Assessment of Treated Wood and Alternate Materials for Utility Distribution Poles

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Technical Update, October 2010

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ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

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This report describes research sponsored by EPRI.

Generation of this report would not have been possible without the assistance of Electric Power Research Institute (EPRI) and Utility Solid Waste Activities Group (USWAG) members, who provided information about alternative wood preservatives and pole materials. In addition, thanks are extended to the Cooperative Research Network (CRN), of the National Rural Electric Cooperative Association (NRECA). Specific thanks go to Steven Lindenberg and Marty Gordon at NRECA. Thanks also go to Jim Carter at Wood Quality Control, Inc. (WQC), a subsidiary of NRECA

This publication is a corporate document that should be cited in the literature in the following manner:

Assessment of Treated Wood and Alternate Materials for Distribution Utility Poles. EPRI, Palo Alto, CA: 2010. 1019849.

REPORT SUMMARY

This report provides salient facts about common and potential alternative wood pole preservatives and common and potential alternative wood pole materials for use in the electrical distribution setting. Relevant organizations are also discussed. The report presents a brief history of the development and use of each preservative and pole material. It characterizes, qualifies, and quantifies (where possible) the potential impacts of shifts from common preservatives to alternative preservatives and from southern pine to alternative distribution structures. It briefly discusses one American hardwood and several tropical hardwoods that have potential as distribution poles that require little or no preservative treatment to provide long in-service lives.

The report was first made available in October 2004; it was updated in October 2005 and December 2007. New and relevant preservative and pole-related developments are presented in this most recent edition.

Background

Southern pine poles have been the predominant electric distribution structure for many years in the United States and Canada. Douglas fir is common in the western United States. Creosote, pentachlorophenol (penta), chromated copper arsenate (CCA), and—to a lesser extent—copper naphthenate (CuN) have been mainstays for preservative treatment of both species. These preservatives and wood pole species work well together and have demonstrated their cost effectiveness and reliability in supporting the distribution of electricity for decades. These pole systems are efficiently managed as a function of several qualities:

- Their properties and limitations are well understood and effectively communicated.
- Supplies are good and relatively stable and affordable.
- Stakeholders have standardized methods and procedures.

However, some properties of common preservatives and pole materials are regarded as disadvantages, primarily related to potential or perceived environmental impacts. This report was developed to assist Electric Power Research Institute (EPRI)/Utility Solid Waste Activities Group (USWAG) members in evaluating potential alternatives.

Objective

- To assess common wood preservatives and distribution structures and identify potential alternatives and new wood species that might provide in-service and environmental benefits

Approach

In a cooperative project between EPRI and USWAG, the research team reviewed the available information on alternative preservatives and distribution pole materials and species. The information is presented here in a structured manner.

Results

The report describes the characteristics of common and alternative wood pole preservatives and pole materials (for a distribution setting) and describes the advantages and disadvantages of each.

In short, creosote, penta, and CCA are the three most common wood pole preservatives, and all three rank favorably in terms of the key factors of cost, supply, and effectiveness. Copper naphthenate possesses many of the same characteristics but lacks the track record of the three common preservatives. Other wood preservative alternatives evaluated included ammoniacal copper zinc arsenate (ACZA), ammoniacal/alkaline copper quaternary (ACQ) compound, copper azole (C-AB), but they lack an industrial track record. In addition, in the case of the latter two, they are more expensive than the three common wood preservatives and apparently not in demand for use as distribution poles. Alternative pole materials evaluated included steel, fiberglass reinforced composite (FRC), spun-cast concrete, plastic, and alternative woods, including American Chestnut and tropical hardwoods. The properties of the manufactured pole alternatives are well known. In the case of alternative woods, little or no preservatives are required. Disadvantages include increased cost, limited availability, little performance data, and/or uncertain ecological effects.

EPRI Perspective

Several hundred million treated wood poles are in service in North America, and more than 1% of those poles are replaced each year. This represents a huge investment in infrastructure, and replacements must be selected carefully. Companies want to choose the optimal poles for their service territory, factoring in performance, cost, environmental impact, and availability. This report provides technical information to support that analysis. The report was first made available in October 2004 and updated in October 2005 and December 2007. New and relevant preservative and pole-related developments are presented in this most recent edition.

Keywords

Utility poles
Distribution poles
Treated wood poles
Alternative poles

ACRONYMS

ACQ	Ammoniacal/Alkaline Copper Quaternary Compound
ACZA	Ammoniacal Copper Zinc Arsenate
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
AWG	American Wire Gauge
AWPA	American Wood Protection Association
Battelle	Battelle Memorial Institute
C-AB	Copper Azole
CA-B	Copper Azole Type B
CBA-A	Copper Azole Type A
CCA	Chromated Copper Arsenate
CFR	Code of Federal Regulations
CLARC	Cleanup Levels and Risk Calculations
CRN	Cooperative Research Network
CuN	Copper Naphthanate
CST	Comprehensive Screening Tool
Cu-HDO or CX-A	Bis(N-cyclohexyldiazeniumdioxy)-Copper Complex
CV	Co-efficient of Variation
EDM	Engineering Data Management
EIA	Federal Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FAO	Food and Agriculture Organization of the United Nations
FPL	Florida Power and Light

