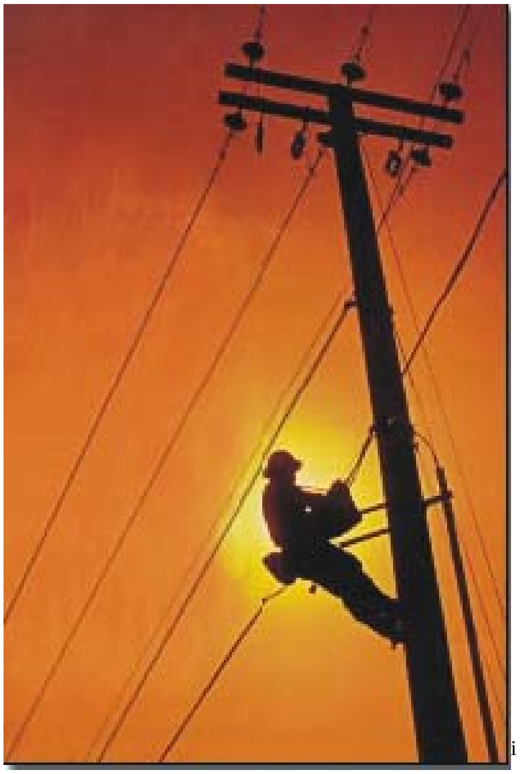
The Environmental Impact of Utility Poles



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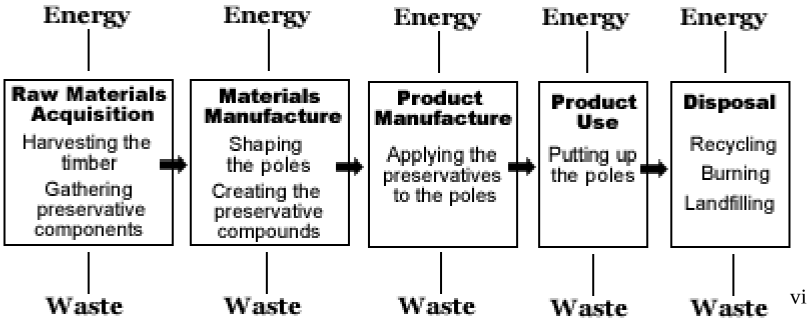
Introduction

Utility Poles hold up the wires and cables that bring electricity and other modern amenities from the power and cable companies to our homes. These poles help provide for our growing network of telephones, televisions, and computers. Though wires are frequently covered underground in new grid expansions, there are still roughly 135 million utility poles in service in the United States.[ii] While some steel and concrete poles are in use, the vast majority of utility poles are wood. Wooden poles are very robust, nonconductive, and allow for overhead wires to be attached in a variety of ways. Another advantage is the low cost: approximately $250 for a standard 45-foot pole versus $260 and $350 for steel and concrete (respectively). As will be shown later using Carnegie Melon University's life cycle analysis (LCA), wooden poles also have a seemingly small environmental impact based on energy consumption, greenhouse gas emissions and toxic releases. There are significant environmental drawbacks, however, which are not addressed by this LCA. These drawbacks revolve around the poisonous chemical preservatives added to the wood to extend their lifespan. For example, each year approximately 18 million[iii] kg of arsenic, a heavy, poisonous metal, are removed from service with the wooden utility poles and dumped in landfills. This project explores the impacts of these preservatives and offers several solutions.

Wooden Utility Pole Life Cycle

Raw Materials

The wooden utility pole life cycle starts with timber harvesting. This generally consists of five components: felling; cutting trees to standard lengths and removing un-usable limbs and tops, moving trees from the woods to a landing area, loading the poles on trucks, and transporting the poles to the processing point.[iv] After de-barking the poles are bent and cut into the specific dimensions. While utility poles can range anywhere from 20' to 125' depending on their final use, most utility poles are around 45 feet tall.[v]



[vi]

Figure 1: Schematic illustrating the wooden utility pole life cycle

Preservatives

The next step in the poles' life cycle is to produce preservatives that protect them from insects, fungi, and fires. The most common types in the United States are creosote, chromate copper arsenate (CCA), and Penta. Coal-tar creosote has been used as a wood preservative in the U.S. for over 100 years and is "produced by the high temperature carbonization of coal and consists principally of aromatic hydrocarbons plus some tar acids and bases."[vii] CCA, another kind of preservative, consists of the oxides or salts of copper, chromium, and arsenic. The arsenic and copper are poisonous to insects and fungi that prey on wood, "while chromium is used to bond the two elements to the wood's cellular components."[viii] Penta (C_6HCl_5O) was one of the most heavily used all-purpose pesticides in the U.S. up until 1984. It is produced using aluminum chloride or ferric chloride as catalysts for the chlorination of phenols.[ix]

It's estimated that of the 135 million poles in service today in the United States, 80% are treated with CCA, 17% with creosote and less than 1% with Penta.[x] The EPA has labeled Creosote a potential carcinogen and sharply limited its use. For this reason the vast majority of new utility poles are treated with CCA. CCA has it own problems, however, as arsenic is a heavy metal that can contaminate air and water with very low concentrations. Table 1 helps to illustrate this concern for both CCA and creosote.

Preservative	**Major Components**	**Air**	**Water**
CCA	Copper	0.1 mg/m^3	1.0 mg/L
	Chromium	52-1000 μg/m^3	1.0 mg/L
	Arsenic	10 μg/m^3	0.05 mg/L
Creosote	Benzo(a)pyrene	0.2 mg/m^3	0.01 μg/L
	Phenols	0.2 mg/m^3	2.0 μg/L

Table 1: Permissible levels of chemicals in the environment[xi]

Disposal

The concluding step in the lifecycle of a utility pole is disposal at the end of its operating life. Three potential methods include: landfill, incinerate, or re-cycle for other uses. With each option, the release of the chemical preservatives into the environment is a large big concern. Since the allowable level of arsenic in the air is so low, incinerating wooden utility poles treated with CCA is banned in the United States. Recycling is not a common option as the poles retain a large amount of the CCA preservative after removal from service. For these reasons, most utility poles are disposed of in landfills. Once in the landfill, the chemicals in the preservatives eventually leach into the ground water. These externalities are very significant and are discussed further in the alternatives section.

Life Cycle Analysis

To analyze the environmental impact of the utility pole's life cycle, we used Carnegie Mellon University's Economic Input-Output Life Cycle Analysis model (EIO-LCA).[xii] The EIO-LCA provides about 500 commodities/services, which one can analyze. The wooden utility poles are listed under the wood preservation sector. This industry sector includes creosote and CCA preservation in one category, so the results include the impact from both preservatives.

As the model's name implies, the model requires an input of the amount of money spent in the desired sector. For this input we used the amount of money that would be spent on each type of utility pole in the United States, if that were the only type of pole being installed throughout the country. The results are displayed in Table 2. (For a more complete display of the results, see Appendix A).

