mine	lb	1.4	1.4	0	0
Rough, green timber from sawmill	ft3	2.0	2.0	0	0
Treated guard timber	ft3	0	0.15	0	0
Zinc	lb	0	0	1.7	1.7
Steel	lb	0	0	51	51
Landfill capacity	ton	0	0.033	0	0
Inputs from nature					
Water	gal	10	10	21	11
Bark from harvest	ft3	0.15	0.15	0	0
Unprocessed coal	lb	4.7	10	38	38
Unprocessed U_3O_8	lb	0.000012	0.000026	0.000025	0.000095
Unprocessed crude oil	gal	0.13	0.15	3.4	0.30
Unprocessed natural gas	ft3	23	23	54	2.6
Biomass/wood energy	Btu	0	0	0.0072	0.00034
Hydropower	Btu	2196	4687	3860	17,366
Other renewable energy	Btu	163	349	1.1	-
Biogenic carbon (from air)	lb	27	19	0	0
Other mined mineral resources	lb	0	0	75	3.6
Outputs to nature					
CO_2-fossil	lb	36	52	119	118
CO_2-non-fossil	lb	–102	–78	0.011	1.9
Carbon monoxide	lb	0.080	0.086	1.3	0.11
Ammonia	lb	0.00014	0.00016	0.000072	0.00012
Hydrochloric acid	lb	0.0038	0.0071	0.0011	0.022
Hydrofluoric acid	lb	0.00035	0.00075	0.00015	0.0028
Nitrogen oxides (NOx)	lb	0.15	0.19	0.19	0.14
Nitrous oxide (N_2O)	lb	0.0011	0.0012	0.000043	0.00022
Nitric oxide (NO)	lb	0.00063	0.00063	0	0
Sulfur dioxide	lb	0.12	0.22	0.10	0.71
Sulfur oxides	lb	0.014	0.016	0.22	0.026
Particulates (PM10)	lb	0.11	0.11	0.0049	0.0074
VOC	lb	0.031	0.032	0.013	0.012
Methane	lb	0.052	2.2	0.064	0.24
Acrolein	lb	0.00019	0.00019	0.00000021	0.0000053
Arsenic	lb	0.0000022	0.0000033	0.00000078	0.0000078
Cadmium	lb	0.00000043	0.00000060	0.00000021	0.0000012
Lead	lb	0.0000036	0.0000047	0.00000077	0.0000081
Mercury	lb	0.00000043	0.00000066	0.00000042	0
Arsenic	lb	0.0000094	0.015	0	0
Chromium	lb	0.000037	0.014	0	0
Copper	lb	0.000021	0.0070	0	0
Zinc	lb	0.00000054	0.00000054	0.0033	0.21
Solid wastes	lb	3.6	80	3.2	65
Process solid & hazardous waste	lb	0.010	0.010	0	0

to not include these impact indicators because of limited and/or insufficient data or concerns regarding misinterpretation. The LCI includes releases of chemicals associated with impacts (such as human health and land and water ecological impacts), but impact indicators for these categories are not calculated.

