Renewable and Sustainable Energy Reviews 15 (2011) 2475–2486

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Life cycle assessment of pentachlorophenol-treated wooden utility poles with comparisons to steel and concrete utility poles

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ARTICLE INFO

*Article history:*
Received 9 December 2010
Accepted 30 January 2011

*Keywords:*
Pentachlorophenol
Utility pole
Life cycle assessment (LCA)
Carbon sequestration
Steel poles
Concrete poles

ABSTRACT

A cradle-to-grave life cycle assessment (LCA) was done to identify the environmental impacts related to pentachlorophenol (penta)-treated wooden utility poles. Penta-treated utility poles commonly are used for electricity distribution and transmission, and telecommunications. In addition, this LCA has evaluated the opportunities to reduce the environmental impacts associated with penta-treated poles and has compared the penta-treated pole product to alternative products. A model of penta-treated utility pole life cycle stages was created and used to determine inputs and outputs during the pole production, treating, service life, and disposal stages. Pole production data are based on published sources. Primary wood preservative treatment data were obtained by surveying wood treatment facilities in the United States. Product service life and disposal inventory data are based on published data and professional judgment. Life cycle inventory inputs, outputs, and impact indicators for penta-treated utility poles were quantified per pole. In a similar manner, an inventory model was developed for the manufacture, service life, and disposal of the primary alternative products: steel and spun concrete utility poles. Impact indicator values, including greenhouse gas (GHG) emissions, fossil fuel and water use, and emissions with the potential to cause acidification, smog, ecological toxicity, and eutrophication were quantified for each of the pole products.

The GHG, fossil fuel use, acidification, water use, eutrophication, and ecological toxicity impact indicator values for penta-treated poles are less than those for concrete poles. The GHG, fossil fuel use, acidification, water use, and ecological toxicity impact indicator values for penta-treated poles are less than those for steel poles. The values are about equal for eutrophication. The smog impact from penta-treated poles is greater than the smog impact from both concrete and steel poles.



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1364-0321/$ – see front matter 
doi:10.1016/j.rser.2011.01.019

## 1. Introduction

Wood products are susceptible to degradation when left untreated [1] and preservative treatments can extend the useful life of a wood product by 20–40 times that of untreated wood [2] in weather-exposed or wet environments subject to microbial or insect attack. To lengthen the service life of wood products susceptible to degradation, chemical preservation was introduced in the late 1700s and early 1800s. By 1842, wood preservation chemicals included mercuric chloride, copper sulfate, zinc chloride, ferrous sulfate with a sulfide, and creosote [3]. Over the years, industry has modified its wood preservation formulations with new preservatives, thereby meeting consumer preferences and addressing various treated wood applications, such as railroad ties, utility poles, marine pilings, guard rail systems, highway bridge timbers, agricultural fencing, and dimensional lumber.

There are an estimated 120–200 million preservative-treated wood utility poles currently in service in the U.S. Common preservatives used in wood utility pole treatment include chromated copper arsenate (CCA), creosote, and pentachlorophenol (penta). Approximately 62 percent of the total annual preserved utility pole production is estimated to be treated with penta [4].

Penta production began experimentally in the 1930s, with commercial use expanding during the 1940s through the 1980s. Prior to 1987, penta was registered for use as a herbicide, defoliant, molluscicide, fungicide, and insecticide [5]. Since then, penta has been a restricted-use pesticide for use by certified applicators only. Penta is mostly used now in the U.S. as a wood preservative. One of the primary products treated with penta preservative is utility poles.

Penta is mixed with petroleum oil, typically diesel or similar oil cuts, and applied under pressure to the wood products. The American Wood Protection Association [6] includes penta-treating as appropriate for round poles used for utility service.

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 [7]. CORRIM's recent efforts by Johnson et al. [8,9] and Oneil et al. [10] have focused on an expanded list of environmental aspects necessary to bring wood products to market. Also, the in-service releases from penta-treated utility poles has been the subject of research conducted by Lorber et al. [11], Bulle et al. [12], Winters et al. [13], Murarka et al. [14], and others.

This study investigates the cradle-to-grave life cycle environmental impacts related to penta-treated wooden utility poles used for electricity distribution and transmission, and telecommunications, and uses life cycle assessment (LCA) to quantify such impacts. It covers one treated wood product in a series of LCAs commissioned by the Treated Wood Council (TWC). The series of treated wood product LCAs also covers alkaline copper quaternary (ACQ)-treated lumber, borate-treated lumber, creosote-treated railroad ties, chromated copper arsenate (CCA)-treated marine pilings, and CCA-treated guard rail systems.

Alternatives to treated wood utility poles include spun concrete and steel. The alternative products are produced by many different manufacturers using differing materials and manufacturing processes. The concrete and steel products have approximately the same dimensions as, and generally are used interchangeably with, penta-treated utility poles.

## 2. Goal and scope

This study inventories the environmental inputs and outputs attributable to penta-treated utility poles, completes a comparable inventory of steel and concrete utility poles, calculates impact indicators for each product, and makes comparisons between the products. This study was performed using life cycle assessment methodologies in a manner consistent with the principles and guidance provided by the International Organization for Standardization (ISO) in standards ISO 14040 and 14044 [15,16]. The study includes the four phases of an LCA: (1) Goal and scope definition; (2) Inventory analysis; (3) Impact assessment; and (4) Interpretation. LCA has been recognized as the tool of choice for evaluating environmental impacts of a product from cradle to grave, and determining the environmental benefits one product might have over its alternative [17]. The environmental impacts of penta-treated, steel, and concrete utility poles 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.

## 3. Life cycle inventory analysis

The inventory phase of the LCA developed the inputs from, and outputs to, the environment through each life cycle stage of the product. Inventory development included defining the products, selecting a means to compile data, obtaining and developing applicable life cycle data for life stages, distributing inputs and outputs appropriately between the target and co- or by-products, and summarizing the flow data. The cradle-to-grave life cycle stages considered in this LCA are illustrated in Fig. 1.

Life cycle inputs and outputs were quantified using functional units of 1000 cubic feet (Mcf). The cubic foot (cf) functional unit is a standard unit of measure for the U.S. pole industry and is equivalent to 0.028 cubic meters ($m^3$). The preservative retention is stated as pounds of preservative retention per cf of treated wood