FRC	Fiberglas-Reinforced Composite
In	inches
IEEE	Institute of Electrical and Electronics Engineers, Inc.
Kg/m^3	Kilograms per cubic meter
MTCA	Model Toxic Control Act
NAAQS	National Ambient Air Quality Standards
NESC	National Electrical Safety Code
NOAA	National Oceanographic and Atmospheric Administration
NRECA	National Rural Electric Cooperative Association
PAHs	Polycyclic Aromatic Hydrocarbons
ppb	Parts per billion
pcf	Pounds per cubic foot
Penta	Pentachlorophenol
psi	Pounds per square inch
PXTS	Polyxylenol Tetrasulfide
RED	Registration Eligibility Decision
RUP	Registered Use Pesticide
SAEFL	Swiss Agency for the Environment, Forests and Landscape
TCLP	Toxic Characteristic Leaching Procedure
TPH	Total petroleum hydrocarbon
UC	Use Category
USGCRP	US Global Change Research Program
USGS	United States Geological Survey
USWAG	Utility Solid Waste Activities Group
UV	Ultraviolet
VOC	Volatile organic compound
WQC	Wood Quality Control, Inc.

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1
INTRODUCTION

This report provides facts, evaluations, and comparisons of wood utility poles and commonly associated wood preservatives. Alternative wood preservatives and are also discussed. The report is intended to assist staff at EPRI/USWAG member utilities as they make decisions about distribution structure purchasing and management.

A Class 4, 40-foot, southern pine wood distribution pole in the 2007 National Electric Safety Code (IEEE, 2006) construction “Grade” C setting is generally used as the basis for comparison with other pole materials, although Douglas-fir poles are also addressed. In-service distribution poles are typically used in two “Grades” of construction (Grades B and C), as specified by the NESC® (IEEE, 2006). Grade B is the highest grade; it corresponds to crossings (highway, railroad, pole lines carrying varying power supply voltage levels, etc.). Grade B calls for greater reliability and strength (for safety purposes) than Grade C.

Grade C construction is for typical power or joint-use (telecommunications and power) distribution pole applications. Grade C construction applies for stretches of the distribution system where each 40-foot pole is directly embedded in the ground, and approximately four poles per mile are electrically grounded. This configuration does not include corners or “dead ends” that require custom design and/or guy wires. It does not include major intersections or railroad crossings. Grade C construction is used where the consequences of a pole failure are potentially less serious than they would be at a busy intersection or similarly active place. For each wood pole in the Grade C setting, there is an estimated average of $25 of galvanized steel hardware used (Carter, 2004).

This scenario is used because the majority of in-service distribution poles in the United States are in the Grade C setting. Estimates of the number of in-service distribution poles (all design Grades) in the United Sates range as high as 100 million. A conservative estimate of the number of in-service preserved wood poles in a Grade C setting is 45 million.

Information regarding the “equivalence” of alternative materials (compared to southern pine or Douglas-fir) must be regarded carefully. Wood poles were (for all practical purposes) the *only* distribution line structure for decades. Since wood has a high co-efficient of variation (CV) for strength (compared to engineered materials), design guidance is based on wood’s “average” strength, with overload factors applied. Engineered materials such as steel, fiber-reinforced composites and concrete have narrower CVs and more predictable performance than wood and generally do not require the same overload factors. An engineering analysis is necessary to determine whether non-wood poles will provide an advantage under the specific conditions.

Information about estimated costs of treated wood distribution poles and poles manufactured from alternative materials must also be regarded carefully. In general, the estimated costs provided in this report are for poles at their point of treatment or manufacture. The prices do not reflect the flexibility a seller may apply if larger numbers of poles are being purchased and the estimated costs do not include the costs of predrilling or framing. As a rule of thumb, preserved pole costs are closely linked to the costs of preservative raw materials, such as petroleum, copper, zinc, arsenic and chromium. The relative costs of these materials follow global demand. As demand for these raw materials changes, so do the costs of preserved wood.

Background

The three most common wood pole preservatives are:

- Creosote
- Pentachlorophenol (penta)
- Chromated copper arsenate, Type C (CCA)

Each of the three preservatives is used for treatment of southern pine. CCA is not generally used for treatment of Douglas-fir because preservative penetration is poor.

Creosote and penta are oil-borne preservatives. CCA is a water-borne preservative. Based on one 2004 survey of 383 utilities in the United States, 56 percent of all in-service wood poles are treated with penta, 34 percent are treated with creosote, and 9 percent are treated with CCA (Roewer, 2004). Annual wood pole replacements consist of 55 percent penta-treated poles, 12 percent creosote-treated poles, and 31 percent CCA-treated poles. Based on anecdotal information and some industrial statistics, the proportion of CCA-treated poles has increased and the proportion of creosote treated poles has decreased. In the short term, CCA treated poles are currently in high demand because they are the most inexpensive.

All three preservatives have a demonstrated ability to preserve the lives of poles for approximately 35 years or more, depending on the decay hazard zone, the quality of initial treatment, and the aggressiveness of inspection and maintenance. These multiple-decade lives are possible because each preservative inhibits establishment and growth of fungi that cause rot and repel footholds by insects (termites, carpenter ants) that mechanically degrade wood and reduce its strength.