6. Life Cycle Interpretation

6.1. Findings

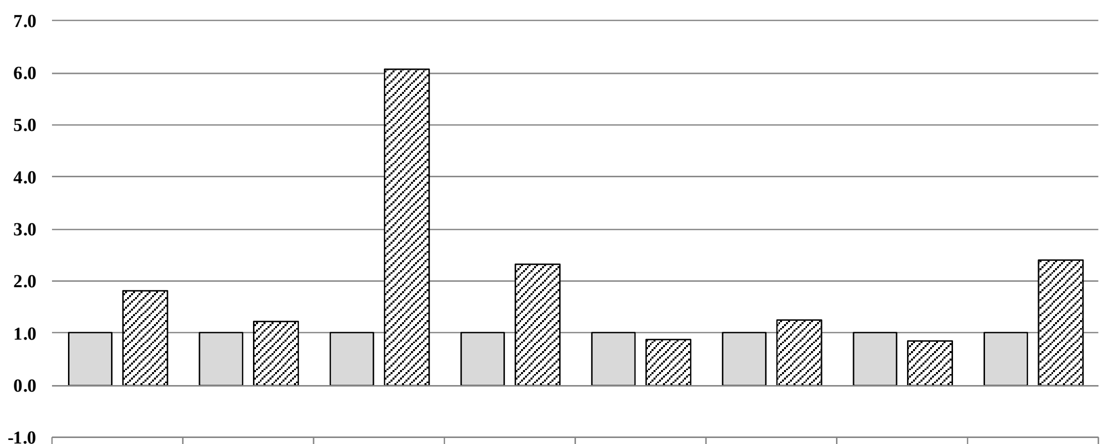
Impact indicator values are totaled at two stages for CCA-treated and galvanized steel guard rail post products: 1) the new guard rail post at the manufacturing facility after production, and 2) after service and final disposition. A summary of impact indicator values is provided in **Table 2**. Comparisons are made per post per year of service.

Impact indicator values are normalized to cradle-to-grave CCA-treated guard rail post values of one (1.0), with the galvanized steel guard rail post impact indicator values being a multiple of one (if larger) or a fraction of one (if smaller). The normalized results of **Table 2** are shown graphically in **Figure 2**, illustrating the comparative assertions about the life cycle impacts of CCA-treated guard rail posts and galvanized steel guard rail posts.

Table 2. Summary of impact indicator totals at life cycle stages for CCA-treated and galvanized steel guard rail posts (per post and per year of use assuming a 40-year service life).

		CCA-treated post (per post per year)		Galvanized steel post (per post per year)	
Impact Indicators	Units	Cradle-to-gate[a]	Cradle-to grave[b]	Cradle-to-gate[a]	Cradle-to grave[b]
Anthropogenic GHG	lb-CO2-eq	0.94	2.5	3.0	3.1
Net GHG	lb-CO2-eq	–1.6	0.52	3.0	3.1
Fossil fuel use	MMBTU	0.0063	0.0082	0.022	0.015
Total energy input	MMBTU	0.0089	0.011	0.023	0.017
Acidification	H+-mole-eq	0.33	0.48	0.61	1.1
Water use	gal	0.30	0.30	0.52	0.26
Smog	g NOx/m	0.0025	0.0029	0.0036	0.0037
Eutrophication	lb-N-eq	0.00017	0.00018	0.00021	0.00015
Ecotoxicity	lb-2,4-D-eq	0.0027	0.0041	0.0026	0.010

[a]Cradle-to-gate includes pre-treatment and treating stages for the CCA-treated guard rail post, where gate is defined as point the product leaves the treating facility. Cradle-to-gate includes steel acquisition (recycled and virgin), and steel post manufacture; [b]Cradle-to-grave includes cradle-to-gate, use, and final disposition.



	Fossil fuel use	Anthropogenic GHG	Net GHG	Acidification	Water Use	Smog	Eutrophication	Ecotoxicity
□ CCA-treated GR posts	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
▨ Galvanized steel GR posts	1.8	1.2	6.1	2.3	0.88	1.3	0.85	2.4

Figure 2. CCA-treated wood and galvanized steel guard rail posts normalized impact comparisons (values normalized to CCA-treated guard rail posts cradle-to-grave = 1.0).

National normalization can be used to provide a means to compare the impact indicator values for guard rail posts to total US annual impact values. Impacts associated with guard rail posts are very small for all indicators for both materials at less than 0.001% of U.S. national impacts. Since relative impacts are so small, further discussion is not included.

6.2. Data Quality Analyses

Data quality analyses per ISO 14044 include a gravity analysis, uncertainty analysis, and sensitivity analysis.

6.2.1. Gravity Analysis

The gravity analysis identifies the CCA-treated guard rail post manufacture, use, and disposition processes most significant to the impact indicator values. This gravity analysis only addresses CCA-treated guard rail posts. The gravity of impacts by life cycle stage is shown in **Figure 3**.