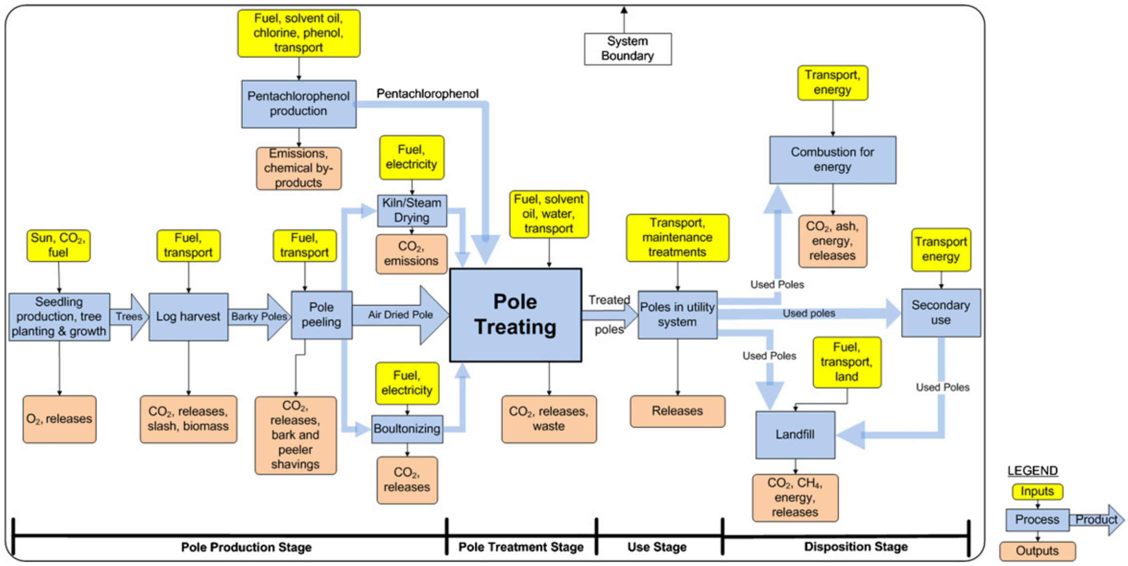



**Fig. 1.** Life cycle stages of penta-treated utility poles.

product (pcf) and is equivalent to 16.0 kg of preservative retention per $m^3$ of treated wood product (kg/$m^3$). Once compiled, the inventory data were converted to a per utility pole functional unit. In the sensitivity analysis, it was necessary to quantify the data per mile (1.61 km) of utility corridor to assess the impact of variance of pole spacing, and per year of service, to assess the impact of service life.

### 3.1. *Penta-treated utility pole inventory*

The product of primary focus in the LCA was pentachlorophenol (penta)-treated wood utility poles treated according to AWPA standards [18,19]. The dominant wood species treated as utility poles include Southern pine in the eastern U.S. and coastal Douglas fir in the western U.S. For the purpose of understanding unit processes that contribute to the environmental impacts of penta-treated utility poles, four main life cycle stages were recognized:

- Pole production stage;
- Pole treating stage;
- Penta-treated utility pole service life stage; and
- Penta-treated utility pole disposition stage.

This study builds on existing CORRIM research for forest resources and adds the treating, service use, and disposal stages of penta-treated poles. For the pole production stage, the main source of forest products life cycle inventory (LCI) data is Johnson et al. [20]. Johnson's data are available through the U.S. Department of Energy National Renewable Energy Laboratory (NREL) U.S. LCI Database [21,22]. The data cover the production of wood grown on Southeastern and Pacific Northwest U.S. forest land with an average level of management intensity (i.e., fertilization and thinning) and delivered to the saw mills.

Manufacturers of penta-treated utility poles were surveyed in 2009, as part of the LCI, to determine primary data inputs and outputs from treating facilities in the U.S. using penta in 2007 and 2008. Ten penta treating plants provided responses to a questionnaire. These survey responses provide the primary data for the pole treating stage assessed in this LCI. Four treating facilities were identified as Western State treaters and six were identified as Southern State treaters. Based on the treater survey results, approximately 60 percent of poles are produced with wood from the Southeast and 40 percent from the Pacific Northwest. The total volume of penta-treated poles reported in the surveys was 13.7 million cubic feet. Vlosky et al. [23] estimated total penta-treated pole volume for 2007 at 35 million cubic feet. Thus, the survey responders and primary data represent approximately 38 percent of the total U.S. penta-treated pole production.

Appropriate proportions of Southeast and Pacific Northwest softwood, based on U.S. production, were used to determine a "representative log" used as a utility pole in the U.S. The proportioned inputs and outputs were calculated based on this "representative log." Utility pole sizes are described by class, which is an indication of bending strength, diameter, and length. An approximate median size pole that is used in this LCI as the "representative" pole is a Class 4, 45-foot (13.7 m) long pole. One Mcf equates to approximately 43 Class 4, 45-foot poles. Processes including inputs and outputs related to forestry, log harvesting, and transportation are normalized to 1 Mcf of whole log product.

Wood density changes as a function of moisture content. For a given sample of wood, oven dry density increases as wood dries because the sample shrinks. Because poles are measured and the class is determined when they are green (prior to drying and treatment), the LCI calculations were done assuming the green basis wood density.

The pole treatment stage begins when the barky log is peeled to produce a pole. "Peeler poles" are measured to determine the class and length best suited for each pole and then cut, usually to the nearest five-foot increment. Poles also are "framed" by drilling holes and cutting flat "gains" for mounting hardware to meet customer requirements. Other framing may include incising or through-boring to improve preservative penetration.

Biomass is produced in the treating stage as a result of peeling and end-trimming poles received as barky poles. Some of the produced biomass is used as fuel in boilers for steam to dry the poles prior to treatment. However, more biomass is produced than can be used. The excess biomass is assumed to be sold as either biomass used for off-site energy recovery or for landscape material. The amount of biomass sold for energy recovery is applied in this LCI as a natural gas credit.

Poles are dried prior to treatment. The most common means of drying poles include the Boulton process (poles are boiled in the treatment cylinder using the preservative liquid while under vacuum), steaming (poles are heated with steam in a cylinder under low pressure followed by a vacuum to flash the superheated wood moisture), kiln-drying (poles are placed in racks in kilns with heat and air circulation), and air drying (poles are stacked in the open yard in dry climate areas until dry).

AWPA [6] specifies penta retentions of 0.30 pcf (4.8 kg/$m^3$) for Use Category (UC) 4A, 0.38 pcf (6.08 kg/$m^3$) for UC 4B, and 0.45 pcf (7.2 kg/$m^3$) for UC 4C for Southern pine poles and penta retentions of 0.45 pcf (7.2 kg/$m^3$) for UC 4A and 4B, and 0.60 pcf (9.6 kg/$m^3$) for UC 4C for Douglas fir (outer zone retention). Different retentions are required for other wood species within these use categories. The higher retentions are required for more challenging environments, such as along the Gulf Coast, and may be required by utilities for conditions where the difficulty or cost of replacing poles is judged worth specifying a higher retention.

Weighted averages were calculated for inputs and outputs provided in the treater surveys. Using the weighted average of penta use and total penta production at each reporting facility, an average retention of 0.36 pcf (5.7 kg/$m^3$) was calculated. This weighted average is greater than the UC 4A, but less than the UC 4B and UC 4C retentions specified by AWPA, but includes both treatable fractions (sapwood) and untreatable fractions (heartwood) and thus is considered representative. To obtain the penta retentions, treaters surveyed reported using a penta concentrate with 7.5 percent pentachlorophenol, by weight.

Penta treating solution is a mixture of penta and diluent oil. Penta is received at treating plants as a concentrate liquid or in solid block form. Approximately 32 percent of the penta delivered to responding plants is in the block form with the remainder delivered as liquid concentrate. Based on the reported use of penta and survey results for the use of diluent, approximately 4.4 lbs (2.0 kg) of diluent oil per cubic foot of treated pole was used on average by the surveyed treaters. This is equivalent to approximately 92.5 percent of the average treating solution.

| Penta-treated pole properties | | |
|---|---|---|
| Length | 45 | ft |
| Representative penta-pole weight[a] | 1315 | lbs |
| Penta use | 8.4 | lbs/pole |
| Diluent oil use | 103 | lbs/pole |
| Spacing | 22 | pole/mile |
| Service life | 60 | years |
| Functional unit conversion[a] | 42.9 | Poles/Mcf |

[a] Weight and functional unit conversion are representative of poles at treatment (and assumes a mix of western and Southern species).