Throughout the past several decades, supplies and costs of wood poles and associated preservatives have been relatively steady and stable. At the same time, the quality of preservative treatments has improved. If wood poles remain the standard structure to support distribution utility lines, then training, hardware, and equipment for transporting and installing wood poles is relatively unchanged. Techniques for design of distribution lines will remain relatively unchanged as well.

Each of the common wood preservatives must be “registered” every fifteen years by the United States Environmental Protection Agency (EPA), and the most recent re-registration process was nearly complete by mid-2010. The re-registration process amounts to a review of costs, benefits, and potential risks of each one. As part of this process, interest in alternative wood preservatives and alternative pole materials (that do not require chemical preservatives) has grown.

The alternatives and their characteristics are becoming better understood, but many of them have limited use histories. In addition, while several alternative pole materials with attractive physical properties are available, they are not typically interchangeable on a direct, one-to-one basis with wood poles. Based on NESC® design recommendations for a particular setting and/or climate (even in Grade C construction), a 40-foot concrete, FRC, or steel pole may be stronger than, weaker than, or “equivalent” to the strength of a Class 4, 40-foot wood pole.

Purpose

This report describes and characterizes several potential wood preservative and pole structure alternatives and the potential economic impacts of shifts away from wood poles and the common preservatives. The report briefly mentions several wood species that are not currently used as poles in the United States, but may have potential as poles requiring little or no preservative treatment.

2
RELEVANT ORGANIZATIONS AND GENERAL WOOD POLE CHARACTERISTICS

The American Wood Protection Association

The role of the AWPA (2010) is promulgating voluntary wood preservation standards for wood preservatives and all preservative treated wood, not just utility poles. The AWPA was formed in 1904 as a non-profit organization and until 2007 was known as the American Wood *Preservers'* Association.

AWPA develops new standards and revises existing standards as new information becomes available. For wood utility poles, the goal of AWPA specifications is to safely prevent decay in wood poles for as long as possible. AWPA membership consists primarily of preservative researchers and manufacturers, wood producers, and treated wood users.

The AWPA specifications (2010) for preservative treatment of any wood are defined by the *Use Category System*. Under the Use Category (UC) System, wood utility poles fall into three use categories, as follow:

- UC4A – "General Use" - ground contact in regions with low natural potential for wood decay and insect attack.
- UC4B – "Heavy Duty" - ground contact in moist and temperate regions, in climates with a high potential for deterioration.
- UC4C – "Extreme Duty" - ground contact in semi-tropical to tropical regions, where the decay hazard may be extreme.

The American National Standards Institute, Committee 05

The American National Standards Institute (ANSI) is a private, non-profit organization that administers and coordinates the United States voluntary standards and conformity assessment system. ANSI has accredited The Alliance for Telecommunications Industry Solutions (ATIS), Committee O5, to develop "...standards for use by the telecommunications industry in areas dealing with wood poles and other wood products" (ATIS, 2010).
The most relevant set of standards generated by ANSI is *Specifications and Dimensions for Wood Poles* (ANSI, 2008). These standards include numerous details, such as the frequency and extent of allowable defects and the definition of wood pole "classes." The classes provide an indication of minimum pole strength, and are based on pole circumference at the pole tip and 6 feet from the butt (largest end of the pole) for particular species, as shown on Table 2-1.

Table 2-1
Circumferences for Two Species of Class 4 Wood Poles

Circumferences for Two Species of Class 4 Wood Poles		
Species	**Circumference (inches) (Tip)**	**Circumference (inches) (6 feet from butt)**
Southern pine	21	33.5
Red pine	21	35.5

Any ANSI-acceptable Class 4 southern pine wood pole is assumed to withstand the groundline stress induced by a transverse (horizontal) load of 2,400 pounds applied 2 feet below the tip of the pole, based on a designated fiber stress at groundline (ANSI, 2008). For southern pine, the minimum required fiber strength is 8,000 pounds per square inch at groundline. The minimum acceptable pole circumference six feet from the butt of the pole is 33.5 inches.

Adherence to AWPA standards and specifications is a common practice for industry

members even if they do not belong to the AWPA, but law does not require it.

The 2007 National Electric Safety Code

The NESC® (2006) was developed to provide distribution and transmission design guidance for electrical engineers, and is updated every five years. Most states require that lines are designed to meet basic NESC® safety factors. The development of the NESC® began when wood poles were nearly the *only* structure available. According to Randle (2004), the guidance evolved based on "successful" experience [with wood poles], as opposed to strong theoretical foundations.

Wood Pole Life Cycle Assessment

EPRI and Battelle Memorial Institute (Battelle) have developed and demonstrated a life cycle environmental profile-screening tool, which is ready for use by utilities as a decision support tool to compare the full life cycle environmental impact potential associated with different types of distribution poles. EPRI (2006) published this approach in Technical Report 1016802, and then made the tool available as web-based software. This tool is unique and more comprehensive compared to other attempts to evaluate life cycle impacts of utility poles (e.g., Erlandsson and Edlund (1992), Künniger and Richter (1995), because it evaluates more types (12) of utility poles for a broader range (26) of engineering, economic, and environmental criteria (Table 2-2) that are scored based on U.S. conditions (rather than conditions in Europe).