Anthropogenic GHG emissions most notably are impacted by decay of the posts in landfills (45%), landfill construction (16%), truck transport in all stages combined (14%), and electricity use at the treating plant (12%). Net GHG most significantly is impacted by tree growth (credit of 47%), decay of the posts in landfills (26%), emissions from fossil and non-fossil energy sources at the treating plant (11%), landfill construction (7%), and combined truck transport (6%).

Fossil fuel use most notably is impacted by fuel use related to landfill construction and disposal (23%), combined truck transport (23%), guard rail post production prior to treatment (11%), and electricity use (17%) and fuel use (19%) at the treating plant.

The potential to cause acidification is most notably impacted by landfill construction (29%), electricity use at the treating plant (23%), truck transport (20%), natural gas used for drying and facility energy (7%), and ship transport (6%).

Water use includes treatment of the post (38%), preservative manufacture (36%), kiln drying (14%), and tree growth (12%).

The potential to cause smog most notably is impacted by transportation in all stages of the life cycle (67%), landfill construction (10%), wood combustion and kiln drying at the treating plant (9%), and electricity use at the treating plant (7%).

The potential to cause eutrophication is most notably impacted by transportation in all stages of the life cycle (82%) and wood combustion at the treating plant (7%).

The potential to cause ecotoxicity most notably is impacted by landfill construction (35%), electricity use at the treating plant (27%), wood combustion at the treating plant (25%), and fossil fuel use at the treating plant (5%).

6.2.2. Uncertainty Analysis

Areas of uncertainty identified in this LCA include:

The CCA preservative producers did not provide detailed LCI input and output data for CCA production. This LCA relies on industry experts for CCA manufacture LCI data.

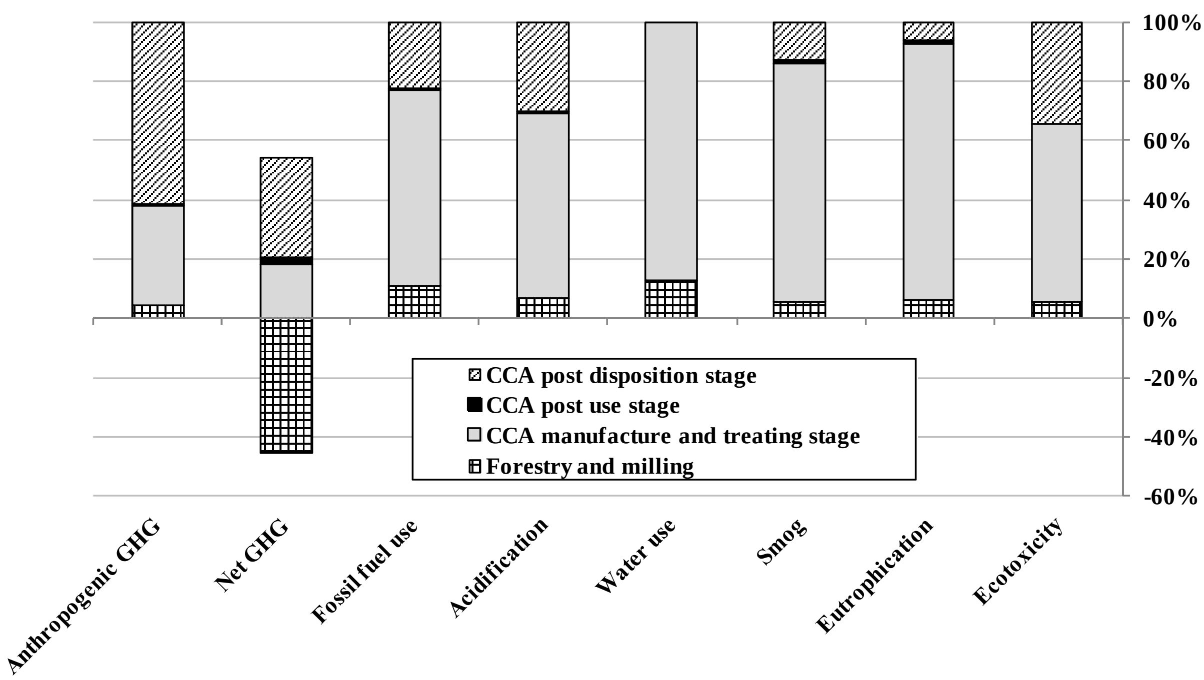


Figure 3. **Contributions to impact indicators by life cycle stage of CCA-treated highway guard rail posts.**