Estimates of penta in the runoff from penta-treated wood in stacks is estimated based on studies done by Morrell et al. [24] at approximately 2 parts per million (ppm). Assuming the treated poles remain at the treatment yard for 1 month and average U.S. rainfall is approximately 33 inches (0.83 m) of rain per year, the result is a release factor of approximately 0.02 lbs (0.0091 kg) per Mcf of penta-treated poles produced. Similar releases are assumed for storage of penta-treated poles in stacks at the utility staging areas, prior to placement in-service.

While some plants discharge waste water to municipal waste water treatment works, data from the survey were not adequate to quantify the volume.

The service life stage begins in the utility companies' staging yards. Poles are assumed to be stored in these yards for approximately 1 month before transport to and installation in the utility use location. Steel bolts used to attach crossarms and other hardware are installed by the utility, but are not considered as inputs in this LCA. Poles are installed by the utilities in rights-of-way at approximately 22 poles per mile or an average spacing between poles of 240 feet (73.2 m).

The length of time that a treated wood pole remains in a utility line is dependent upon a number of factors. Often, poles are removed from service before the end of their useful service life, such as for road widening. Morrell [25] surveyed western utilities and found that utility personnel expect pole service lives of between 30 and 59 years, but replacement rates indicate longer average lives of between 60 and 80 years. Pope [26] cites pole inspection data of over 750,000 poles showing that poles with no maintenance had an average service life (50 percent rejected as needing replacement) of 40–50 years, but with normal inspection and maintenance (the current practice), the average service life would extend to 60 or more years. Thus, assuming current inspection practices will continue, the average service life of 60 years is modeled in this LCI.

Most utilities have regular inspection programs of 8–12 years. Inspections include minor excavation around the ground-line of the poles for visual and, in some cases, physical testing, for indications of decay [27]. Maintenance treatments are surface treatments (applied at and just below ground-line) or internal treatments. Surface applied materials are copper, boron, and/or sodium fluoride in pastes that both coat and diffuse into the wood and are wrapped with a waterproofing material. Internal treatments, including metham sodium, chloropicrin, MITC-Fume®, sodium fluoride, and borate based materials, are fumigants or diffusible salts placed into ground-line bored holes for slow diffusion into the wood.

An inspection and maintenance program is assumed for the LCI. Each pole is assumed to be inspected once every 12 years and to require maintenance treatments three times during the service life. The treatment model assumes 0.25-gallon of paste is needed per treatment, consisting of two percent copper, 43 percent borate (DOT), 10 percent petroleum (as a surrogate for other possible fossil fuel derived ingredients), water, and mineral filler/thickeners. Inputs and outputs for the treatment paste components, including the copper and borate, are considered in the LCI.

Release of penta and volatile organic compounds (VOCs) from poles during service life are estimated in the LCI, including releases to both air and ground. Air emissions of penta from small penta-treated wood samples were researched by Ingram et al. [28,29]. The laboratory analyses included constant air flow at various temperatures. Assumptions were used with Ingram's data to calculate total service life air emissions of penta of 1.7 percent of the initial penta retention.

Air emissions of VOC treatment components are based on a model of total treatment component losses from poles and fractional losses to air and to ground. The emissions are based on vapor pressures of constituents in the penta solution ranging from 10 to $1E^{-10}$ mm mercury (mmHg). Components with a vapor pressure greater than 0.1 mmHg were modeled as 100 percent emissions of VOCs released over the pole life of 60 years or 1.67 percent per year (100 percent/60 year) with 95 percent released to air and five percent to the ground. Components with a vapor pressure of 0.01–0.1 mmHg were assumed to be released at 1.3 percent per year with 50 percent to air and 50 percent to ground. Diesel fuel is included in this range, for which service life releases of diesel are estimated at 39 percent to air (1.3 percent $\times$ 60 year $\times$ 50 percent) and 39 percent to ground. Components with vapor pressure of 0.0001–0.001 mmHg are assumed to release at 1.0 percent per year with three percent to the air and 97 percent to ground. Penta is within this vapor pressure range and the model predicts service life releases of 60 percent with 1.8 percent released to the air and 57.2 percent released to the ground. The model prediction of 1.8 percent penta released to air matches estimates from assessments done by Ingram et al. [28,29]. All organic components released from the penta and oil preservative solution are assumed to be VOCs. The 60-year service life results in approximately 76 percent of initial penta treating solution released of which 34 percent is released to air as VOCs.

Releases of penta to the surrounding ground from in-service poles are modeled based on reports of penta remaining in poles after up to 25 years of service [30,46]. The release model assumes 0.01 pcf of penta is released over the first 10 years followed by a release rate at 20 percent of the initial rate for the remainder of the pole life. Based on a 60-year service life, approximately 0.2 pcf or 57 percent of the initial penta retention is released to the ground over the pole service life. The fate of penta released from poles to the ground is adsorption and biodegradation within an approximate 12-inch radius of the pole's base [31]. This release model is further supported in studies performed by Brooks [32].

At the end of use by the utility companies, poles may have recycling value as treated wood, such as for use as fence posts or landscaping or as fuel to produce process heat and/or electricity. Some utility companies simply dispose of the used poles as solid waste in landfills. Disposition, as modeled in this LCI, is based on Morrell's [25] survey of utilities in the western U.S. and assumes that 47 percent of out-of-service utility poles are recycled for other treated wood use, 21 percent are recycled for energy recovery, and 32 percent are disposed in landfills.

Poles recycled for energy are assumed to be combusted in large cogeneration or utility type boilers that include scrubbers or electrostatic precipitators and achieve approximately 60 percent thermal to electric energy conversion efficiency. During the energy recovery process, the wood carbon is released as biogenic carbon dioxide and combusted preservative carbon will be released as fossil carbon dioxide.

Polycyclic aromatic hydrocarbon (PAH) emissions are considered in emissions from the combustion of treated wood. Emissions data from a boiler in Mississippi with only particulate controls [33] and burning a 50/50 mixture of creosote-treated and pentachlorophenol-treated wood demonstrated in both low and high fire conditions that total PAHs are less when burning treated wood than when burning untreated wood. Pentachlorophenol and total chlorophenols were destroyed by combustion at greater than 99.99 percent removal efficiency. However, up to 50 percent of the chlorine in the fuel was emitted as hydrochloric acid (HCl). Emissions from today's cogeneration facilities are expected to be much lower since flue gas acid treatment technologies, such as scrubbers, are effective in removing HCl and are commonly used at industrial combustion facilities.

Holtzman and Atkins [34] reports that PAH emissions from facilities burning a mixture of untreated wood and creosote-treated crossties have similar PAH emissions to facilities burning only untreated wood. The studies indicate that combustion conditions and emission control equipment are the primary factors related to PAH emissions.

This LCI uses the research done by Smith and Holtzman as a basis for assuming that 40 percent of the chlorine in pentachlorophenol treated utility poles (used for energy recovery) will be emitted as HCl.