Material	Cost ($/pole)	Average Life	Annual Production	Cost per year ($)
Wood	250	30	6.00E+06	1.50E+09
Steel	260	35	5.36E+06	1.39E+09
Concrete	350	35	5.36E+06	1.88E+09

Table 2: Values used to arrive at monetary inputs necessary for the CMU EIO-LCA

Wood is the least expensive, however, its average lifespan is slightly less than the alternatives. To calculate the annual production of utility poles, we divided the total amount of utility poles installed in the U.S. (135 million)[xiii] by each pole's average lifespan, then added 1.5 million. The additional 1.5 million accounts for increased demand and reserve stocks. The cost per year is then calculated as the product of the annual production and the cost per pole. One can see that although the wood is the least expensive per pole, steel lasts longer and thus costs less per year. The concrete is all around the most expensive choice. These three values were input into the respective sectors and LCA model output the values in Table 3.

Material	Energy (TJ)	Greenhouse Gases (MTCO2E)	Toxic Releases (kg)
Wood	1.48E+04	1.20E+06	1.07E+06
Steel	4.18E+04	3.82E+06	6.76E+06
Concrete	3.34E+04	2.47E+06	7.26E+05

Table 3: Impact of each type of utility pole per year if that were the only type installed throughout the country.

The wooden poles have the smallest impact overall with respect to energy and greenhouse gases. The toxic releases category includes the total releases and transfers of toxic substances by the product during its production, use and disposal. This includes "transfers of toxic substances to publicly owned treatment works" (e.g. run-off from the poles leaching) and "offsite transfers of toxic substance, including disposal, energy recovery, recycling and treatment."[xiv] While there is a substantial amount of toxic releases from the wooden poles, the dirty process of steel production creates more. As discussed later, these toxic release values are misleading because of misrepresented costs of disposal of the wooden poles.

One can also view data on a per pole basis as in Table 4 (a graphical representation of this data my be seen in Appendix B).

Material	Energy (TJ)	Greenhouse Gases (MTCO2E)	Toxic Releases (kg)
Wood	0.0025	0.20	0.18
Steel	0.0078	0.71	1.26
Concrete	0.0062	0.46	0.14

Table 4: Impact per pole

Per pole the toxic releases of the wooden pole calculated by the LCA are slightly more than the concrete. Since the concrete poles last longer and thus fewer are installed each year, the toxic releases on a per year basis are much greater for the wood as seen in Table 3.

Alternatives

There are several ways to avoid or reduce the environmental impacts of utility poles. The inverted pyramid model shown in Appendix C illustrates various actions that can be taken. The best solution would be to avoid the use of utility poles and instead use underground transmission lines, or produce electricity locally to avoid transmission over long distances. Another way to prevent pollution due to the preservatives is to use a more benign preservative or use materials like steel and concrete which are not prone to rot and pests.

Poles could also be redesigned for superior strength, which would increase the spacing between poles. Hollow poles could also be installed, which would use less material. The next step down on the pyramid is to reuse or recycle by using the poles for timber or for indoor construction. The biggest environmental impact in the lifecycle of utility poles occurs in the disposal stage, with large quantities of arsenic entering landfills. This can be avoided by separating the chemicals from the wood prior to the landfill or incineration.

Two levels of redesign were explored for this project:

1. *Product Improvement*: A list of specifications (Appendix D) describing an ideal utility pole were used to find alternative designs and materials. Utility poles could be made up of 100% recycled materials like discarded rubber tires and recycled plastics and be designed to last longer, have superior strength and be recyclable (Appendix E). Other materials such as fiberglass or carbon fiber could also be used as an alternative to wood, steel and concrete.

2. *Process Improvement*: Disposal of used utility poles has a very big environmental impact and creative end of life strategies need to be employed to close the loops to the greatest extent possible. Currently, many remediation methods are possible. These methods separate the chemicals from the wood and allow the arsenic to be recovered and used again in the preserving process.

Product Improvement

Alternative Pole Design

In order to develop a utility pole superior to the state of the art with a smaller environmental impact, we developed a simple table of specifications to guide us (Appendix D). The most important factors to take into consideration are the durability and environmental impact of the new alternative.

A finite element analysis (FEA) program was used to validate the strength of the new pole. This strength was then balanced with the energy of the pole's life cycle. If the pole were too weak, it would not hold up under the stress of the attached wires, if it were over designed, its lifecycle would require more energy than the current wooden pole.

First, the standard, 45-foot, douglas fir wooden pole was analyzed using SolidWorks' COSMOSWorks FEA software. As seen in Figure 2a), a force of 2,400 lbs was applied to the top of the pole to simulate the force imparted by attached wires. This is the force that the American National Standards Institute requires all class 4 utility poles be able to withstand. The displacement of 25 inches at the top of the wooden pole was recorded and compared with the displacement of the alternatives under the same force. In order for an alternative to satisfy the durable specification, it must displace no greater than the baseline wooden pole under the same force.

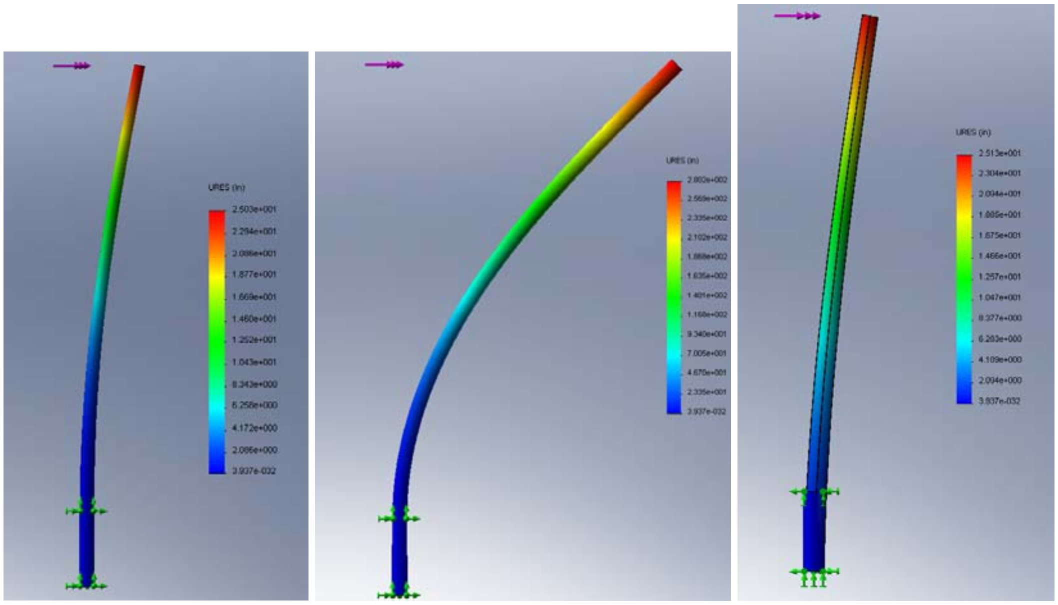


Figure 2: The displacements of 3 poles under 2,400 lb of force, a) Wooden pole displacement: 25" b) HDPE pole displacement: 280" c) Final alternative displacement: 25"

Several alternatives were explored before arriving at one that satisfied both the durability and environmental impact specifications. Initially, high-density polyethylene (HDPE) was used with the same dimensions as the wooden pole. The displacement in Figure 2b), however, illustrates the shortcoming of just using a different material with the same dimensions. So the diameter was expanded for added durability, but a displacement of less than 24 inches could not be achieved without drastically increasing the mass, which led to a high-energy impact from manufacturing and transportation.

