215 Jamestown Park, Ste. 100 ◦ Brentwood, TN 37027 ◦ Phone (615) 373-8532
7340 E. Caley Ave., Ste. 200 ◦ Centennial, CO 80111 ◦ Phone (303) 771-9150
7080 Landmark Place ◦ Helena, MT 59601 ◦ Phone (406)449-6216

Creosote-Treated Ties
End-of-Life Evaluation

Stephen Smith[1] and Chris Bolin[2]

Introduction

The full life cycle of creosote-treated railroad ties includes: the growth of trees on forested land; harvest of logs; milling to create ties and lumber; treatment of ties with creosote; use of the ties by the railroads as part of the railroad bed; and, at the end of their use lives, disposal or use as an energy source. End-of-life alternatives include: recycling ties to produce useful energy, disposing ties in landfills, and legacy ties along the railroad's right-of-way. This paper reports the results of evaluation done to determine some of the energy and environmental consequences of these end-of-life options. Calculations for this paper were completed in spreadsheet tables that are available from the authors.

Description of Creosote-Treated Ties

Crossties are primarily made of hardwood species, mostly species of oak. Approximately 8 percent are made of softwood species, predominantly Douglas fir. After milling, ties are dried either by air seasoning in stacks open to the air for several months or by the Boulton process, in which ties are heated in the treating cylinders immersed in liquid creosote and under vacuum to drive off excess moisture. The "dry" ties average approximately 40 to 50 percent moisture on a dry wood basis.

Ties are treated by pressure impregnation of creosote preservative. Standards for treatment are stated in the American Wood Protection Association (AWPA) standards. Most ties are treated to a gauge retention of seven (7) pounds per cubic foot (pcf) of wood with refractory species, such as white oak and Douglas-fir, being treated to refusal. Gauge retention is calculated simply as

[1] Stephen Smith, P.E. AquAeTer, Helena, MT. E-mail: stephentsmith@earthlink.net.
[2] Chris Bolin, AquAeTer, Centenial, CO. E-mail: cbolin@aquaeter.com.

the amount of creosote injected into a charge of wood divided by the volume of wood in the charge. Since some wood species are "refractory", meaning the wood is resistant to treatment, the actual U.S. average creosote retention in ties is probably in the range of 5 to 6 pcf. 5.5 pcf is assumed in this evaluation.

Ties vary in size depending on use. The standard or "typical" tie measures 7-inches high by 9-inches wide by 8.5-feet long. The volume for this size tie is 3.72 cubic feet. Thus, the average new tie contains approximately 20 pounds of creosote (5.5 lb/ft^3 x 3.72 ft^3).

The composition of a treated tie changes from initial treatment through the use life such that it is different at the end-of-life. Ties spend their use life in an extreme environment; placed horizontally, the top surface fully exposed to sun and weather, the sides and bottom embedded in ballast rock, repeatedly heated, cooled, wetted, and dried, in varying climates, while being subjected to repeated compression and bending stresses as they support the transport of millions of tons of freight each year. A portion of the creosote is lost due to volatilization, and biological and photo-chemical degradation that takes place on the surface of the ties and to a lesser extent in surrounding ballast.

Kohler and Kunniger (2003) determined creosote levels in ties following 2, 5, 10, and 32 years in service. Although the loss rate early in life was higher, the long term straight line average at 32 years was approximately 32 percent loss. Thus, a simple approximation of 1 percent loss of creosote per year of service and an average service life of 35 years supports an estimate that 35 percent of the creosote initially injected into the ties is lost during the use life. All of the creosote loss is assumed to degrade or oxidize so that the carbon fraction is eventually converted to carbon dioxide.

Some biological decay of the wood also occurs during the use life. While this fact is clear by observation of some used ties, we are not aware of any data to document the amount of wood mass typically lost. For this evaluation, we assume 5% is decayed with that fraction of the wood carbon converted through aerobic processes to carbon dioxide.