Landfill fate and release models are based on USEPA GHG emission inventory data [28], and modeled assumptions result in variability of impact indicator values, especially GHG. In this LCA, CCA-treated guard rail posts are conservatively assumed to degrade to the same degree and at the same rate as untreated round wood limbs disposed in a landfill.

The comparative analysis phase of this LCA includes the assembly of an LCI for galvanized steel highway guard rail posts. The cradle-to-grave LCI of galvanized steel posts includes data inputs that involve professional judgments, as no survey of manufacturers of the steel posts was done.

6.2.3. Sensitivity Analysis

Sensitivity analysis determines the magnitude of changes to impact indicators resulting from alternative assumptions. Certain items or categories stand out as most important in affecting the sensitivity of LCA impact indicator outcomes.

Copper source. Copper used in CCA preservative generally comes from recycled, off-specification sources. This LCA applies a fraction of the burdens associated with the production of market-grade copper to the use of recycled copper in CCA. LCI data for recycled copper was not found, so the baseline evaluation assumes one-third of the inputs and outputs associated with market-grade copper is representative as a surrogate for the recycled off-specification copper used in CCA. A sensitivity test assumes that inputs for copper are the same as if all was from primary production. This analysis results in impact indicator increases between 0% and 12%.

CCA preservative use. If CCA retention is increased to 125% of baseline, net GHG (19% increase) and water use (9% increase) impact indicators are most notably impacted. The sensitivity test did not change the comparative results with galvanized steel posts.

CCA-treated highway guard rail post service life. Altering the estimated average service life (40 years) of CCA-treated highway guard rail posts to either 20 or 60 years results in notable impact indicator value changes. Reducing the service life to 20 doubles all of the impact indicators. Similarly, increasing the service life to 60 years, decreases all impact indicators by 33%. Even with service life shortened to half that of galvanized steel, many of the impact indicators for CCA-treated guard rail posts, including net GHG, acidification, and ecotoxicity continue to compare favorably to steel posts.

Post-use disposition of CCA-treated guard rail posts and the impact. The baseline case assumes 10% of used guard rail posts have a secondary use application and 90% are disposed at a landfill. A sensitivity test considers 70% of posts being recycled for energy using combustion cogeneration facilities with appropriate air emission control devises and 20% being landfilled. Beneficial energy recovery at a cogeneration facility, instead of landfill disposal, reduces anthropogenic GHG (155%) and net GHG (596%), fossil fuel use (165%), acidification (212%), smog (53%), and ecotoxicity (253%) impact indicator values and increase eutrophication (9%) in comparison to the baseline values. Impact indicator reductions result from fossil fuel offsets generated with the use of the wood product for energy recovery and the absence of landfill construction and landfill emission impacts. Reductions of greater than 100% result in overall impact indicator credits.

Landfill decay models. Barlaz [29] reports that approximately 77% of the carbon in wood fiber of branches disposed in landfills is sequestered after primary decomposition has occurred. The presence of lignin (a major carbon-based component of wood) can interfere greatly with cellulose and hemicellulose degradation under the anaerobic conditions of landfills. Laboratory research shows lignin to be very resistant to decay in landfills because cellulose and hemicellulose are embedded in a matrix of lignin [30-32]. Preservative in disposed CCA-treated guard rail posts is expected to further increase carbon sequestration by retarding decay, but such effects are not considered in the baseline assumptions. To demonstrate the sensitivity of carbon storage, a test case assumes 90% wood fiber carbon storage. Increasing wood fiber storage to 90% reduces the anthropogenic GHG (24%) and net GHG (158%) impact indicators, and results in increases for most other impact indicators (most notably ecotoxicity (4%)) because less methane is collected to generate power. Comparisons of indicators between products do not change.