Table 2-2
Comprehensive Screening Tool (CST) Criteria

Engineering/Technical Performance Criteria	Life Cycle Cost/Economic Criteria	Environmental Criteria
Expected Service Life with Maintenance	Acquisition Costs at Pole Yard (pole, liner, sleeve, cross arms, hardware, and transport to yard)	Acidification Potential
Regulatory and Treated-Wood Registration Status	Transportation Costs from Pole Yard to Installation Site	Carcinogenicity
Adaptability of Field Procedures and Hardware for Emergencies	Installation Costs	Ecological Habitat Alteration
Equipment Requirements for Transport/Install/ Removal	Maintenance Costs During Pole Use (retreatment, inspection)	Energy Use
Handling Protection to Avoid Damage	Disposal Costs	Global Warming Potential
Grounding	Recycle or Reuse Costs	Inhalation Toxicity
Weight	Resource Renewability/Sustainability (including future raw material availability)	Smog Creation Potential
Hardness	Raw Materials Delivery Infrastructure	Recyclability Potential (Post-consumer)
	Manufacturing Capability (pole supply and available facility output)	Toxic Material Mobility upon Landfilling or Incineration

The decision tool allows utilities to make a comprehensive evaluation of distribution pole options in an organized and semi-quantitative fashion across the full life cycle of the poles.

Battelle has completed a final report for EPRI (Product 1014096) using the CST process to evaluate transmission poles (80 ft., Class 2) across their full life cycle, using the same 26 criteria divided between three evaluation groups that were used in the screening demonstration for distribution poles. However, two of the engineering criteria have been modified for the decision tool to account for the greater length and weight of transmission poles.

Wood Pole Advantages and Disadvantages

Wood poles have solid cross-sections (steel, fiberglass reinforced composites, plastics, and concrete are hollow). A solid cross-section eliminates the possibility of buckling and provides very good compressive strength. This characteristic provides a generally high shear strength, making it a poor choice in areas where “breakaway” poles are necessary (EPRI, 1997).

Wood has an inherent flexibility that allows it to deflect and absorb dynamic loads, and transfer loads to other poles in the line (EPRI, 1997). Most alternative pole materials stressed to the bending point require replacement.

Wood poles have been the traditional mainstay for distribution structures for many years. Linesman and electrical engineers are familiar with their properties (Section 3) and the appropriate methods for managing them. The supply is good and the prices are generally low and relatively stable (for southern pine and Douglas-fir) compared to other materials.

Wood poles are generally climbable with gaffs, compared to alternative materials that may or may not have steps built into them. Wood poles require preservative treatment if their service lives are to be extended. These preservatives can potentially leach from the pole. After wood poles are removed from service, their potential for reuse and/or recyclability is a function of the preservative type, landfill space/disposal costs, and management costs.

3
SOUTHERN PINE AND DOUGLAS-FIR DISTRIBUTION POLES

Southern pines are the predominant species used for distribution poles in the United States and much of Canada (red pine and Douglas-fir are also used in parts Canada). In 1997, approximately 82 percent of all treated poles in the United States were southern pine (Mickelwright, 1998). Douglas-fir is frequently used for distribution poles in the western US. Douglas-fir is also valued for use as cross-arms because it tends to twist and warp less than other materials.

Treatability

The cross-section of a southern pine tree consists mostly of sapwood. Sapwood is more permeable than the inner heartwood because the heartwood contains "extractives" (natural deposits that plug the pores) and the pits that interconnect pores are aspirated (closed). Douglas-fir has a much higher proportion of heartwood (and extractives), so on a relative basis, preservative penetration is more difficult to attain.

The thick sapwood of southern pine allows deep penetration of preservative solutions, a characteristic not matched by other native species with desirable properties for wood poles. The deep penetration will only occur, however, if the pole is properly conditioned (dried) prior to treatment, as it is virtually impossible for preservatives to penetrate into wet wood. Deep preservative penetration is a key factor for long life because an in-service pole, over time, may develop deep cracks in the wood that can facilitate entry of insects and decay organisms. However, if preservative is present and deeper than a developing crack, decayers will struggle to become established.

Both southern pine and Douglas-fir poles must be debarked and dried prior to preservative treatment from initially high moisture content down to about 25 percent. The moisture reduction makes room in the wood cells for impregnation with preservative solutions. The drying is commonly referred to as seasoning or conditioning. For oil-borne preservatives (creosote, penta, or copper naphthenate), treatment is usually conducted by the Rueping, or empty-cell process. This consists of injecting air into the wood before pressurization with preservatives (Smith, 2002). For waterborne preservatives, such as CCA, the Bethell, or full cell processes are typically used.

Pole manufacturers frequently use *through-boring* or *incising* in the butt portion of Douglas-fir prior to pressure treatment. Through-boring consists of drilling many small holes through the butt. Incising drives short, stiff knives into the butt section. Both techniques result in greater preservative penetration, without significantly changing the strength characteristics.