It became evident that HDPE alone would not suffice as a replacement and so a small amount of recycled steel reinforcement was added. This combination eventually led to the design in Figure 3 which had a displacement of 25 inches as seen in Figure 2c).

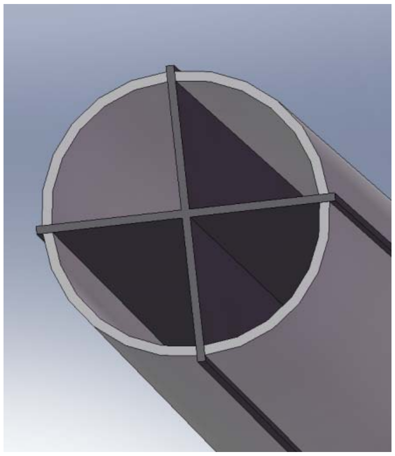


Figure 3: Final design for alternative HDPE and steel composite utility pole

The steel is 0.4 inches thick and the HDPE around the outer edge is 0.5 inches thick.

Alternative Pole LCA

A life cycle analysis was then performed to determine the energy used during the manufacturing, transportation and disposal of the new pole (Appendix F). This energy was then compared with the energy required by the wooden utility pole.

The energy due to manufacturing the plastic and steel was calculated using the values of 56,000 and 18,100 MJ/kg for recycled HDPE and steel respectively.[xv] Several assumptions were then made to calculate the energy required for transportation: the most notable include an extended lifespan to 80 years versus the 35 years for wood and 2.33 MJ/ton-mile required to transport goods by truck in the U.S. The disposal of the pole actually provided a net energy gain, as the plastic and steel are 100% recyclable. The sum off energy due to manufacturing, transportation and disposal may be seen in Table 5.

Energy Consumption (MJ)	
Manufacturing	29165.946
Transportation	1094.69458
Disposal	-26249.351
Total (per pole)	4011.289
Total energy (per year)	1.28E+10

Table 5: Total energy of alternative pole

When all the energy is added up on a per year basis, the alternative pole requires less energy compared to the wooden utility pole as seen in Figure 4.

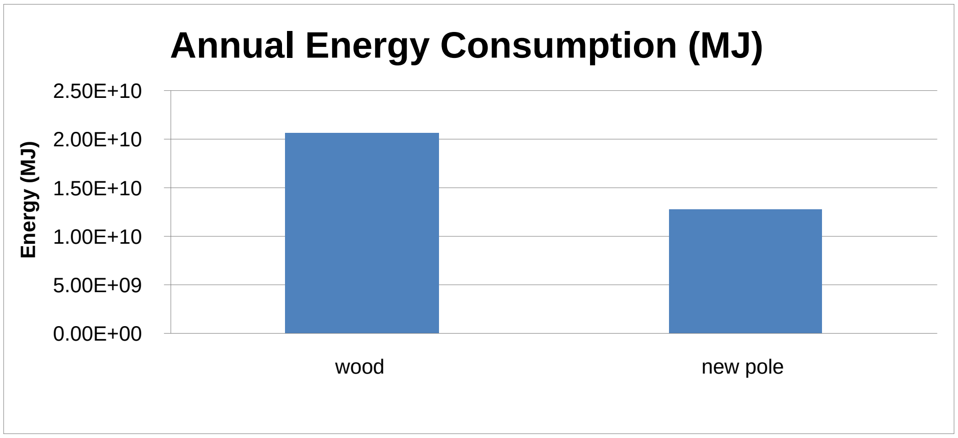


Figure 4: Total energy for each pole over the course of one year

Process Improvement

CCA Separation Methods

As mentioned earlier, approximately 18 million kg of arsenic contained in utility poles are removed from service each year. One solution to this poison problem is to physically remove the chemicals from the wood, and then incinerate or reuse the benign leftover wood. While no industrial scale CCA separation processes exist, many studies have been carried out to address this issue.

Some studies have focused on evaluating chemical extraction as a means to remove the CCA (Kim and Kim, 1993; Clausen and Smith, 1998; Kazi and Cooper, 1999; Kartal, 2003), while others tried using biological processes (Clausen and Smith, 1998). One study combined the chemical and biological processes (Clausen, 2000). Table 6 summarizes these studies and the extent of separation possible.

Method	Means	Percent Removed (%)		
		Cu (as CuO)	**Cr (as CrO3)**	**Arsenic (as As2O5)**
Biological Process	Bacillus licheniformis CC01	91	15	45
Chemical Process	Oxalic acid extraction	81	62	89
Combined Chemical/ Biological Process	Acid extraction and Bacterial fermentation	80	80-90	90-99
Electrodialytic Process	The method uses a low-level direct current as the "cleaning agent", combining the electrokinetic movement of ions in the matrix with the principle of electrodialysis.	90	85	85
Electrokinetic Process	Oxalic acid, Citric acid, EDTA, and Ascorbic acid	74	97	88

Table 6: CCA separation methods recently studied[xvi]

Shortcomings associated with these treatment processes include the structural integrity of wood fibers after treatment, the required treatment duration, and the challenge of controlling full-scale biological reactors for selected micro-organisms.

Electrodialytic remediation is a method that uses a direct electric current as a cleaning agent and combines it with the use of ion exchange membranes to separate the electrolytes from the wood.[xvii] The drawbacks to this method include a relatively complex operation, a substantial capital investment in operating hardware, and the fact that it is unable to remove soluble ions from a bulk medium.

Chartherm CCA Separation

One of the only CCA separation methods operational on an industrial level is the "Chartherm" process (Appendix G). The primary strength of this process lies in the fact that it allows recycling, irrespective of the level of pollution, without the need for prior sorting. The process makes it possible to extract heavy metals, purify coal and possibly facilitate separation of heavy metals. It consists of three stages: grinding, "chartherisation" and separation.

Once the wood is fed into the system it is ground into small pieces. The next stage is called "chartherisation" and involves heating the ground wood by subjecting it to a current of hot gases. This causes an adiabatic combustion, which leads to gasification of volatile elements and mineral elements being entrapped in a coal-type residue, which is very rich in carbon. This charcoal cannot be used as such, especially if it is produced from the wood treated with CCA. It is essential to extract the polluting elements to obtain clean charcoal suitable for use.