The moisture content of the ties will change over time to be in equilibrium with the environment. While this will vary significantly for used ties, an average of 20 percent moisture for ties at end-of-life is assumed in this evaluation.

The average composition of ties at life stages of untreated, newly treated, and end-of-use are shown in Table 1.

Table 1 - Composition of Ties by Life Stage

Tie Components	Untreated, green	Treated	Loss/ change in Use	Used ties
	(lb/tie)	(lb/tie)		(lb/tie)
Wood (dry mass)	148	148	5%	141
Water (% of dry mass)	70%	40%		20%
Water mass	104	59		28
Creosote mass	0	20	35%	13
Whole tie	252	228		182

Impact Indicators

As noted above, each end-of-life option has consequences. The following indicators of potential impacts (consequences) are evaluated for each option.

- Fossil Energy Use – Fossil energy is a non-renewable resource. Use of fossil energy is a measure of resource depletion. When renewable resources, such as wood, are beneficially used, they offset fossil fuel use and reduce resource depletion.
- Greenhouse Gases – Global warming is thought to be at least partially caused by human (anthropogenic) releases of gases that trap heat within the earth's atmosphere, called greenhouse gases (GHG). Carbon dioxide is the reference compound used to assess warming impact. Methane is released in much smaller quantities, but is estimated to have 21 times the warming potential of carbon dioxide on a mass basis. Wood is biogenic, rather than fossil fuel. Wood combustion results in the release of carbon dioxide to the atmosphere in a manner similar to other fuels; however, because the carbon in wood was first removed from the atmosphere through photosynthesis as the trees grew and would naturally return to the atmosphere when the trees die and either rot or burn, the use of wood fuel is considered carbon neutral. Use of wood fuel therefore does not increase GHG emissions.
- Acidification – Acid rain or precipitation impacts include building corrosion, water body acidification, vegetation effects, and soil effects. Acid forms in the atmosphere due to releases of compounds such as nitrogen oxides, hydrochloric acid, and sulfur oxides. Combustion of fuel results in emissions that contribute to acidification. The relative potency of each compound to cause acidification, in units of hydrogen ion mole equivalents per pound released (H^+mole-eq) has been summarized in the USEPA Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) model. These factors have been applied to standard emission rates for natural gas, wood,

and coal combustion boilers to evaluate the potential acidification impact of each disposal option.

Tie Impact Indicators Prior to End-of-Life

The wood in each tie contains 71 pounds of carbon that equates to the removal of 260 pounds of carbon dioxide during tree growth. Each tie also contains 13 pounds of fossil carbon in the creosote. Thus, treated ties begin with negative 260 pounds of CO_2 and this value increases through life as the fossil components decay or are combusted. While in use, 5 percent of the wood and 35 percent of the creosote are converted to carbon dioxide, raising the GHG emissions by 34 pounds for a net of negative 226 pounds.

Recycle Ties for Energy Recovery

Used ties have value as a source of energy. The heat value of wood varies generally from about 4,500 to 8,000 BTU per pound (9,000 BTU per pound at zero percent moisture), depending on moisture content. Creosote adds to the heat value with approximately 12,500 BTU per pound. Thus, each tie offers approximately 1.4 million BTU (MMBTU) of heat energy.

Ties may be used as fuel in a facility designed specifically to burn ties, in industrial wood fired boilers, in utility boilers co-fired with coal, or other solid fuel combustion systems, such as cement kilns. With new technology, ties are being used in gasification facilities to produce electric energy or liquid biofuel. In a cogeneration (also called combined heat and power) facility, ties and other fuel, as applicable, are burned to produce high pressure steam that drives a turbine to produce electricity while some or all of the low pressure steam from the turbine is used for process heating, thereby increasing the overall thermal efficiency of energy conversion.

When ties are burned beneficially as fuel, they offset fossil fuel that would otherwise have been used to produce the same energy. The energy value of one tie is approximately equal to that of 125 pounds of coal.