Typically, only oil borne preservatives (pentachlorophenol and creosote) are used for treatment of Douglas-fir because they can be heated. The heated fluids help dissolve extractives in the heartwood and allow for better penetration.

Southern Pine and Douglas-fir Physical Characteristics

Table 3-1 below presents the relevant physical characteristics of Class 4, 40-foot southern pine and Douglas-fir poles.

Table 3-1
Class 4 Southern Pine and Douglas-Fir Physical Characteristics

	Southern Pine	Douglas-fir
Modulus of Rupture, Groundline	10,190 psi	9,620 psi
Modulus of Elasticity, Groundline	2.68 (10^6 psi)	3.35 (10^6 psi)
Unpreserved Weight, green	1,090 pounds/494 kilograms	800 pounds/363 kilograms
Approximate volume -cubic foot/cubic meter	21/0.59	21/0.59

(ANSI 05.1, 2008) psi - pounds per square inch

In general, southern pine and Douglas-fir poles treated with oil-borne preservatives are considered easier to climb with gaffs, as the oil carrier tends to act as a lubricant. Waterborne preservatives often result in a drier surface and an associated "harder" wood.

Pole Supplies and Costs

Southern pine and Douglas-fir pole supplies are generally expected to be good well into the future because both are primary species of profit for forest landowners and forest products companies. Therefore, both are intensively managed and produced.

The volume of poles of both species is small compared to the volume of lumber manufactured from both species. Any increase in cost for both pole species is expected to be a function of increased demand for all products, as opposed to escalations in management and harvesting costs for wood poles.

Numerous hurricanes (NOAA, 2006) made landfall in the southern United States in the summer/fall of 2005. Each event caused acute damage to distribution systems in the southeast: over 12,000 wood poles in the Florida Power and Light (FPL) distribution area were lost (Brown, 2006) due to Hurricanes Katrina and Wilma. The combined effects of damage had a short term impact on the supply of southern pine distribution poles. According to Rollins (2007), approximately 90,000 wood poles were destroyed by all the hurricanes.

Pole producers do not generally maintain inventories sufficient to replace so many damaged in-service at one time. Based on anecdotal evidence, it took approximately 8 months for the pole industry to rebuild pole inventories and keep pace with *typical* demand.

Climate Change and Potential Effects on Wood Poles

Several climate change models predict increases in atmospheric levels of carbon dioxide over the next 90 years. As a result, the global rate of photosynthesis is expected to increase (USGCRP, 2007) and the global volume of forest biomass is expected to increase too, at least initially. Increased biomass production is not directly translatable to increases in the output of *desired* products or species.

In the southeast region of the United States, climate change is expected to result in a general increase in the range of southern pine (Iverson et al., 1999). As with global biomass production, an associated increase in the total biomass is expected. This has potential economic benefits for pole users, because increased supplies will potentially moderate changes in pole costs. Warmer, dryer weather conditions are also generally predicted in the southeast US (USGCRP, 2007). Climate change researchers believe that localized effects may be severe. Forest managers can plan for *general* changes over time. Planning for severe localized effects is not possible. Informal conversations with forest managers suggest that forest products companies are not adjusting management strategies to address potential effects of climate change.

Thompson et al. (1998) predict that the range of Douglas-fir may be reduced by as much as one-half its current range, primarily because rainfall patterns are expected to change.

4
COMMON WOOD POLE PRESERVATIVES

Creosote

Creosote History

Creosote was the first common wood pole preservative. Beginning around 1680, crude coal tar was suggested for use as a wood preservative. By 1776, the Royal Navy began using coal tar to treat ship hulls. By 1900, creosote manufactured from coal tar was applied to utility poles, and it remained the most common pole preservative until the 1960s. Its use as a pole preservative has declined since that time. The most common use of creosote today is for preservative treatment of railroad ties (Zak, Neuhauser and Smith, 1998).

Creosote Manufacture

Coal tar is a by-product of high-temperature treatment of metallurgical coal used for generation of coke, the most common current use. Coke production has fallen in the United States, but risen by nearly 4% on a global scale since 1988. The main contributors to increased production include China and India (Steiner, 2007).

Creosote Composition

Coal tar creosote consists of aromatic hydrocarbons, anthracene, naphthalene, and phenanthrene derivatives. At least 75 percent of the coal tar creosote mixture is polycyclic aromatic hydrocarbons (PAHs) (ATSDR, 2002).

Creosote is considered an oil-borne preservative. With creosote, the carrier “oil” and the preservative are one in the same.

Creosote Regulatory Status

Coal tar creosote is a Restricted Use Pesticide (EPA, 2004). In 2008, EPA published their conclusion that creosote containing products were eligible for re-registration, provided that risk mitigation measures were adopted and labels were amended accordingly. Manufacturers and marketers responded positively and the full re-registration was nearly complete in summer 2010.

Creosote Supply and Cost

According to Steiner (2010), about 835,000 and 525,000 metric tons of coal tar were produced in North America in 2008 and 2009, respectively. Production of 720,000 metric tons is expected for 2010. Thirty percent of the coal tar generated in North America is used in the distillate market (creosote is distilled from coal tar).