The residue is further ground down to progressively release the metal particles from the layer of coal surrounding them. They are then passed through a pneumatic sieve and transported to a pneumatic centrifuge where, as a result of the difference in density between the carbon and the metals, the latter precipitates outwards against the outer walls of a rotating pneumatic air cushion. The carbon is sucked into the center and conveyed towards a large sleeve filter. The heavy metals are then recovered from under the centrifuge and contain a low percentage of carbon whereas pure carbon is recovered from the outlet of the sleeve filter. By recovering clean charcoal, the system is able to produce much more energy than it consumes.

Chartherm LCA

A new lifecycle analysis was conducted using energy consumption as a metric. This analysis includes manufacturing costs as calculated by the CMU model, transportation costs based on average MJ/ton-mile and energy recovery during disposal as reported by Chartherm.

The table in Figure 5 presents details of the lifecycle analysis, which are summarized in Appendix H.

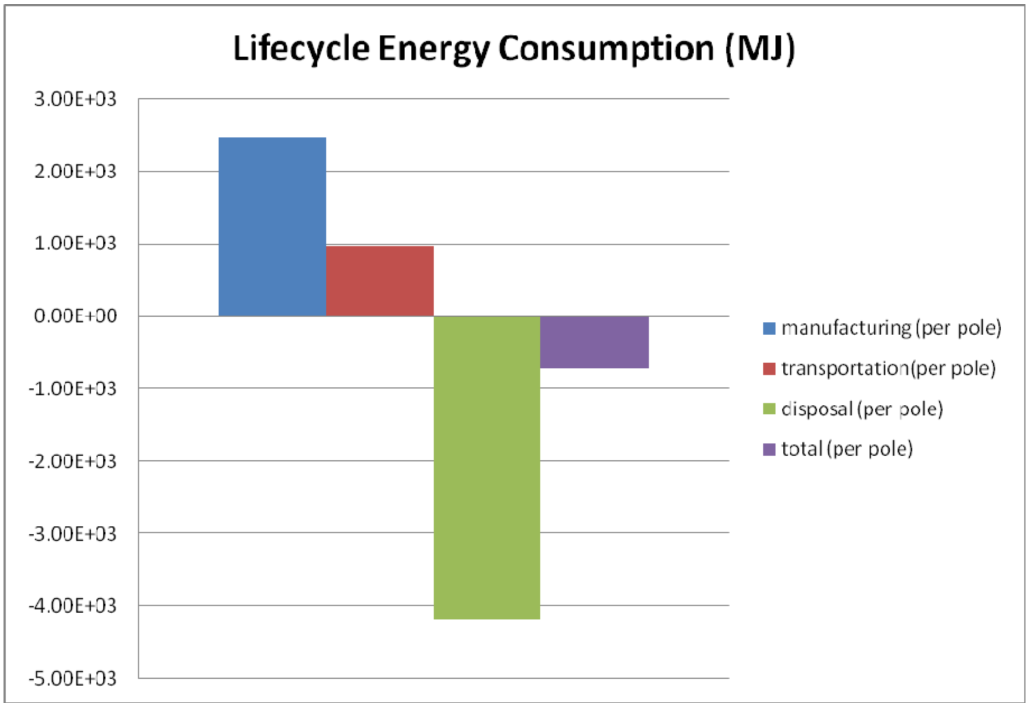


Figure 5: Energy breakdown of wooden utility pole life cycle implementing "Chartherm" as a disposal technique

It can be observed that the net energy consumption over the lifecycle of a wooded utility pole is negative. This occurs because the disposal phase allows one to capture the intrinsic energy embedded in wood when it converts it to charcoal. Furthermore, this is done in a safe way by isolating the heavy metals used for preservation.

A typical plant has a capacity of 500,000 poles a year and installing these to meet the U.S. levels of disposal could be capital intensive. Changes in disposal policy, such as imposing a higher cost on land filling could improve the economics of the process and the likelihood of its success.

Conclusions

An initial look at the life cycle of current utility poles suggests that wood is by far the superior choice. The CMU LCA shows that with respect to energy use and greenhouse gas emissions wooden utility poles produce less environmental impact than both steel and concrete poles. Only steel poles have a larger toxic impact than wooden poles. These numbers are deceiving, however, because they do not account for externalities such as the vast amounts of arsenic deposited in landfills once the useful life of the pole has expired (approximately 18 million kg per year).

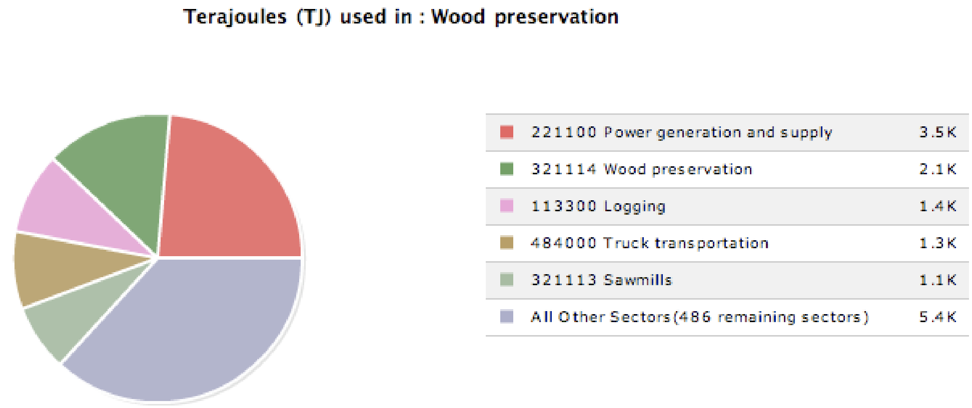
To avoid these externalities, a product improvement was implemented: an alternative pole design was created that avoided preservatives by using recycled plastic and steel. Energy was used as a metric to compare the old and the new. The strength of the new pole was balanced with the amount of energy used to produce it. The energy required by the pole's life cycle was then compared with the traditional wooden pole. It was found that per year the new alternative pole would use less energy.

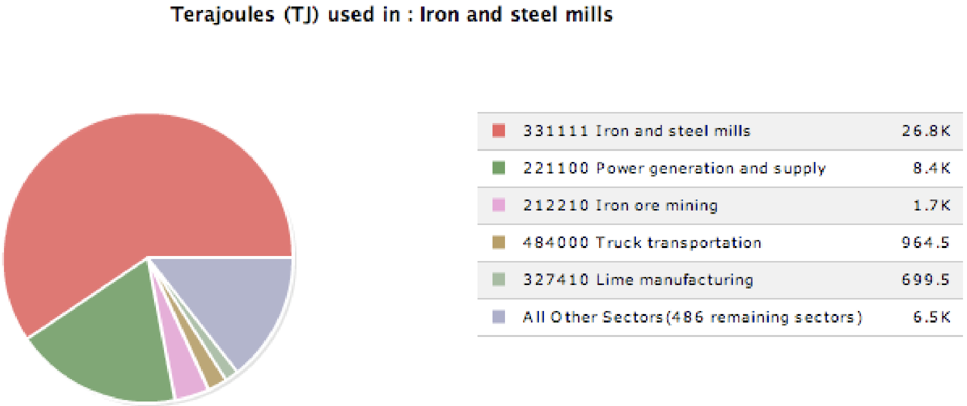
Lastly, process improvements were explored. Several methods of separating the CCA from the wood during the disposal stage were researched and one was analyzed. There at least five methods currently being studied, but none of these have been implemented on an industrial level, separation for some of them do not exceed 90% and the costs are unknown. The "Chartherm" method was analyzed more closely to determine its potential. Using energy as a metric, it was determined that this separation method would have a net energy gain, making it very appealing as a means of dealing with poles currently being removed from service. The cost of the process, however, is unknown.