This LCI assumes that penta-treated poles are disposed in a range of landfill types, including municipal landfills of wet (bioreactor) or dry types (with and without methane collection), and construction and demolition (C&D) waste landfills (without methane collection). Assumptions about the fate in each type are made based on USEPA [35] reports and professional judgment. The disposal model results in 77 percent of the wood carbon being sequestered, 17 percent released as carbon dioxide, and 6 percent released as methane. The treating of wood likely will slow or prohibit the degradation of wood in landfills and increase the sequestration of carbon in landfills; however, no data from published sources were found to support such claims. Thus, the USEPA value of 77 percent sequestration (sequestration for round limbs) was used. A portion of the methane is assumed to be collected. Methane capture efficiencies depend on the landfill type and have been estimated using professional judgment. Of the captured methane, a portion is assumed to be used to generate electricity and the remainder is assumed to be destroyed by combustion (flaring), so that all the recovered methane is converted to carbon dioxide. The landfill stage considers 100 years of product life in the landfill after disposal, allowing the primary phase of anaerobic degradation to take place. In addition, inputs and outputs related to landfill construction and closure [36] were apportioned on a mass disposed basis.

Penta not leached during product life is allocated as a release to land in the landfill phase. Given the limited decay of wood and the long-term storage design for landfills, including landfill liners designed to contain leachate, this LCA assumes penta and oil remaining in the wood, when disposed, will decay or be sequestered in the landfill to the same degree modeled for wood.

Transportation-related inputs and outputs were included in each life cycle stage. Distances and transport modes for preservative supply to treaters, inbound untreated poles, and outbound treated poles were based on treater survey weighted averages. Other material transport distances and modes were based on professional judgment. Inputs and outputs (per ton-mile) resulting from transportation modes were based on NREL U.S. LCI database information.

### 3.2. Concrete utility poles inventory

Comparable cradle-to-grave life cycle inventories are not available for concrete utility poles; thus, an LCI had to be developed. A "representative" concrete utility pole product design has been assumed to be representative of the general product category. Published LCI data on cement, concrete, aggregate, and steel were downloaded from the NREL's U.S. LCI database, but a survey of spun concrete pole manufacturers was not done for production inputs and outputs. Thus, some inputs and outputs may not be fully identified or quantified.

Because of the way in which pole standards have been written, the concrete pole "equivalent" to a Class 4, 45-foot wood pole meeting National Electric Safety Code (NESC) Grade C design standards is likely to be a Class 2 concrete pole. A smaller class number is a larger pole. The comparable concrete pole can withstand 2400 pounds of horizontal load applied two feet from the pole's tip. Concrete poles are further assumed to be spun-cast high-strength concrete, steel-reinforced designs, intended for direct bury installation (as opposed to being bolted to a foundation).

Steel reinforcement in concrete poles is assumed to include four strands of 0.6-inch longitudinal reinforcement, a spiral of 0.125-inch diameter wire with 3-inch pitch, in a 10-inch diameter pole. Steel bolts used to mount crossarms generally are the same for all poles and were not considered in the LCI. Steel steps are typically installed with concrete poles because they cannot be climbed in the manner wood poles are climbed, using spiked climbing boots. Steps are therefore included in the LCI of concrete poles, but not wood poles. Concrete components include water, cement, and coarse and fine aggregate. A mix is assumed based on information received from a confidential manufacturer of concrete poles.

| Concrete pole properties | | |
|---|---|---|
| Length | 45 | ft |
| Representative concrete pole weight | 3793 | lbs |
| Cement | 897 | lbs |
| Water | 294 | lbs |
| Coarse aggregate | 1444 | lbs |
| Fine aggregate | 1158 | lbs |
| Steel[a] | 207 | lbs |
| Spacing | 22 | pole/mile |
| Service life | 60 | years |

[a] Includes stressed strands, spiral wire, and 23 steel steps per pole.

The pole casting process includes electricity and natural gas (to heat the concrete for accelerated curing), diesel, and water inputs. Concrete pole manufacturing component transport to the casting plant is modeled as if by truck. Transportation of outbound concrete poles to the utility yard and ultimately to the use site is modeled as if by truck. Post-use transport also is assumed by truck. Transport distances were assumed for each stage.

Concrete poles, manufactured with high strength concrete, are unlikely to be recycled because of the low value of recovered products per cost of recovery. This LCI models 100 percent of used concrete poles as landfill disposed. Recycling to aggregate is investigated in the sensitivity analysis.

Concrete pole disposal in landfills includes inputs and outputs for landfill construction and closure proportional to the mass of disposed poles. No environmentally significant emissions result from disposed concrete poles.

### 3.3. Steel utility poles inventory

As with concrete poles, cradle-to-grave life cycle inventories are not available for steel utility poles; thus, an LCI of steel utility poles was developed. A "representative" steel utility pole product design has been assumed to be representative of the general product category. Published LCI data on steel production and galvanizing were used. A survey of steel pole manufacturers was not done, thus some inputs and outputs at the steel pole manufacturing facility may not be fully accounted for.

As with concrete poles, the steel pole comparable to a Class 4, 45-foot wood pole can withstand 2400 pounds of horizontal load applied two feet from the pole's tip. Steel poles are assumed to be tapered, round, welded, galvanized plate steel designs, intended for direct bury installation (as opposed to being bolted to a foundation).

According to the American Institute of Steel Construction, steel utility poles are typically constructed of 11-gauge sheet steel. Utility poles generally are tapered with approximately the same dimensions as wood poles of similar class and length. The steel poles are hollow with top caps and a bottom plate to help prevent sinking into soft soil (direct bury only). Most poles are hot-dip galvanized with zinc after initial manufacture to decrease corrosion. Also, direct-burial steel poles commonly are installed with a plastic synthetic coating applied to the ground-line section. Inputs or outputs associated with plastic synthetic coatings were not considered in this LCI. As with concrete poles, steel steps are included.

| Steel pole properties | | |
|---|---|---|
| Length | 45 | ft |
| Total steel weight | 631 | lbs |
| Total galvanizing zinc weight | 7.17 | lbs |
| Spacing | 22 | pole/mile |
| Service life | 60 | years |

U.S. LCI database information does not include water use; thus data from the U.S. Department of Energy [37] were used. The steel pole manufacturing model includes electricity use of 0.1 kWh/lb of steel utility pole produced. Electricity is required for shaping, cutting, and welding. Inputs for hot dip galvanizing of the fabricated poles include 100 gallons of water for caustic and acid rinses before galvanizing and for quenching after galvanizing, and electricity to heat the pole to the temperature of the molten zinc bath.

Hot dip galvanizing at 0.96 ounce per square foot of surface, interior and exterior or 5.7 pounds (2.6 kg) of zinc per pole was modeled. According to the California Steel Industries [38], the process of galvanizing steel requires heating to between 1300 and 1500 degrees Fahrenheit as a heat treatment prior to galvanizing, and keeping the galvanizing liquid around 850 degrees Fahrenheit during the galvanizing process. Energy requirements to heat the steel and the galvanizing solution were calculated for the LCI. Zinc lost during service life, because of corrosion and weathering, is modeled in the LCI as a release to the ground.

Sources of steel sheet include a mix of domestic and international sources. Transport of poles from the manufacturer to the utility yard includes a mixture of rail and truck. Transport of poles from the utility yard to the points of use is modeled as if by truck. Post-use transport to recycle sites involves both rail and truck modes. Distances are estimated in the LCI.

Steel poles are modeled in the LCI as if 100 percent is recycled as scrap steel. No landfill apportionment is made for steel poles in the LCI.

Concrete and steel utility poles, designed to provide the same strength as wood poles, are installed at equivalent spacing to wood poles. Concrete and steel poles are modeled with an average service life equal to wood poles. In addition concrete and steel poles are modeled with inspections occurring once every 25 years. No maintenance inputs or outputs are included, except transportation.