However, only about 7 percent of the world’s coal tar is produced in North America, and United States production is expected to fall as the costs of environmental regulations bring about closure of old coke plants. In 1999, Harris reported that remaining international sources should easily fill the gap created by declining United States production for the near future (Harris, 1999). However, in 2007, the cost of creosote-treated poles had risen significantly.

The cost of creosote is primarily a function of metallurgical coal cost. The cost of metallurgical coal is mostly a function of the cost of the fuel required to generate it – fuel for mining, transport, and heating of the coal. From 2008 to 2010 crude oil costs have been volatile.

In 2005, the approximate cost of a creosote-treated southern pine pole, Class 4, 40 feet long was $198. This estimate is based on 7.5 pcf (120 kg/m^3) creosote retention (Surrency, 2004). In 2007, the same pole cost approximately $220-$230 (Healey, 2007). In 2010, a southern pine pole treated to the same retention would cost approximately $377 (Leigh, 2010).

In 2010, a Douglas-fir pole treated to the same retention would cost approximately $205 (Laughlin, 2010).

Creosote Effectiveness

The effectiveness of creosote as a wood preservative is well known and well documented for both utility poles and railroad ties. In addition, ample physical evidence of effectiveness and increased service life is apparent in existing distribution systems and on railroad lines that have been in place for 30 or more years.

Creosote Environmental Studies, In-Service Poles

Vassou, et al., (1998) found that creosote retention in Pinus sylvestris (Scots pine) poles stored horizontally decreased at an average rate of 3 percent to 6.8 percent per year. Some of the loss was due to volatilization. The remaining loss was attributed to drippage from the underside of the poles.

EPRI (1997) sampled soil at 22 in-service creosote-treated utility poles (at retentions ranging from 8.0 to 12.0 pcf) in 14 states of the United States.

PAH concentrations ranged from non-detected to 24,000 milligrams per kilogram (mg/kg). The overall average was 240 mg/kg. Sixty-seven percent of all samples with detectable PAHs had concentrations less than 10 mg/kg.

PAH concentrations were highest in surface soils closest to the pole, and consisted of the heavier molecular weight PAHs. Concentrations decreased exponentially with distance from the pole. The highest concentrations at depth were found in the intermediate depth samples (closest to the butt end of the pole). Overall, EPRI found that PAH concentrations in soils adjacent to in-service creosote poles decreased rapidly with increasing distance from the pole.

Creosote-Treated Pole Recycling/Disposal.

Creosote-treated poles can be safely disposed in properly engineered and permitted incinerators, where temperatures are high enough to destroy the organic components. Loading costs can be high because the poles are frequently cut into many pieces, making them easier to transport from the field to the loading area. Shipping costs can be high as well, depending on the location with respect to a permitted facility. Frequently, any metal in the pole (nails, old hardware) must be removed before it can be accepted by the facility. As a result, the labor and logistics can become expensive.

According to EPRI (2001), permitted incinerators for creosote treated wood are present in only 14 states. Incineration costs ranged from $30 per ton to $500 per ton. Boilers permitted to combust treated wood are present in just ten states. Combustion costs ranged from $8 to $30 per ton (excluding shipping costs). Healy (2007) suggests that many more facilities are permitted to burn creosote-treated wood (such as cement kilns). However, they rarely take advantage of the permit.

Secondary use via sale or donation to the public has been a successful, effective means to manage poles removed from service. Utilities engaging in this management option typically provide use and handling information to the secondary user.

Retired creosote poles slated for landfill disposal are subject to passing the Toxicity Characteristic Leaching Procedure (TCLP) test. Research by EPRI in 1991 (Goodrich-Mahoney, 1992) found extract levels to be well below the TCLP limits for cresols. Based on these results ("generator knowledge"), landfills may or may not request TCLP testing from the generator.

Landfill costs ranged from $3 to $100 per ton, with higher costs associated with limited space at northeast landfills and at landfills where poles were considered a distinct category of waste (EPRI, 2001). More recent estimates (Fogarty, 2010) for non-hazardous landfill disposal ranged from $30 to $70 per ton, depending on the type of processing (cut to short lengths or chipped).

Shi, et al., (2001) evaluated the feasibility of timber reclamation from creosote-treated marine pilings and bulkhead materials that were resawn into wheel chocks and wales. They did so by sawing the original material into 12-inch by 12-inch and 8-inch by 8-inch timbers. They concluded that manufacture of chocks and wales in this process was economically feasible. It follows that many of the original material diameters would have been larger than a Class 4 southern pine pole (in order to produce 12-inch by 12-inch square timbers).

King and Lewis (2000) conducted an economic feasibility and profitability study of two scenarios based on remanufactured products derived from a mix of transmission and distribution poles. They did not specify the type of preservatives used in the imaginary poles. The first scenario was based on no retreatment of derived products. The second scenario was based on retreatment of derived products with preservatives. The authors concluded that the first scenario had an internal rate of return of 42.6 percent and a return on investment of 15.8 percent. The second scenario resulted in a negative net present value of 2.1 million dollars.