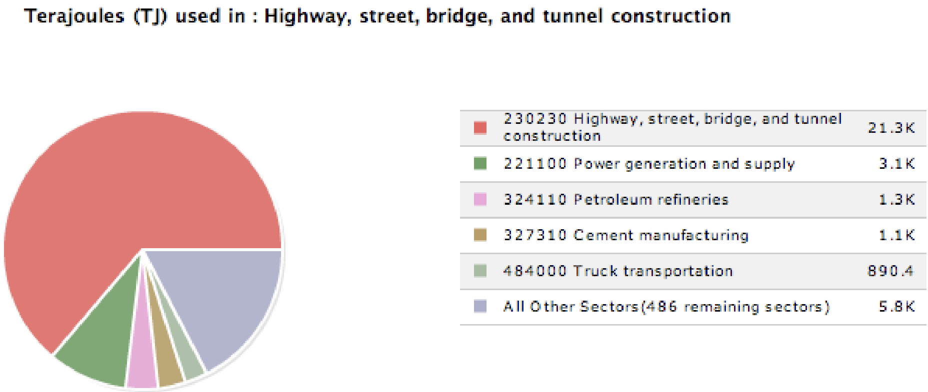
Appendix A

The output pie charts from the LCA of the three sectors, wood, steel and concrete, are below. These represent the impact of each sector per year.

Energy:

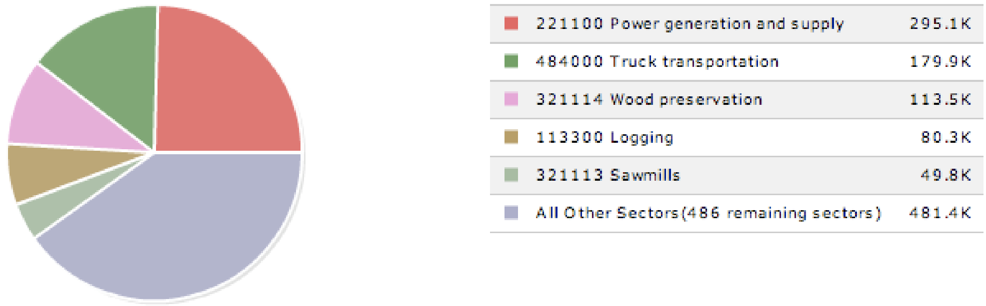




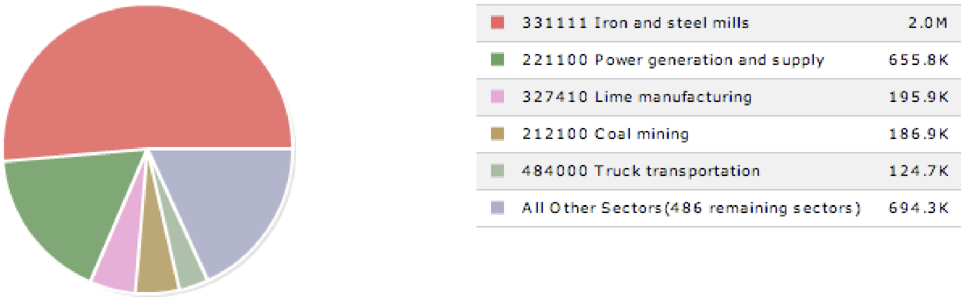


Greenhouse Gas:

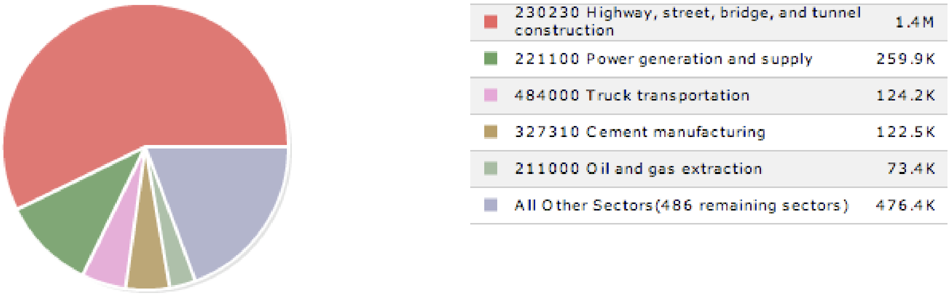
Metric Tons of CO2 Equivalent (MTCO2E) used in : Wood preservation



Metric Tons of CO2 Equivalent (MTCO2E) used in : Iron and steel mills

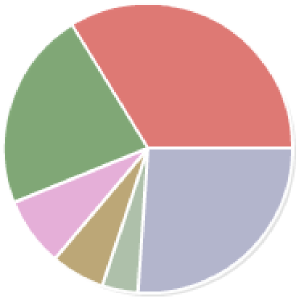


Metric Tons of CO2 Equivalent (MTCO2E) used in : Highway, street, bridge, and tunnel construction



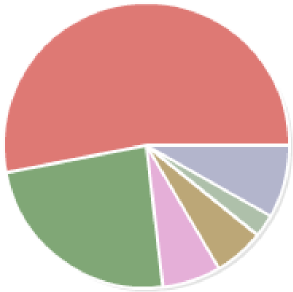
Toxic Releases:

Kilograms (kg) used in : Wood preservation



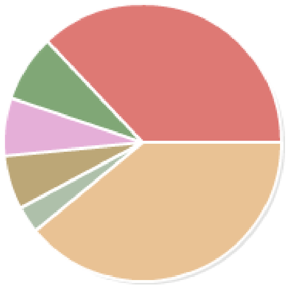
🟥	321114 Wood preservation	361.6K
🟩	212230 Copper, nickel, lead, and zinc mining	238.9K
🟪	325180 Other basic inorganic chemical manufacturing	82.9K
🟫	221100 Power generation and supply	64.4K
🟩	2122A0 Gold, silver, and other metal ore mining	42.8K
🟦	All Other Sectors(486 remaining sectors)	279.4K