A summary of selected inventory inputs and outputs for penta-treated, concrete, and steel utility poles is shown in Table 1.

## 4. Life cycle impact assessment

### 4.1. Selection of the impact indicators

The impact assessment phase of the LCA uses the inventory results to calculate indicators of potential impacts of interest. The environmental impact indicators are considered at "mid-point" rather than at "end-point" in that, for example, the amount of greenhouse gas (GHG) emission in pounds of carbon dioxide equivalent ($CO_2$-eq) was provided rather than estimating end-points of global temperature or sea level increases. The life cycle impact assessment was performed using USEPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) [39] to assess GHG emissions, acidification, ecological toxicity, eutrophication, and smog emissions. Other indicators also were tracked, such as fossil fuel use and water use.

#### 4.1.1. GHG emissions

Emissions of the GHGs – carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) – were multiplied by their respective greenhouse gas equivalence factors [39] of 1, 21, and 296, respectively, to calculate pounds $CO_2$-equivalent emissions per pole. The intent of the GHG impact indicator is to quantify human-caused (anthropogenic) emissions that have the potential to affect global climate. Although carbon dioxide molecules behave the same, whether from fossil fuels or biomass, they are addressed differently in calculating GHG emissions. Carbon dioxide resulting from burning or decay of wood grown on a sustainable basis is considered to mimic the closed loop of the natural carbon cycle [40] and is not included in the calculation of GHGs. However, methane that results from the decay of wood or other carbon-based waste in landfills is counted. This methane is produced because disposal in engineered landfills results in anaerobic decay instead of combustion or surface (aerobic) decay.

#### 4.1.2. Resource depletion (fossil fuel use)

The chosen impact indicator for assessment of resource depletion was fossil fuel use. Fossil fuel use currently is an issue related to greenhouse gas impact (as a non-renewable source of $CO_2$ emissions), national security (dependency on imports), and national and personal finances (diminishing resources result in increased costs and limited availability). The selected impact indicator unit of measure was total million BTU (MMBTU) of fossil fuels used.

#### 4.1.3. Acidification

The acidification impact indicator assesses the potential for emissions to air that result in acid rain deposition on the Earth's surface. Factors relating to the relative potential of released chemicals to form acids in the atmosphere [39] were multiplied by the chemical release amounts to calculate equivalent acid rain potential as hydrogen ion ($H^+$) mole equivalents.

**Table 1**
Cradle-to-grave inventory summary for penta-treated, concrete, and steel utility poles.

| Infrastructure process | Units | Penta-Trt pole (/pole) | Concrete pole (/pole) | Steel pole (/pole) |
|---|---|---|---|---|
| Inputs from technosphere | | | | |
| Electricity, at grid, US | kWh | −125 | 772 | 886 |
| Natural gas, processed, at plant (feedstock) | $ft^3$ | −176 | 1571 | 1600 |
| Natural gas, combusted in industrial boiler | $ft^3$ | −71.9 | 111 | 241 |
| Diesel fuel, at plant (feedstock) | gal | 14 | 0 | 0 |
| Diesel fuel, combusted in industrial boiler | gal | 0.0069 | 0.66 | 0.55 |
| Liquefied petroleum gas, combusted in equipment | gal | 0.018 | 0 | 0 |
| Residual fuel oil, processed (feedstock) | gal | 0.21 | 0 | 0 |
| Residual fuel oil combusted in industrial boiler | gal | 0.12 | 0.085 | 0.063 |
| Diesel fuel, combusted in industrial equipment | gal | 1.1 | 0.87 | 0 |
| Gasoline, combusted in industrial equipment | gal | 1.6 | 0.68 | 1.3 |
| Hogfuel/biomass (50%MC) | lb | 335 | 21 | 24 |
| Coal-bituminous and sub. comb in industrial boiler | lb | 0.18 | 0.41 | 0.24 |
| Coal-bituminous and sub. (feedstock) | lb | 0.022 | 116 | 0 |
| Energy (unspecified) | Btu | 859 | 134,892 | 0 |
| Truck transport | ton-miles | 201 | 2109 | 256 |
| Rail transport | ton-miles | 258 | 180 | 645 |
| Barge transport | ton-miles | −2.8 | 17 | 20 |
| Ship transport | ton-miles | 240 | 35 | 366 |
| Diesel use for transportation | gal | 2.8 | 23 | 4.3 |
| Residual oil use for transportation | gal | 0.45 | 0 | 0.64 |
| Harvested sawlogs | $ft^3$ | 29 | 0 | 0 |
| Treated poles | $ft^3$ | −1.4 | 0 | 0 |
| Zinc | lb | 0 | 0 | 7.2 |
| Steel | lb | 0 | 0 | 631 |
| Landfill capacity | ton | 0.16 | 2.0 | 0 |
| Inputs from nature | | | | |
| Water | gal | 46 | 180 | 107 |
| Bark from harvest | $ft^3$ | 2.6 | 0 | 0 |
| Unprocessed coal | lb | −76 | 588 | 532 |
| Unprocessed uranium | lb | −0.00020 | 0.0012 | 0 |
| Unprocessed crude oil | gal | 18 | 17 | 5.6 |
| Unprocessed natural gas | $ft^3$ | −148 | 406 | 167 |
| Biomass/wood energy | Btu | 0 | 0.029 | 0 |
| Hydropower | Btu | −35,784 | 218,696 | 241,023 |
| Other renewable energy | Btu | −2663 | 15,117 | 17,767 |
| Biogenic carbon (from air) | lb | 343 | 0 | 0 |
| Other mined mineral resources | lb | 0 | 4353 | 45 |
| Outputs to nature (air) | | | | |
| $CO_2$-fossil | lb | −52 | 3111 | 1630 |
| $CO_2$-non-fossil | lb | −950 | 23 | 26 |
| Carbon monoxide | lb | 2.8 | 7.6 | 1.6 |
| Ammonia | lb | 0.0036 | 0.0062 | 0.0019 |
| Hydrochloric acid | lb | 0.21 | 0.32 | 0.30 |
| Hydrofluoric acid | lb | −0.0057 | 0.033 | 0.037 |
| Nitrogen oxides (NOx) | lb | 1.5 | 7.1 | 2.4 |
| Nitrous oxide ($N_2O$) | lb | 0.010 | 0.014 | 0.0030 |
| Nitric oxide (NO) | lb | 0.020 | 0 | 0 |
| Sulfur dioxide | lb | −1.6 | 10 | 9.7 |
| Sulfur oxides | lb | 0.41 | 1.2 | 0.39 |
| Particulates (PM10) | lb | 0.37 | 0.54 | 0.11 |
| VOC | lb | 37 | 0.36 | 0.17 |
| Methane | lb | 10 | 3.6 | 3.3 |
| Acrolein | lb | 0.0061 | 0.000064 | 0.000072 |
| Arsenic | lb | 0.000020 | 0.00010 | 0.00011 |
| Cadmium | lb | 0.0000049 | 0.000015 | 0.000016 |
| Lead | lb | 0.000060 | 0.00010 | 0.00011 |
| Mercury | lb | 0.0000042 | 0.000077 | 0.000022 |
| Pentachlorophenol | lb | 0.14 | 0 | 0 |

### *4.1.4. Water use*

The total amount of water used in each unit process of the product life was calculated in gallons. Since water use data were not available for all supporting process units, most importantly for electricity production, results for this impact category may be of limited value.