Both studies described above relied on a mix of piles/poles that can be compared to transmission and distribution sized utility poles. The inclusion of larger sized stock has a positive effect on production and success because the same process and energy is required to handle both large and small wood pieces, yet larger pieces generate a larger volume of final product. In addition, the expense of appropriate health and safety procedures (related to preservative treated sawdust, etc.) appeared to be underestimated, as neither study commented on the difficulty of sawdust containment or health and safety factors for workers.

Recycling of *only* Class 4, 40-foot southern pine poles into non-restricted use lumber by sawmilling has not generally been pursued because preservative penetration is so deep and the poles are generally too small diameter for efficient use as sawlogs. Dirt and stones in checks and the likely presence of metal that must be removed before sawing, as well as subsequent disposal of preservative treated sawdust are concerns with sawing. In general, the enterprise of sawing distribution-sized poles is not regarded as economically feasible (Hull, 2005). However, at least two sawmills have demonstrated success in the venture

One sawmill in Texas has been sawing retired creosote-treated distribution and transmission poles for 16 years. The mill produces lumber from six to twenty-eight feet long and from one to six inches in thickness. Most of the lumber is used for fencing at horse farms. The sawmill operator reported that horses do not "crib" creosote-treated wood (Stice, 2010).

A Georgia sawmill reported a thriving creosote pole recycling business as well, claiming to saw approximately 40,000 retired poles in 2006 (Dart, 2007). Since then, however, the sawmill owner has shifted away from creosote poles for reasons unrelated to the economy or regulation (Dart, 2010).

Neither the Texas nor the Georgia sawmill owners reported any difficulty with health and safety issues or disposal of sawdust.

Creosote Advantages, Disadvantages, and Unique Characteristics

A practical disadvantage is that typical creosote-treated poles frequently have pitchy or tarry spots on their surfaces and are considered "dirty." "Clean" creosote liquid has been developed to address this issue. This type of creosote is reformulated by removing significant amounts of xylene insolubles during distillation. Combined with the appropriate treatment methods, a clean, dry, smooth pole is produced.

The effects of gravity may result in downward movement of creosote in and on the surface of the pole.

From an operational and functional perspective, creosote-treated wood poles are often desired for use by utilities for several specific reasons, as follow.

- For use along coastal areas. Penta-treated poles cannot be used in these environments because salt spray and salt water will hydrolyze the penta, reducing its effectiveness. Creosote-treated poles repel salt water better than CCA-treated poles.
- In coastal settings, where poles may experience occasional flooding, creosote poles are more effective at preventing marine borer damage (Lebow, et. al., 2001).
- Creosote-treated wood poles are often specified for use by utilities in hot and dry environments, such as utility service areas in southwest Texas, and parts of Arizona and California. Creosote keeps the wood "lubricated" and "soft." There is less splitting/cracking/checking than typically occurs with CCA poles in this environment.
- In alkaline soils, penta can be converted to sodium penta. This form of penta has higher water solubility than creosote. In settings with alkaline soils and the potential for high soil moisture or a high water table, the effectiveness of penta will be reduced, increasing the risk of early failure and unplanned outages. In this environment, creosote is specified.

- Creosote-treated poles may have greater flexibility than CCA-treated poles, which are more brittle. Creosote may be specified in areas with extreme loading conditions such as wind and ice.
- Creosote-treated poles exhibit reduced tendency to smolder after a fire (compared to CCA).
- Creosote-treated poles impart some corrosion resistance to metal hardware because of the presence of the carrier oil. CCA treated poles require galvanized or stainless steel hardware because CCA enhances corrosion of unprotected metal.

Pentachlorophenol

Pentachlorophenol History

Oil-borne pentachlorophenol (penta) was developed and used by the 1930s. In 1947 nearly 3,200 metric tons of penta were used in the U.S. by the commercial wood preserving industry. By the 1960s, AWPA had approved the use of penta for wood preservation. Its use increased in popularity until the 1980s, and began to decline somewhat as CCA use increased.

Pentachlorophenol Manufacture

Penta is manufactured by the direct chlorination of phenol. The US EPA currently identifies one "Basic Manufacturer" as KMG- Bernuth, Inc. (EPA, 2010).

Pentachlorophenol Composition

Penta is a halogenated synthetic organic chemical.

Pentachlorophenol Regulatory Status

Penta is classified by EPA as a Restricted Use Pesticide (EPA, 2004). Indoor applications of penta are prohibited except for a few low exposure uses (i.e., those support structures that are in contact with the soil in barns, stables, and similar sites). In 2008, EPA published their conclusion that pentachlorophenol containing products were eligible for reregistration, provided that risk mitigation measures were adopted and labels were amended accordingly. Manufacturers and marketers responded positively and full re-registration was nearly complete in summer 2010.

Pentachlorophenol Supply and Cost

The raw materials, chlorine and phenol, are readily available and there are no foreseeable supply outlook problems. In 2004, costs for chlorine and phenol were reported as steady (Butler, 2004). However, phenol is typically manufactured from benzene, a petroleum product.

Oil prices (with respect to the solvent carrier for penta) traditionally vary with demand and political and commercial influences. Increases in the cost for penta treated poles may be expected, linked to the cost of petroleum.