Galvanized steel guard rail post service life. Changes in service life affect all galvanized steel guard rail post impact indicators proportionately. Increasing service life 50% results in a of 33% decrease in impact indicator values.

7. Conclusions and Recommendations

7.1. Conclusions

CCA treated wood guardrail posts offer notably lower environmental impacts for fossil fuel use (almost half), net GHG emissions (one-sixth), acidification (approximately half), and ecotoxicity (approximately half) relative to galvanized steel posts. The other indicators are approximately the same; anthropogenic GHG, water use, smog, and eutrophication. See **Figure 2**.

The LCA process demonstrates the advantage of wood products in relation to GHG. Only wood products begin their life cycles by taking carbon out of the air. This is shown in **Figure 3** where the Net GHG value is negative for the forestry and milling stage. Even with wood posts disposed in landfills following use, the net full life GHG emissions of treated wood posts are one sixth that of galvanized steel posts.

The GHG advantage of wood is dramatically increased under a scenario in which most used wood guardrail posts are recycled for energy production. The LCI credit for energy from recycled wood offsets fossil energy inputs and impacts, resulting in negative impacts (benefits to the environment) for the following; fossil fuel use, anthropogenic and net GHG emissions, acidification, and ecotoxicity.

Recycling of steel has less benefit than expected because, at best, the electric energy input to an electric arc furnace is required for every cycle of use and recycle.

7.2. Recommendations

Production facilities of guard rail posts should continue to strive to reduce energy inputs through conservation and innovation, including sourcing materials from locations close to point of treatment and use. Also, the use of biomass as an alternate energy source can reduce some impact category values compared to the use of fossil fuel energy or electricity off the grid.

The treated wood industry and highway authorities should seek to find beneficial secondary use opportunities for out-of-service wood guard rail posts. Secondary use reduces disposal of wood products in landfills and includes opportunities for beneficial energy recovery in cogeneration or synthetic gasification systems or with reuse as agricultural fencing or landscaping applications. If disposed in a landfill, selection of a disposal facility with methane capture can reduce emissions of GHGs and can result in energy recovery through the capture and reuse of methane.

This study includes the comparison of CCA-treated highway guard rail posts to galvanized steel guard rail posts. The results conform with the ISO 14040 and ISO 14044 standards and are suitable for public disclosure. A detailed, peer-reviewed Procedures and Findings Report can be requested by contacting the TWC at www.treated-wood.org/contactus.html. This LCA covers one treated wood product in a series of LCAs commissioned by the Treated Wood Council (TWC). The other treated wood product LCAs are for alkaline copper quaternary (ACQ)-treated lumber [33], borate-treated lumber [34], pentachlorophenol-treated utility poles [35], creosote-treated railroad ties, and CCA-treated marine pilings.

8. Acknowledgements

The authors wish to thank the TWC for their funding of this project. The TWC members and its Executive Director, Mr. Jeffrey Miller, have been integral in its completion. We also thank the internal reviewers, James Clark, Craig McIntyre, and Maureen Puettmann, and the independent external reviewers, Mary Ann Curran, Paul Cooper, and Yurika Nishioka for their support, patience, and perseverance in seeing this project through to completion.

REFERENCES

[1] A. Atahan, R. Bligh and H. Ross, "Evaluation of Recycled Content Guardrail Posts," *Journal of Transportation Engineering*, Vol. 128, No. 2, 2002, pp. 156-166.

[2] J. Morrell, "Disposal of Treated Wood," In: *Environmental Impacts of Preservative Treated Wood*, National Pesticide Information Center, Orlando, 2004, p. 27.