### *4.1.5. Ecological toxicity*

The ecotoxicity impact category includes ecologically toxic impact indicators that are normalized to a common herbicide of accepted ecological toxicity, 2,4-dichlorophenoxyacetic acid (2,4-D). The amounts of constituents released to air during the products' life cycle stages are multiplied by the factors contained in TRACI [39] to calculate the indicator values.

### *4.1.6. Eutrophication*

The eutrophication impact indicator was normalized to pounds of nitrogen equivalent. The factors contained in TRACI [39] were used to calculate the indicator values in pounds of nitrogen equivalents. Eutrophication characterizes the potential impairment of water bodies (such as algal blooms and use of dissolved oxygen) resulting from emission to the air of phosphorus, mono-nitrogen oxides (NOx), nitrogen oxide, nitric oxide, and ammonia.

**Table 2**
Penta-treated utility poles environmental impacts per utility pole and by life cycle stage (per pole).

| Impact indicator | Units | Life cycle stage | | | | Penta poles cradle-to-grave |
|---|---|---|---|---|---|---|
| | | Pole production | Treating | Service life | Disposition | |
| GHG emissions | lb-$CO_2$-eq | 44 | 95 | 57 | −35 | 162 |
| Fossil fuel use | MMBTU | 0.42 | 4.4 | 0.53 | −1.2 | 4.1 |
| Acid rain potential | $H^+$ moles-eq | 11 | 66 | 10 | −75 | 11 |
| Water use | gal | 17 | 29 | 0.34 | 0 | 46 |
| Smog potential | g-NOx-eq/m | 0.098 | 0.67 | 12 | −0.062 | 13 |
| Eutrophication | lb-N-eq | 0.0075 | 0.046 | 0.0065 | 0.0077 | 0.068 |
| Ecological impact | lb-2,4-D-eq | 0.052 | 1.1 | 1.0 | −0.92 | 1.3 |

*Notes*: Pole production includes: replanting a harvested area of forest, growing and maintaining the forest plantation until harvest, harvesting of the trees, drying, and milling and associated transportation; treating includes: pole peeling, pole drying, preservative manufacture and transport, treatment, storage of untreated and treated poles, releases, and transportation of poles to the utility yard; use includes: transportation of utility poles to the installation site, install, maintenance, releases, and removal; disposition includes: impacts of landfill construction, disposal, energy recovery, secondary use, and associated transportation; cradle-to-grave is the sum of pole production, treating, use, and disposition.

*4.1.7. Smog forming potential*

The smog impact indicator assesses the potential of air emissions to result in smog formation. The factors contained in TRACI [39] were used to calculate the indicator values. Smog emissions result in decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage [41]. Factors relative to smog forming emissions were multiplied by the TRACI [39] factors and reported in grams of NOx equivalents per meter.

## *4.2. Impact indicators considered but not presented*

The TRACI [39] model, a product of USEPA, and the USEtox model, 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 LCA, including, but not limited to, human health impacts and impacts to various impact indicators from releases to soil and water. The decision was made to not include all impact indicators because of limited and/or insufficient data or concerns regarding misinterpretation. Thus, the life cycle inventory 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. Land use impacts were beyond the scope of this LCA.

## *4.3. Total energy*

The total amount of energy input to a product over its life cycle is not considered an impact indicator, but was tracked in the LCA. Total energy is the energy derived from all sources, including fossil, biogenic, and grid electricity converted to common units of millions of BTU (MMBTU) per unit. Energy sources are, to varying degrees, fungible, meaning they can be transferred from one use to another. For example, wood fuel (biomass) can be used to fuel dry kilns, as home heating pellets, or fuel for electric power generation. Similarly, kilns could be heated with natural gas. Generally, products that require less input of energy will have less environmental impact. Tracking total energy and the proportions as biogenic versus fossil allows users to compare this aspect of each product.

# **5. Life cycle interpretation**

## *5.1. Findings*

To assess the processes that result in environmental impact from penta-treated utility poles, impact indicator values were totaled at the four life cycle stages. The impact indicator values at each of the four life cycle stages, and a total for the cradle-to-grave life cycle of penta-treated utility poles, are reported in Table 2.

Impact indicator values were totaled at two stages for concrete and steel products including: (1) the new concrete or steel pole at the utility yard and (2) after service and final disposition. For concrete and steel poles there is no life stage comparable to pole production prior to treatment. Impacts resulting from the service life of concrete and steel are minimal and thus included with the final disposition stage for simplicity. A summary of impact indicator values for all three products is provided in Table 3.

The contributing factors to each impact indicator are not specifically discussed in this report. The purpose of the concrete and steel pole assessment is solely to assess relative impacts when compared to penta-treated poles. Therefore, no discussion of the impact indicators and their product-specific contributions is provided.

To allow relative comparison of indicators between products, impact indicator values were normalized to the product (penta-treated pole, concrete pole, or steel pole) having the highest cradle-to-grave value. The product with the highest value at final disposition receives a value of one, and the other products then are fractions of one. The results of Table 3 are normalized and shown graphically in Fig. 2 to visually illustrate the comparative data.

The life cycle of penta-treated utility poles requires the use of both fossil and biomass sources of energy. Together, the fossil and biomass energy result in a total energy requirement. Much of the fossil fuel energy needed during the life cycle of penta-treated utility poles is attributed to diluent oil use and landfill construction and closure. Much of the biomass energy use attributable to penta-treated utility poles is a result of biomass use at saw mills as a substitute for fossil energy. Energy requirements for concrete and steel are mostly from fossil fuel sources. A summary of biomass and fossil energy and their contribution to total energy is shown in Table 4.

## *5.2. Data quality analyses*

Data quality analyses per ISO 14044 [16], Section 4.4.4, included a gravity analysis, uncertainty analysis, and sensitivity analysis.

*5.2.1. Gravity analysis*

A gravity analysis was conducted to identify the processes that are most significant to the impact indicator values. The indicator values of each process are divided by the sum of the absolute value of each stage. Gravity analysis identifies the significance of recycling poles for energy production. Beneficial recycling of poles for energy, at the end of their service life, off-sets inputs and outputs required to produce the equivalent amount of grid electricity. The gravity of the negative impacts, are shown in Table 5.

**Table 3**
Summary of impact indicator totals at life cycle stages for penta-treated, concrete, and steel utility poles (per pole).

| Impact indicator | Units | Penta-pole manufacture and delivery to utility | Penta-pole service life and disposition | Penta-pole cradle-to-grave | Concrete pole manufacture and delivery to utility | Concrete pole service life and disposition | Concrete pole cradle-to-grave | Steel pole manufacture and delivery to utility | Steel pole service life and disposition | Steel pole cradle-to-grave |
|---|---|---|---|---|---|---|---|---|---|---|
| GHG emissions | lb-$CO_2$-eq | 139 | 23 | 162 | 1985 | 1205 | 3190 | 1653 | 45 | 1699 |
| Fossil fuel use | MMBTU | 4.8 | −0.68 | 4.1 | 10 | 5.6 | 16 | 12 | −3.5 | 8.4 |
| Acid rain potential | lb-mole $H^+$ | 77 | −66 | 11 | 458 | 428 | 886 | 368 | 253 | 622 |
| Water use | gal/year | 46 | 0 | 46 | 180 | 0 | 180 | 236 | −130 | 106 |
| Smog potential | g NOx-eq/m | 0.77 | 12 | 13 | 3.8 | 1.2 | 5.0 | 2.2 | 0.092 | 2.3 |
| Eutrophication | lb-N-eq | 0.054 | 0.014 | 0.068 | 0.27 | 0.041 | 0.32 | 0.13 | −0.026 | 0.10 |
| Ecotoxicity | lb-2,4-D-eq | 1.1 | 0.13 | 1.3 | 14 | 4.1 | 19 | 1.7 | 3.7 | 5.5 |

### *5.2.2. Uncertainty analysis*

Many data inputs involve uncertainty. Some assumptions were based on professional judgment, resulting in additional uncertainty.