Since the wood fuel is carbon neutral, for each tie burned for energy recovery, only the creosote portion is considered a fossil fuel that results in the addition of approximately 39 pounds of carbon dioxide to the atmosphere. The carbon dioxide from burning coal of equal energy would be approximately 288 pounds. Thus, each tie used for energy results in a net offset of carbon dioxide emissions of approximately 249 pounds.

Acidifying emissions from burning wood (13 H^+-mole-equivalents/tie) are less than for burning an equivalent amount of coal (136 H^+-mole-eq/tie); thus, use of ties for fuel results in lower net acidifying emissions.

Landfill Disposal of Ties

Following removal from the railroad bed, used ties are collected into either trucks or railcars and are transported to landfill disposal sites. At the landfills, ties are placed and buried with other construction and demolition (C&D) waste and/or municipal solid waste for long term disposal. Within the landfill, some of the wood and creosote will degrade anerobically, producing both carbon dioxide and methane. Some of the methane will further degrade to CO_2, some will be collected and burned, and some will be emitted to the atmosphere. The carbon dioxide from wood degradation is considered carbon neutral and does not count as a GHG. However, the methane would not result from natural decay in the forest, which is mainly aerobic, so is considered a GHG.

This evaluation considers ties being disposed in an assumed "typical" mix of 55 percent municipal waste landfills and 45 percent C&D landfills. Laboratory data of the fate of wood in landfills (EPA, 2006) is used to model the fate of ties in landfills. 77 percent of the mass is assumed to remain in long term storage (sequestered) in the landfill. Of the rest, half is decayed into carbon dioxide and half to methane. Of the methane, 75 percent is collected from municipal waste landfills while none is collected from the C&D landfills. We further assume that of the methane not collected, 10 percent from municipal waste and 25 percent from C&D landfills decays to carbon dioxide and the rest is emitted to the atmosphere as a GHG. Of the collected methane, 60 percent is assumed to be used beneficially as a fuel and the rest burned by flares with no beneficial use, meaning that all of this is converted to CO_2.

From the model, each tie disposed in a landfill will have 5.5 pounds of methane released to the atmosphere, 4.9 pounds of methane captured, of which 1.9 pounds are burned in a flare, and 3.0 pounds are used beneficially offsetting the use of an equal amount of natural gas. Approximately 44 pounds of biogenic carbon dioxide and 7.0 pounds of fossil carbon dioxide will be emitted. However, the GHG emission of methane and fossil carbon dioxide will be 116 pounds of CO_2-equivalent less 8 pounds of CO_2 for offset natural gas combustion for a net of 108 pounds CO_2-equivalent of GHG.

Legacy Ties in the Right-of-Way

It is unknown to what extent legacy ties exist along the right-of-way. Assuming that following removal from the rail bed a small number of used ties remain along the railroad within the rightsof-way land, then those ties will decay through aerobic bacterial action on the soil surface. Complete decomposition is assumed to occur over approximately 40 to over 100 years. In areas where access is practical, some ties may be reclaimed by residents for landscape or fence uses, but the ties would still decay in about the same time. Since decay is aerobic, no methane emissions result.

The used tie wood decays to produce approximately 247 pounds of biogenic carbon dioxide and the creosote would decay to produce approximately 39 pounds of fossil carbon dioxide. No fossil fuel offsets would occur.

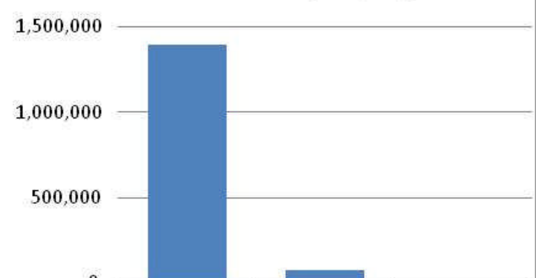
Comparison to National Energy Use

The GHG and fossil fuel use reductions possible through recycling ties for energy are significant. In the U.S., the average energy use per capita is approximately 337 MMBTU, of which 286 MMBTU are fossil fuel. Each tie recycled is estimated in this calculation to yield 1.4 MMBTU of energy. Thus, each tie recycled represents approximately 0.5 percent of the annual U.S. per capita fossil fuel usage. Furthermore, the average GHG emissions per capita are estimated at 51,600 pounds of CO_2-eq. Each tie recycled results in the elimination of approximately 225 pounds of CO_2-eq. and represents approximately 0.5 percent of the annual per capita GHG emissions.