[3] J. Bigelow, S. Lebow, C. Clausen, L. Greimann and T. Wipf, "Preservation Treatment for Wood Bridge Application," *Transportation Research Record*: *Journal of the Transportation Research Board*, No. 2108, Transportation Research Board of the National Academies, Washington DC, 2009, pp. 77-85.

[4] US Environmental Protection Agency (USEPA), "Reregistration Eligibility Decision for Chromated Arsenicals," Office of Prevention, Pesticides and Toxic Substances, Washington DC, 2008.

[5] C. Plaxico, G. Patzner and M. Ray, "Finite Element Modeling of Guardrail Timber Posts and the Post-Soil Interaction," *Transportation Research Record*: *Journal of the Transportation Research Board*, Vol. 1647, No. 1998, 1998, pp. 139-146. doi:10.3141/1647-17

[6] R. Faller, J. Reid, D. Kretschmann, J. Hascall and D. Sicking, "Midwest Guardrail System with Round Timber Posts," *Transportation Research Record*: *Journal of the Transportation Research Board*, Vol. 2120, No. 2009, 2009, pp. 47-59. doi:10.3141/2120-06

[7] K. Andersson, M. Eide, U. Lundqvist and B. Mattsson, "The Feasibility of Including Sustainablility in LCA for Product Development," *Journal of Cleaner Production*, Vol. 6, No. 3-4, 1998, pp. 289-298.

[8] International Organization for Standardization (ISO), "Environmental Management—Life Cycle Assessment—Principles and Framework," ISO 14040:2006, Geneva, 2006.

[9] International Organization for Standardization (ISO), "Environmental Management—Life Cycle Assessment—Requirements and Guidelines," ISO 14044:2006, Geneva, 2006.

[10] International Iron and Steel Institute (IISI), "Life Cycle Inventory Data for Steel Products and Application of the IISI LCI Data to Recycling Scenarios," Brussels, 2006.

[11] C. Boyd, *et al*., "Wood for Structural and Architectural Purposes," *Wood and Fiber Science*, Vol. 8, No. 1, 1976, pp. 3-72.

[12] L. Johnson, B. Lippke, J. Marshall and J. Comnick, "Forest Resources-Pacific Northwest and Southeast. CORRIM Phase I Final Report Module A: Life-Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Building Construction," 2004.

http://www.corrim.org/reports

[13] L. Johnson, B. Lippke, J. Marshall and J. Comnick, "Life-Cycle Impacts of Forest Resource Activities in the Pacific Northwest and the Southeast United States," Wood Fiber Science, Vol. 37, No. 12, 2005, pp. 30-46.

[14] B. L. Johnson, E. Oneil, J. Comnick and L Mason, "Forest Resources-Inland West. Corrim Phase II Report Module A. Environmental Performance Measures for Renewable Building Materials with Alternatives for Improved Performance," Seattle, 2008. http://www.corrim.org/pubs/reports/2005/phase1/

[15] E. Oneil, *et al*., "Life-Cycle Impacts of Inland Northwest and Northeast/North Central Forest Resources," *Wood and Fiber Science*, Vol. 42, Special Issue, 2010, pp. 29-51.

[16] M. Milota, C. West and I. Hartley, "Phase I Final Report, Module C, Softwood Lumber—Southeast Region," 2004. http://www.corrim.org/pubs/index.asp#2004

[17] R. Vlosky, "Statistical Overview of the US Wood Preserving Industry: 2007," Louisiana Forest Products Development Center, Baton Rouge, 2009.

[18] USDA, Forest Products Service, Forest Products Laboratory, "Wood Handbook, Wood as an Engineering Material," General Technical Report FPL-GTR-190, USDA, Forest Products Service, Forest Products Laboratory Madison, 2010.

[19] American Wood Protection Association, "Standard P5-09 Standard for Waterborne Preservations," In: 2010 *AWPA Book of Standards*, American Wood Protection Association, Birmingham, 2010.