Kilograms (kg) used in : Iron and steel mills



🟥	331111 Iron and steel mills	3.9M
🟩	212230 Copper, nickel, lead, and zinc mining	1.7M
🟪	331419 Primary nonferrous metal, except copper and aluminum	484.0K
🟫	2122A0 Gold, silver, and other metal ore mining	412.8K
🟩	331112 Ferroalloy and related product manufacturing	189.0K
🟦	All Other Sectors(486 remaining sectors)	599.8K

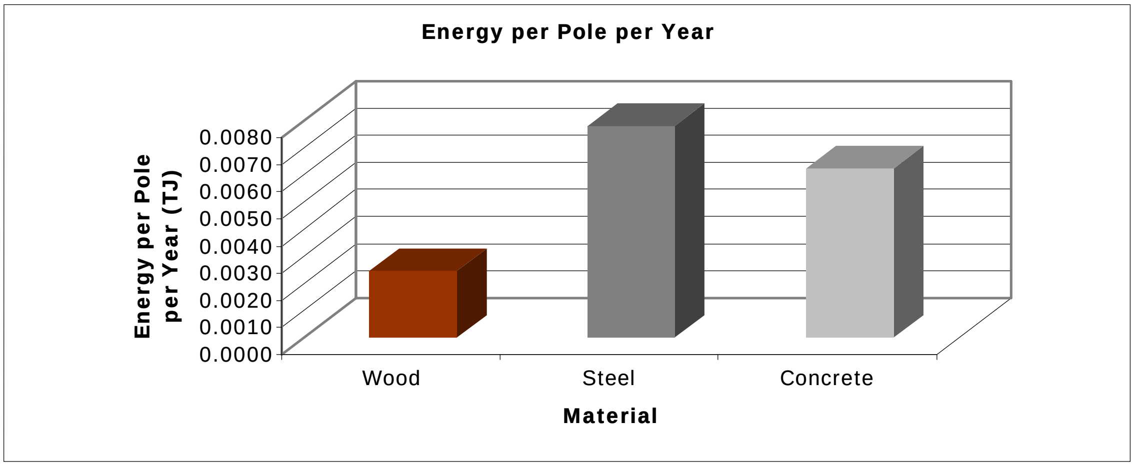
Kilograms (kg) used in : Highway, street, bridge, and tunnel construction

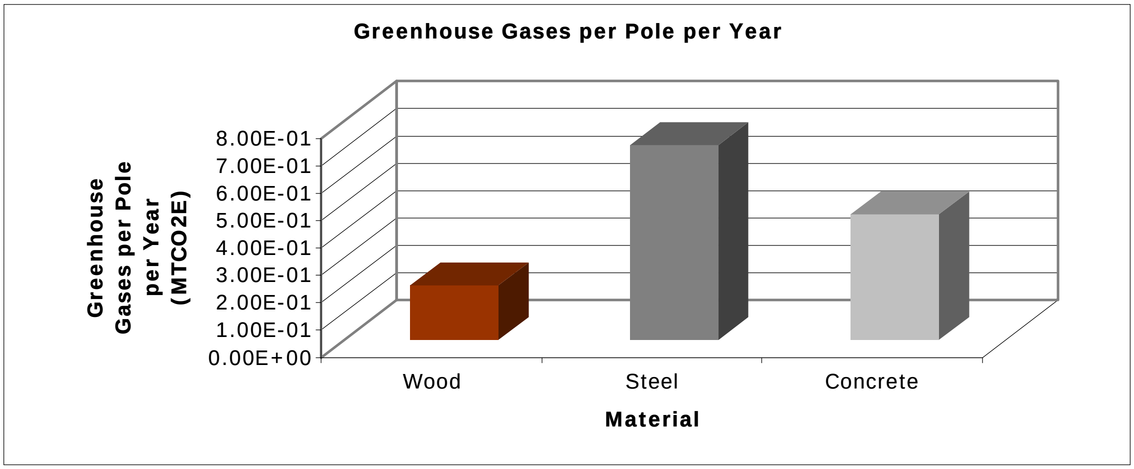


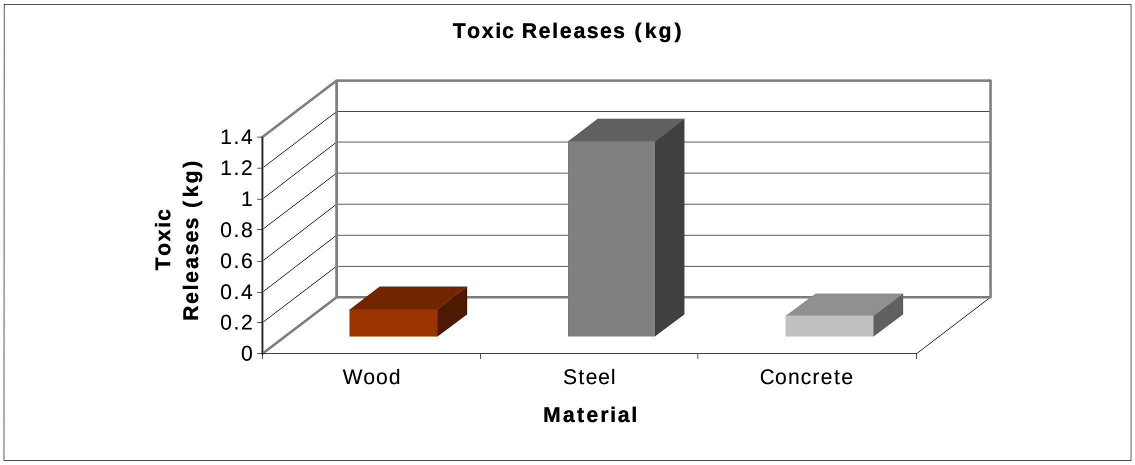
🟥	212230 Copper, nickel, lead, and zinc mining	268.8K
🟩	221100 Power generation and supply	56.7K
🟪	331111 Iron and steel mills	48.9K
🟫	2122A0 Gold, silver, and other metal ore mining	45.4K
🟩	324110 Petroleum refineries	22.9K
🟦	230230 Highway, street, bridge, and tunnel construction	0.0
🟧	All Other Sectors(485 remaining sectors)	283.3K

Appendix B

Below are graphs comparing the impact per pole using the data in Table 4.