The service life stage of poles includes inputs for inspection and maintenance of poles while in service. Materials, quantities, and/or frequencies of application different from the assumptions are possible and, as such, may impact findings. Such differences are not expected to impact comparative results.

Penta released during pole treatment, storage, service life, and at disposition can be estimated only by use of assumptions. The uncertainty of these assumptions is large because of variations in production facility containment structure integrity, production facility housekeeping practices, regional location of the treating facility and service location (i.e., precipitation amount will directly impact leaching), and disposition.

The methods employed by utilities to dispose of poles after service vary considerably by utility, based on their policies, locations, economics, and available options. Definitive data for the U.S. are unknown; however, a study of western U.S. utility practices [25] was used as a basis for disposition practices of penta-treated utility poles in this LCA. As is shown by the sensitivity analysis, changes to the relative proportions of poles routed to recycling for energy versus being disposed in landfills can significantly impact the comparative results of this LCA. The current (baseline) assumptions for post-use fates are judged reasonable for the purpose of this LCA.

Landfill fate and release models are based on USEPA data [40] used to estimate GHG emission for USEPA's inventory, and modeled assumptions result in variability of impact indicator values, especially GHG. In the LCA, penta-treated poles are assumed to degrade to the same degree and at the same rate as round wood limbs disposed in a landfill. If treatment retards or prevents degradation of the wood in a landfill, then releases of methane could occur over a longer period, reducing the rate per time unit. Because of the landfill uncertainties, further analysis was conducted as part of the sensitivity analysis. Additionally, releases of penta from landfills to soil and groundwater are unknown. Modern landfills are designed to prevent such releases. Also, it is assumed that carbon-based components of penta preservative and oil remaining in the treated poles are decomposed in the landfill in the same proportions as the wood.

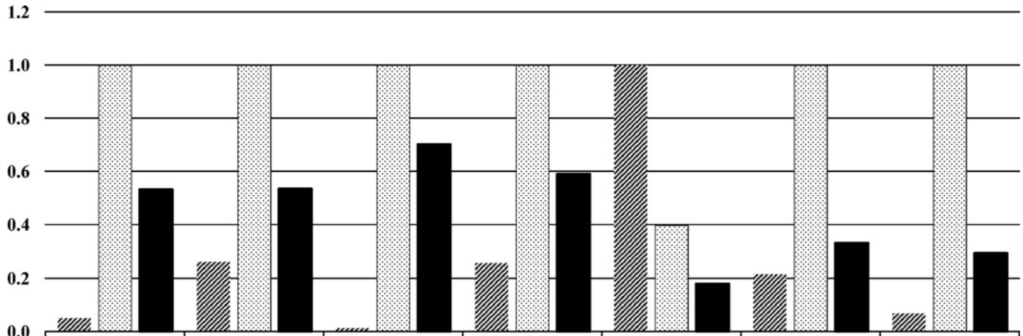
The comparative analysis phase of this LCA includes the assembly of LCIs for concrete and steel utility poles. The cradle-to-grave LCIs of concrete and steel poles include data inputs that involve professional judgments and include uncertainty. Some assumptions are based only on professional judgment. No survey of manufacturers of the concrete or steel products was done.

### *5.2.3. Sensitivity analysis*

Sensitivity analysis was completed to determine the magnitude resulting from assumptions and uncertainties identified in the LCI and the impact on LCA results.

*Penta preservative retentions*. Penta retention in utility poles was adjusted, as low retention and high retention scenarios. The baseline treatment retention used in the assessment was 0.36 pcf (4.2 $kg/m^3$). Impact indicators are sensitive to changes in gross retention and have the greatest impact on acidification. Smog was the least impacted indicator. Relative to the other products, the sensitivity changes did not change the comparative results.

*Peeler biomass use*. Biomass is used by many pole-treating facilities to fuel boilers. The biomass is an alternate fuel to natural gas, and results in lower fossil fuel use. The amount of biomass and natural gas used to fuel boilers was modeled in a sensitivity analysis. Acidification is the most sensitive indicator, while water use and smog are not sensitive. The sensitivity analysis shows that drying with biomass fuel, positively affects impact indicators except for eutrophication and ecological toxicity. Increased natural gas




| | Greenhouse Gases | Fossil Fuel Use | Acid Rain | Water Use | Smog | Eutrophication | Ecological Toxicity |
|---|---|---|---|---|---|---|---|
| Penta pole | 0.051 | 0.26 | 0.013 | 0.26 | 1.0 | 0.21 | 0.068 |
| Concrete pole | 1.0 | 1.0 | 1.0 | 1.0 | 0.40 | 1.0 | 1.0 |
| Steel pole | 0.53 | 0.53 | 0.70 | 0.59 | 0.18 | 0.33 | 0.29 |

**Fig. 2.** Cradle-to-grave impact indicator comparison of representative penta-treated, concrete, and steel utility poles (normalized to maximum impact = 1.0).

**Table 4**
Energy sources by product and stage.

| Product and life cycle stage | Total energy input (MMBTU) | Fossil fuel use (MMBTU) | Biomass energy (MMBTU) | Fossil fuel intensity (% of total) | Biomass intensity (% of total) |
|---|---|---|---|---|---|
| Penta pole manufacture and delivery to utility | 5.4 | 4.8 | 0.58 | 89% | 11% |
| Penta pole cradle-to-grave | 5.5 | 4.1 | 1.5 | 75% | 27% |
| Concrete pole manufacture and delivery to utility | 10 | 10 | 0.011 | 98% | 0.10% |
| Concrete pole cradle-to-grave | 17 | 16 | 0.094 | 94% | 0.56% |
| Steel pole manufacture and delivery to utility | 12 | 12 | 0.010 | 98% | 0.079% |
| Steel pole cradle-to-grave | 9.5 | 8.4 | 0.11 | 89% | 1.1% |

*Note*: Intensity percentages do not always add to 100% because of non-fossil, non-biomass and energy recovery (recycling) contributions.

use results in increases to GHG, fossil fuel use, and acid rain, but results in decreases in eutrophication and ecological toxicity. Relative to the other products, the sensitivity changes did not change the comparative results.

*Penta-treated utility pole service life*. Changes in service life affect all impact indicators proportionately. Penta-treated utility pole service life, if modeled at 40 years while alternative products are assumed to have a service life of 60 years, results in favorable comparison of all impact indicators for penta-treated utility poles except smog.