Limitations

This paper presents a simplified analysis of creosote treated tie life cycle and disposal and is not a Life-Cycle Assessment. The items analyzed and the impact indicators presented were selected for the purpose of highlighting the differences applicable to the end-of-life options for ties. Impacts potentially associated with the production and use of creosote or releases of creosote during the use life are beyond the scope of this paper. Additionally, impacts associated with transportation of ties to recycle or landfill sites is not included because 1) it is highly variable depending on tie removal and disposal locations, 2) is likely to be very similar for recycle and landfill disposal options, 3) impacts may be overstated where ties bound for recycle are transported on the same cars that will be reloaded with new ties, and 4) the overall impacts would be minimal.

Figure 1.
Fossil Fuel Saved (BTU/tie)

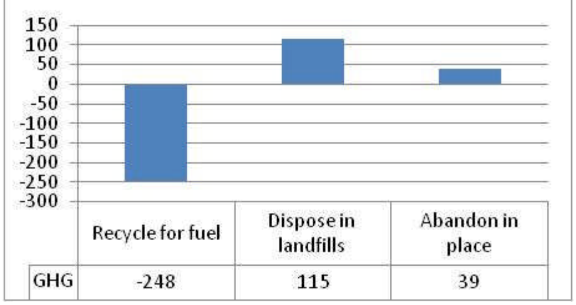


	Recycle for fuel	Dispose in landfills	Abandon in place
Fossil Fuel Saved	1,397,177	74,189	0

Comparison of End-of Life Alternatives

Use of fossil fuel is reduced, or offset, by the amount of fuel value in each tie that is used beneficially. The amount of fossil fuel saved for each tie recycled, disposed, or abandoned is shown in Figure 1. The largest fuel savings results from recycling ties to energy production, since all of the embodied biogenic and fossil energy is beneficially used. Only a small fraction is beneficially used in landfill disposal and none is recovered when ties are abandoned.

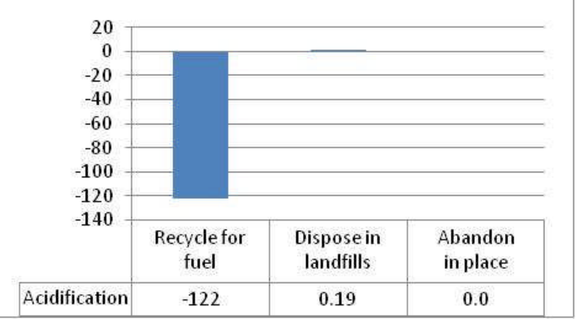
Figure 2.
Fossil/Anthropogenic GHG
(lb CO2-eq/tie)



The GHG balance resulting from each end-of-life alternative is shown in Figure 2. Recycling for energy results in a decrease in GHG emissions, because only the fossil (creosote) fraction of ties burned contributes to GHG while all of the energy (biogenic and fossil) is used to offset combustion of fossil fuel. Landfill disposal increases GHG the most, due to both CO_2 and methane releases resulting from anaerobic decay within the landfill. For abandoned ties, the fossil (creosote) carbon fraction of tie mass is converted to fossil CO_2.