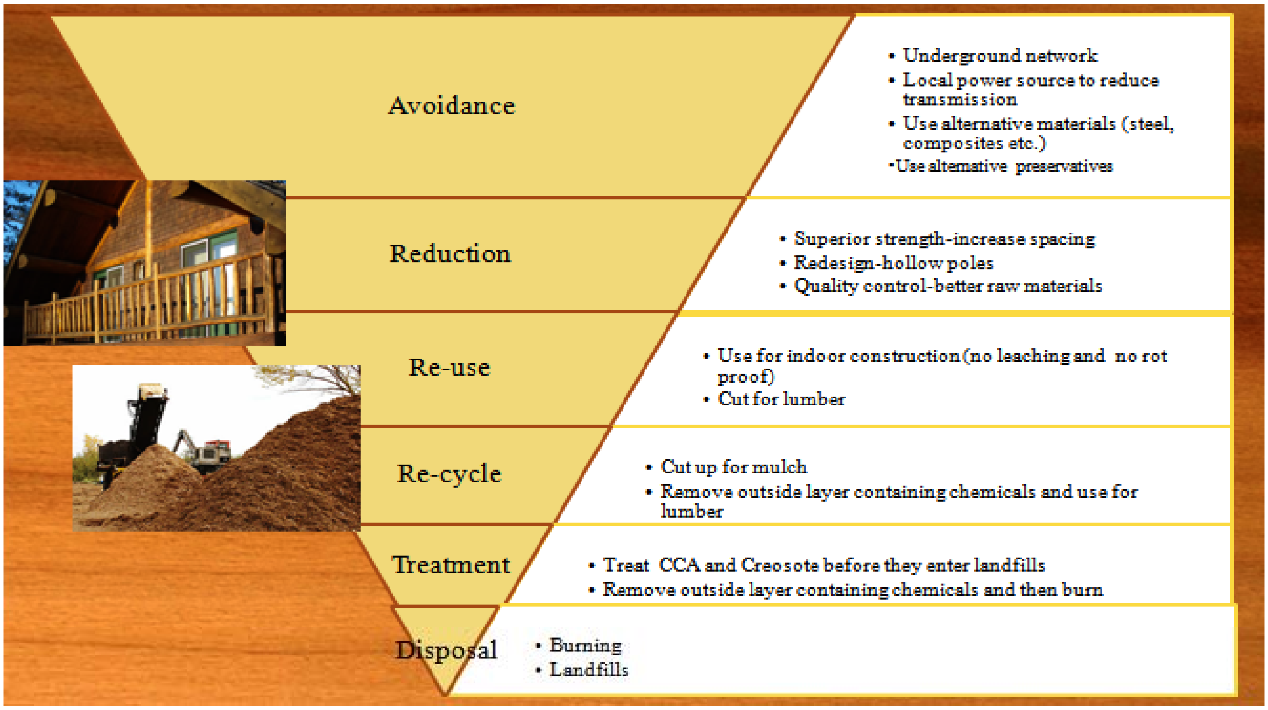






Appendix C

Pollution prevention hierarchy



Avoidance

- Underground network
- Local power source to reduce transmission
- Use alternative materials (steel, composites etc.)
- Use alternative preservatives

Reduction

- Superior strength-increase spacing
- Redesign-hollow poles
- Quality control-better raw materials

Re-use

- Use for indoor construction (no leaching and no rot proof)
- Cut for lumber

Re-cycle

- Cut up for mulch
- Remove outside layer containing chemicals and use for lumber

Treatment

- Treat CCA and Creosote before they enter landfills
- Remove outside layer containing chemicals and then burn

Disposal

- Burning
- Landfills

Appendix D

Alternative pole specifications

Specification	**Justification**	**Quantification**
Initial and life-cycle costs	Should provide most economic value	Dollar Value
Environmental Impact	Low energy consumption and use of toxic substances; Easily recycled or reused	EPA standards, Cost of recycling, energy recovery
Strength	high strength for increased durability and low material usage	Grade
Life Span	Longer life reduces life cycle costs	Average life span
Design Flexibility	Efficient use of materials	
Weight	Less Materials, Easier Transportation and installation	Pounds or kg
Maintenance	Must have low maintenance cost	Labor costs, Failure rates

Appendix E

Alternative utility pole using recycled plastic and rubber (patent pending)

Source: http://www.designrecycleinc.com/products.html

Appendix F

LCA of alternative pole

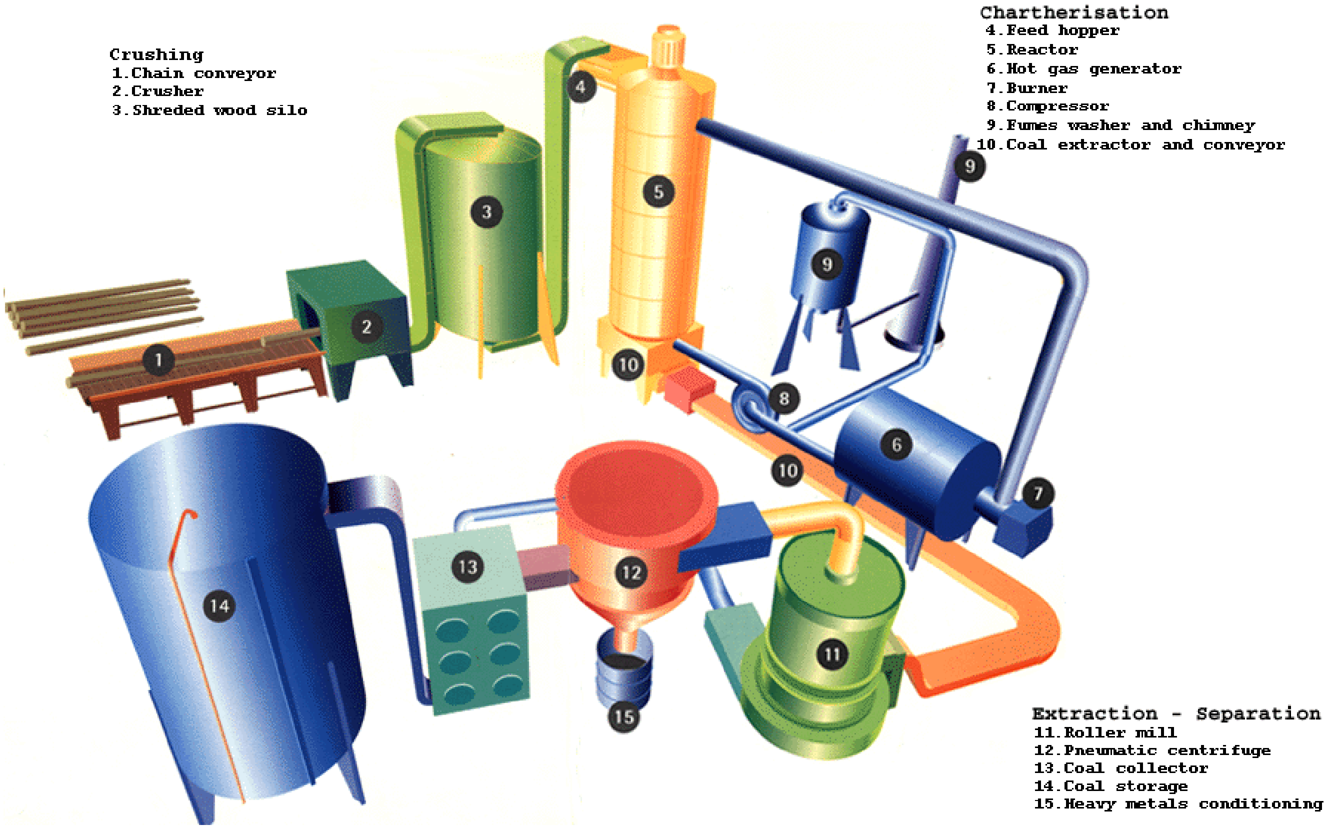
New Pole - manufacturing			
	plastic	**steel**	**total**
weight (ton)	0.209	0.966	1.175
energy manufacture (MJ)	11682.16	17483.7855	29165.946