*Penta-treated poles impact of secondary use.* The proportion of utility poles having a secondary use, such as landscaping or fencing material, will carry the environmental impacts associated with their secondary use and final fate separately. However, since its primary use was a utility pole, it is fair to assume that the utility pole should carry some portion of these secondary use burdens. For this LCA, the baseline scenario has penta-treated utility poles carrying 25 percent of the secondary use burdens. If secondary use impacts attributable to the original product are set at 0 percent, reductions of impact to acidification and GHG emissions result. If secondary use impact is set at 100 percent, increases to acidification and GHG emissions result. A change in secondary use impact, attributable to original product, does not change overall comparisons with alternative products.

*Post-use disposition of penta-treated poles and the impact.* The baseline model assumes five percent pole reuse by utilities, 45 percent reuse for landscaping or fencing, 30 percent disposal in landfills, and 20 recycling for energy recovery. If 80 percent of used poles are diverted for energy recovery, then decreases to GHG, fossil fuel, acid rain, and ecological toxicity are observed. Minor increases in eutrophication also are observed. Increased landfill disposal of used poles results in increases to GHG, fossil fuel use, acidification, and ecological toxicity. In both sensitivity cases, comparisons with alternatives do not change.

*Landfill decay models*. Barlaz [42] reported that approximately 77 percent of the carbon in wood fiber of branches disposed in landfills is sequestered after primary decomposition has occurred. This estimate of carbon sequestration was used in the landfill model. The presence of lignin (a major carbon-based component of wood) can interfere greatly with cellulose and hemicellulose degradation

**Table 5**
Contributions to impact indicators by life cycle stage of penta-treated utility poles.

| Impact indicator | Life cycle stage | | | | Penta poles cradle-to-grave |
|---|---|---|---|---|---|
| | Pole production | Treating | Service life | Disposition | |
| GHG emissions | 19% | 41% | 25% | **(15%)** | 100% |
| Fossil fuel use | 6% | 67% | 8% | **(19%)** | 100% |
| Acid rain potential | 7% | 41% | 6% | **(46%)** | 100% |
| Water use | 37% | 62% | 1% | 0% | 100% |
| Smog potential | 1% | 5% | 93% | **(1%)** | 100% |
| Eutrophication | 11% | 68% | 10% | 11% | 100% |
| Ecological impact | 2% | 35% | 34% | **(29%)** | 100% |

*Notes*: Bold values in parentheses indicate negatives. Negatives are the result of credits recognized from energy recovery and off-sets for supplementing fossil fuel needs. The absolute value of stage impacts are used to calculate the percentage of total impact.

under the anaerobic conditions of landfills. Laboratory research shows it to be very resistant to decay in landfills because cellulose and hemicellulose are embedded in a matrix of lignin [43–45]. Preservative in disposed penta-treated poles is expected to further increase carbon sequestration by retarding decay, but is not included in the baseline assumptions. To demonstrate the sensitivity of carbon sequestration, a test case was assessed where 90 percent wood fiber carbon sequestration occurs in the landfill. Based on the results of this modeling, increased sequestration of 90 percent reduces the GHG impact indicator by approximately 70 percent, but results in an approximate 30 percent increase in acid rain potential. Comparisons of indicators between products do not change.

*Concrete pole service life*. Changes in service life affect all impact indicators proportionately. When concrete poles are assessed with a service life of 99 years, decreases in all impact indicators are observed; however, none of the overall comparisons with penta-treated utility poles change.

*Post-use fate of concrete poles.* The LCI model assumes 100 percent of used concrete poles are disposed in landfills following their service life. If recycling to aggregate and steel recovery is proven to be cost efficient, the steel could be recycled and the aggregate used as a low-grade material offsetting new aggregate. A test case considered recycling of 80 percent of concrete poles to aggregate and recycled steel. Life cycle impacts were reduced with recycling; however, changes are not significant to overall comparative results with penta-treated utility poles.

*Steel pole life*. Changes in service life affect all impact indicators proportionately. When steel poles are assessed with a service life of 99 years, decreases in all impact indicators are observed. None of the overall comparisons with penta-treated utility poles change, except eutrophication, which is equal to penta-treated utility poles.

### 5.3. Limitations

The scope of the study was limited to boundaries established in the Goal and Scope document prepared for this LCA. Limitations included reliance on published or publicly available information in many instances. Such information was assumed to be accurate. Value judgments such as purchase price and ease of installation were beyond the scope of this LCA.

The life cycle inventory completed for both concrete and steel was designed as a representative alternative product, and therefore by design, likely will not be accurate for a specific product in this category. A survey of manufacturers of concrete and steel utility poles was not done; therefore, inputs such as fuel and electricity use, water use, and solid waste generation at the manufacturing facilities are estimated using professional judgment and confidential sources of information. Available inventory data covering the manufacture of cement, aggregate, and steel were downloaded from the NREL's U.S. LCI database.

## 6. Conclusions and recommendations

### 6.1. Conclusions

The use of penta-treated utility poles offers lower fossil fuel and water use and environmental impacts than similar products manufactured of concrete and steel, with the exception of emissions with the potential to create smog. Compared to a penta-treated utility pole, and using the assumptions of this LCA, with the understanding that assumptions can vary, use of a concrete utility pole results in approximately four times more fossil fuel use and results in emissions with potential to cause approximately 20 times more GHG, 77 times more acid rain, four times more water use, almost five times more eutrophication, and over 14 times more ecological toxicity. Penta-treated utility poles result in over two times more smog in comparison to concrete utility poles.

Compared to a penta-treated utility pole, use of steel utility poles results in two times more fossil fuel use and results in emissions with potential to cause 10 times more GHG, 54 times more acid rain, over two times more water use, 1.5 times more eutrophication, and over four times more ecological toxicity. Penta-treated utility poles result in over five times more smog in comparison to steel utility poles.

The total energy use value (including fossil fuel use, biogenic, and renewable resources) of concrete and steel are three and 1.7 times more than for a penta-treated utility pole, respectively. Of the total energy, approximately 75 percent is from fossil fuel sources for penta-treated utility poles, in comparison to 94 percent and 89 percent for concrete and steel, respectively.

### 6.2. Recommendations

Production facilities of all types of utility poles 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.

Treated-wood pole service life varies greatly and often is a function of proper inspection and maintenance. Pope [26] has shown that poles with no maintenance have an average service life (50 percent rejected as needing replacement) of 40–50 years, but with normal inspection and maintenance, the average service life would extend to 60 or more years. Improved inspection and maintenance programs should be used to maximize pole life, thereby decreasing impacts.

Utilities should seek to minimize releases of methane resulting from disposal of wood in landfills in two ways: minimize disposal in landfills by recycling or as a fuel, and limit disposal to landfills that do not have methane collection systems. Minimizing disposal is doubly beneficial, since it generally is accomplished by shifting the disposition of post-use poles to biomass utilization instead of disposal, thus offsetting other fossil fuel use and reducing landfill emissions. Landfills that collect methane become carbon positive as the carbon dioxide equivalent release becomes less than the amount sequestered.

This study includes the comparison of penta-treated utility poles to concrete and steel poles. The results conform with the ISO 14040 and ISO 14044 standards and are suitable for public disclosure. The peer-review Procedures and Findings Report can be requested by contacting the TWC at http://www.treated-wood.org/contactus.html.

## Acknowledgments

The authors wish to thank the TWC for its funding of this project. The TWC members and their Executive Director, Mr. Jeff Miller, have been integral in its completion. We also thank the internal reviewers, James H. Clark, Mike H. Freeman, and Craig R. McIntyre 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.

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