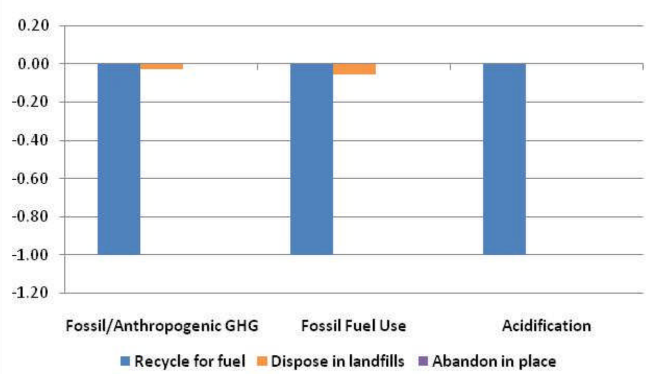
Releases potentially causing acid precipitation for each end-of-use alternative are shown in Figure 3. Recycling ties for energy produces a negative acidification indicator because combustion of wood results in lower emissions of acidifying gases than combustion of coal. The acidification caused by burning ties is small, so that when credit for the higher coal emissions are subtracted, the result is negative. Landfill disposal results in a negligible increase related to methane combustion and abandoning ties has no impact to acidification.

Figure 3.
Acidification (H+mole eq./tie)



Comparison of all impact indicators for the full life cycle is shown in Figure 4. Rather than indicating actual indicator values, these have been normalized to show the recycle option as a negative 1, since all

Figure 4.
Used Tie Impacts by End-of-Life Alternative
(Normalized to Recycle, Less is Better)



indicators for this option are negative. Values for disposal in a landfill and abandonment are relative to the recycle option. While previously shown figures address only emissions that occur due to the disposal method applied, this figure includes the full life cycle, beginning with growing the trees. Negative values mean that releases causing the indicator are reduced by implementing the disposal option. Positive values indicate the disposal method increases the impact indicator values.

Another way to consider the full life cycle is to consider the flux of GHG interchange with the atmosphere as depicted in Figure 5. All end-of-life alternatives start with the same GHG values from tree growth through the end of tie use. The flux begins at negative 260 pounds of CO_2-eq. due to the CO_2 removed from the atmosphere and stored in the tie wood and remains unchanged as tie is treated. Injection of creosote does not result in a change since it is not released as CO_2 or methane. During the tie's use the GHG value increases by 33 pounds CO_2-eq. per tie due to decay (creosote and wood loss) while in use. Values for the three alternatives diverge at the end-of-life stage. The recycle for energy and abandon alternatives increase to a positive 61 pounds CO_2-eq. per tie as all carbon remaining in the ties is converted by combustion or decay, respectively, to carbon dioxide. The landfill option results in less CO_2 emissions, but includes methane emissions (with CO_2 equivalent at 21 times those of CO_2), raising the landfill alternative GHG total to negative 59 pounds CO_2-eq. per tie. As a final analysis at the end-of-life, offsets to fossil fuel use are applied as shown in Figure 5. Abandoned ties have no offset. Recycled ties have a large offset that brings the final CO_2-eq. per tie value to a negative 227 pounds. Landfilled ties have a small offset, due to methane capture and energy recovery, bringing the final to negative 67 pounds of CO_2-eq. per tie.