[20] American Wood Protection Association, "Standard U1-10 Use Category System: User Specification for Treated Wood," In: 2010 *AWPA Book of Standards*, American Wood Protection Association, Birmingham, 2010.

[21] US Environmental Protection Agency (USEPA), "Solid Waste Management and Greenhouse Gases: A Life Cycle Assessment of Emissions and Sinks," 3rd Edition, USEPA, Washington DC, 2006.

[22] J. Menard, *et al*., "Life Cycle Assessment of a Bioreactor and an Engineered Landfill for Municipal Solid Waste Treatment," 2003. www.lcacenter.org/InLCA-LCM03/Menard-presentation.ppt

[23] US DOT, "Drawings," 1994. http://flh.fhwa.dot.gov/resources/pse/standard/st61711.pdf

[24] American Galvanizers Association, "Galvanize It," 2002. http://www.galvanizeit.org/images/uploads/publicationPDFs/SP_SGRS_02.pdf

[25] J. Bare, G. Norris, D. Pennington and T. McKone, "TRACI—The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts," *Journal of Industrial Ecology*, Vol. 6, No. 3-4, 2003, pp. 49-78. http://mitpress.mit.edu/jie doi:10.1162/108819802766269539

[26] US Environmental Protection Agency (USEPA), "Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)," 2009. http://www.epa.gov/nrmrl/std/sab/traci/

[27] R. Rosenbaum, *et al*., "USEtox—The UNEP-SETAC Toxicity Model: Recommended Characterization Factors for Human Toxicity and Freshwater Ecotoxicity in Life Cycle Impact Assessment," *The International Journal of Life Cycle Assessment*, Vol. 13, No. 7, 2008, pp. 532-546. doi:10.1007/s11367-008-0038-4

[28] US Environmental Protection Agency (USEPA), "Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007," Report No: EPA 430-R-09-004, USEPA, Washington DC, 2009.

[29] M. A. Barlaz, "Carbon Storage during Biodegradation of Municipal Solid Waste Components in Laboratory-Scale Landfills," *Global Biogeochemical Cycles*, Vol. 12, No. 2, 1998, pp. 373-380. doi:10.1029/98GB00350

[30] R. Ham, P. Fritschel and M. Norman, "Refuse Decomposition at a Large Landfill," *Proceedings Sardinia* 93, 4*th International Landfill Symposium*, Cagliari, 11-15 October 1993, pp. 1046-1054.

[31] R. Ham, P. Fritschel and M. Norman, "Chemical Characterization of Fresh Kills Landfill Refuse and Extracts," *Journal of Environmental Engineering*, Vol. 119, No. 6, 1993, pp. 1176-1195. doi:10.1061/(ASCE)0733-9372(1993)119:6(1176)

[32] Y.-S. Wang, C. S. Byrd and M. A. Barlaz, "Anaerobic Biodegradability of Cellulose and Hermicelluloses in Excavated Refuse Samples Using a Biochemical Methane Potential Assay," *Journal of Industrial Microbiology*, Vol. 13, No. 3, 1994, pp. 147-153. doi:10.1007/BF01583999

[33] C. A. Bolin and S. Smith, "Life Cycle Assessment of ACQ-Treated Lumber with Comparison to Wood Plastic Composite Decking," *Journal of Cleaner Production*, Vol. 19, No. 6-7, 2011, pp. 620-629. doi:10.1016/j.jclepro.2010.12.004

[34] C. A. Bolin and S. Smith, "Life Cycle Assessment of Borate-Treated Lumber with Comparison to Galvanized Steel Framing," *Journal of Cleaner Production*, Vol. 19, No. 6-7, 2011, pp. 630-639. doi:10.1016/j.jclepro.2010.12.005

[35] C. A. Bolin and S. Smith, "Life Cycle Assessment of Pentachlorophenol-Treated Wooden Utility Poles with Comparisons to Steel and Concrete Utility Poles," *Renewable and Sustainable Energy Reviews*, Vol. 15, No. 5, 2011, pp. 2475-2486. doi:10.1016/j.rser.2011.01.019