New Pole – Transportation	
number	135000000
life (years)	80
number per yr	3187500
weight (ton)	1.175
MJ/ton-miles	2.33
distance to site (miles)	200
distance to disposal site (miles)	200
energy per year (MJ)	3489338974
energy per pole (MJ)	1094.69458

New Pole - Disposal			
	plastic	**steel**	**total**
intrinsic energy	95%	95%	1.900
(MJ)	11098.052	16609.59623	27707.648
energy lost due to attrition	5%	5%	0.100
(MJ)	584.108	874.189275	1458.297
energy recovered on disposal (MJ)	10513.944	15735.40695	26249.351
net energy (MJ)	1168.216	1748.37855	2916.595

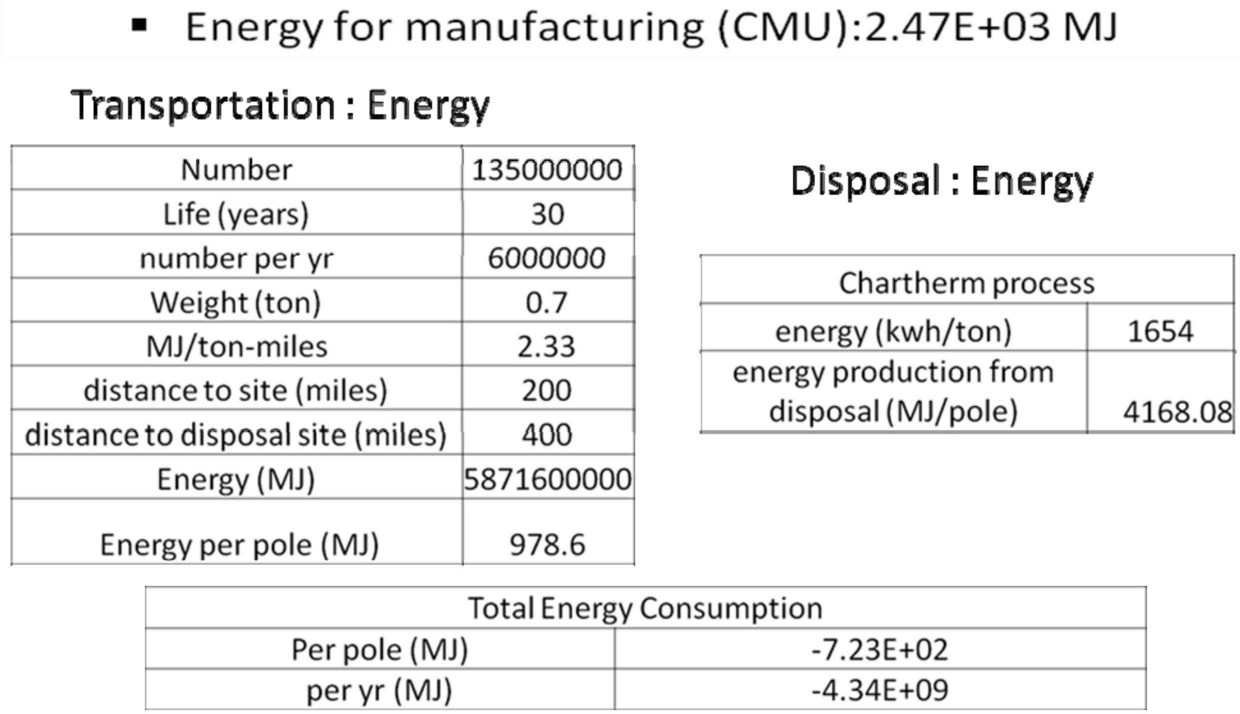
Appendix G

Chartherm Process



Appendix H

LCA of wooden utility including the Chartherm process



- Energy for manufacturing (CMU):2.47E+03 MJ

Transportation : Energy

Number	135000000
Life (years)	30
number per yr	*6000000*
Weight (ton)	0.7
MJ/ton-miles	2.33
distance to site (miles)	200
distance to disposal site (miles)	400
Energy (MJ)	5871600000
Energy per pole (MJ)	978.6

Disposal : Energy

Chartherm process	
energy (kwh/ton)	1654
energy production from disposal (MJ/pole)	4168.08

Total Energy Consumption	
Per pole (MJ)	-7.23E+02
per yr (MJ)	-4.34E+09

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[i] http://www.ncn-uk.co.uk/DesktopDefault.aspx?tabindex=119&tabid=420

[ii] AISI, 2005, Environmental Literacy Council

[iii] Calculated assuming V = 1.25 m^3, 0.6 lbs CCA/ft^3, 4.5 million poles removed per year, and no leaching during use

[iv] CORRIM, 2004, Environmental Literacy Council

[v] Green and Hernandez, 1998, Environmental Literacy Council

[vi] http://www.enviroliteracy.org/article.php/1311.html

[vii] AWPA, 2005, Environmental Literacy Council

[viii] Chirenje et al, 2003; HowStuffWorks.com, Environmental Literacy Council

[ix] ATSDR, 2001, Environmental Literacy Council

[x] http://www.ncn-uk.co.uk/DesktopDefault.aspx?tabindex=119

[xi] As specified by the EPA, OSHA and the Canadian Department of Environment and Conservation

[xii] http://www.eiolca.net/about.html

[xiii] Coalition Against the Misuse of Pesticides: http://www.beyondpesticides.org/wood/resources/Fact%20Sheet%20Revised%20Treated%20Wood%202-21-03.pdf

[xiv] http://www.eiolca.net/about.html

[xv] http://engineering.dartmouth.edu/~cushman/courses/engs171/UsefulNumbers.pdf

[xvi] Sources: http://www.liebertonline.com/doi/pdf/10.1089/ees.2005.22.642?cookieSet=1, http://pubs.acs.org/cgi-bin/article.cgi/esthag/2000/34/i05/html/es990442e.html, http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V63-4DB59WM-1&_user=4257664&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000022698&_version=1&_urlVersion=0&_userid=4257664&md5=2d7b6973a7723ba7ba92bb818900fdb7, http://www.fpl.fs.fed.us/documnts/pdf1998/claus98b.pdf, http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VFR-4FH4V24-2&_user=4257664&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000022698&_version=1&_urlVersion=0&_userid=4257664&md5=fb90df7e0323b5eebb9ccc41076eb2ce

[xvii] Ribeiro *et al.*, 2000; Velizarova *et al.*, 2002, 2004