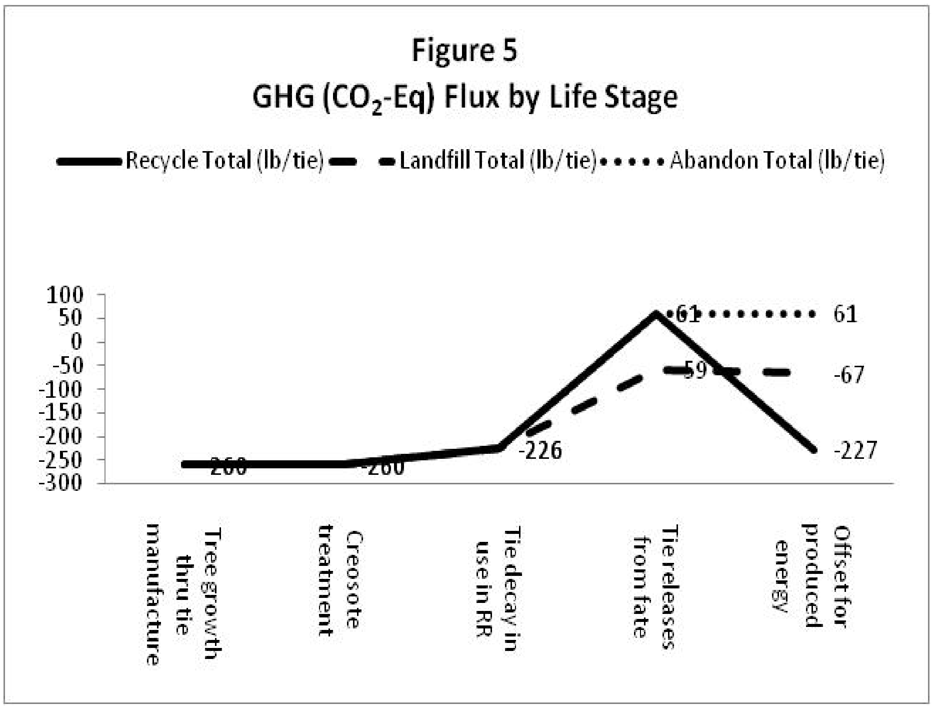


Figure 5
GHG (CO_2-Eq) Flux by Life Stage

Conclusions

Of the three end-of-life alternatives for creosote-treated railroad ties considered, recycling for energy recovery provides clear and significant benefits of conserving fossil fuel resources, reducing greenhouse gas levels in the atmosphere, and reducing emissions that lead to acid precipitation.

The fuel offset gained by recycling creosote-treated ties for energy recovery is 20 times greater than energy recovery from landfill disposal.

Offsets result in a significant decrease in GHG emissions when ties are recycled for energy compared to a slight increase in GHG emissions when landfilled.

If ties are abandoned, no change results to fossil fuel use or acidification and GHG emissions are increased approximately one-third as much as by landfill disposal.

The GHG and fossil fuel use reductions possible through recycling ties for energy are significant. Each tie recycled represents approximately 0.5% of the annual U.S. per capita GHG emissions and fossil fuel usage. Thus, approximately 200 ties recycled for energy offsets the GHG and fossil fuel impacts of one typical U.S. resident. If all ties replaced annually in the U.S., approximately 20 million ties, were recycled for energy, the result would be to offset the GHG and fossil fuel use equivalent to a city of nearly 100,000 people.

References

AP-42. AP-42, Section 1.6, Wood Residue Combustion in Boilers

CameoChemicals. Available at: http://cameochemicals.noaa.gov/chris/CCT.pdf

EIA (2007). EIA, 2007. Annual Energy Review 2007. June 2008, Energy Information Administration, DOE/EIA-0384(2007)

Engineering Toolbox. The Engineering Toolbox at: http://www.engineeringtoolbox.com

EPA (2006). Solid Waste Management and Greenhouse Gases, A Life-Cycle Assessment of Emissions and Sinks. U. S. EPA. Available at: http://www.epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf.

FPL Wood Handbook. Forest Products Laboratory Wood Handbook, FPL-GTR-113. Available at: http://www.fpl.fs.fed.us.

Holtzman (1995). Holtzman, M. I. and Atkins, R. S. Emissions From Combustion of Treated Wood Fuel and Tires in Industrial Boilers. 88th Annual Meeting of The Air and Waste Management Association, 1995.

Kohler and Kunniger (2003). Kohler, M. and Kunniger, T., 2003. Emissions of polycyclic aromatic hydrcarbons (PAH) from creosoted railroad ties and their relevance for life cycle assesment (LCA). Holz als Roh- und Werkstoff 61 (2003) 117-124.

NREL. National Renewable Energy Laboratory (NREL), detail spreadsheet-DSButuminousCombustionUtilityBoilers.xls

TRACI. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), U.S. EPA. Database available from Jane Bare at bare.jane@epa.gov.

Zarembski (2007). Zarembski, A.M. and Kondapalli, S., 2007. Development of Comparative Crosstie Unit Costs and Values. CrossTies. Jan/Feb 2007, pp. 17-18.