In 2004 the estimated cost of a Class 4, 40-foot southern pine pole treated with penta to 0.45 pcf retention was $199 (Surrency, 2004). The same pole in 2007 cost approximately $225 (Healy, 2007), due to the increased cost of petroleum oil (the carrier). In 2010, a southern pine pole treated with penta to the same retention would cost approximately $308 (Leigh, 2010).

A Douglas-fir penta treated pole today will cost approximately $300 to $320 (Laughlin, 2010).

Pentachlorophenol Effectiveness

The effectiveness of penta for extending the life of wood poles is well recognized, and the physical evidence of its effectiveness is apparent in distribution systems throughout the United States today.

Pentachlorophenol Environmental Studies, In-Service Poles

EPRI (1997) conducted a nationwide study of penta in soil around in-service southern pine poles in 26 states. The sampling methods were the same as those identified for the EPRI creosote study.

EPRI findings were similar to those for creosote. The highest detected concentration was 5,800 mg/kg. Fifty-six percent of samples had penta concentrations less than 50 mg/kg. Sixty-eight percent of samples had penta concentrations less than 1 mg/kg.

In general, penta concentrations were highest in surface soils closest to the pole; at depth, samples collected near the butt end of the pole had higher concentrations than did the shallow samples; penta concentrations decreased exponentially as distance from the pole increased.

Pentachlorophenol-Treated Pole Recycling/Disposal

Penta-treated poles can be safely disposed in properly engineered and permitted incinerators, where temperatures are high enough to destroy the organic components.

Landfilling of penta poles removed from service is subject to passing the Toxicity Characteristic Leaching Procedure (TCLP) test. Research by EPRI in 1991 (Goodrich-Mahoney, 1992) found extract levels for penta-treated poles and cross arms to be well below the TCLP penta limits.

However, landfill disposal costs ranged from $3 to $100 per ton, with higher costs associated with limited space at northeastern landfills and at landfills where poles were considered a distinct category of waste (EPRI, 2001). More recent estimates (Fogarty, 2010) for non-hazardous landfill disposal ranged from $30 to $70 per ton, depending on the type of processing (cut to short lengths or chipped).

Secondary use via sale or donation to the public has been a successful, effective means to manage poles removed from service. Utilities engaging in this management option typically provide use and handling information to the secondary user.

Resawing of distribution poles for wood products is not generally regarded as economically feasible, for several reasons. However, based on recent EPRI efforts and the comments from sawmill owners in Georgia and Texas, it appears that profitable sawmill recycling of penta-treated distribution poles might be possible.

Pentachlorophenol Advantages, Disadvantages, and Unique Characteristics

Improper preservative treatment, though rare, may result in an accumulation of the preservative solution on the ground at the base of a pole.

As with creosote, the effects of gravity may result in downward migration of penta carrier oil. This leaching has both advantages and disadvantages.

From an operational and functional perspective, penta-treated wood poles (or cross-arms) are often desired for use by utilities for several specific reasons, as follow.

Southern pine cross-arms treated with CCA generally have poor dimensional stability because of wide growth rings (due to fast plantation growth conditions) and the "dryness" of CCA-treated wood (compared to Douglas-fir treated with penta or creosote). When these fundamental characteristics are combined with the fact that cross-arms are constantly exposed to direct sunshine, differential drying and shrinking occurs. The differential stresses can cause severe twisting and warping of cross-arms, a physical action that strains electrical wires. The strain may result in unplanned electrical outages.

The dimensional stability issue is addressed by utilities by specifying one of two solutions, as follow:

- Cross-arms are manufactured using dimensionally stable Douglas-fir treated with penta.
- Cross-arms are manufactured with southern pine but treated with penta instead of CCA. The oil carrier for penta prevents exaggerated warping of cross-arms by preventing extreme drying of the wood.

AWPA has standardized the use of CCA with Douglas-fir sawn cross-arms and poles, but cautions treaters that Douglas-fir is "extremely difficult" to adequately treat with CCA. This is the case because Douglas-fir consists primarily of heartwood, which is laden with extractives. The extractives block the wood pores, and preservatives such as CCA have difficulty penetrating to an adequate depth. Lebow and Tippee (2001) confirmed the practical difficulties of treating Douglas-fir with CCA.

Penetration and retention specifications for Douglas-fir are more readily achieved with pentachlorophenol because the preservative can be heated for use during pressure-treatment. The heated solution helps dissolve extractives in the heartwood, allowing better penetration.

Penta-treated poles may have greater flexibility than CCA-treated poles, which are more brittle. Penta may be specified in areas with extreme loading conditions such as wind or ice.

Penta has several additional attributes that cannot be matched by CCA, as follow:

- Penta is oil-borne. The oil repels rain and moisture from the pole surface. Moisture is one of the requirements for any type of decay. Reduced moisture will contribute to reduced decay.
- In freshwater "splash" settings, the oil also repels splash better than CCA. Salt spray on CCA-treated poles can, over time, physically degrade the wood itself.
- The oil keeps the pole "soft." This enhances penetration of gaffs, making penta-treated poles among the easiest for lineman to climb.

- The oil reduces checking and splitting. This minimizes physical avenues that would otherwise allow easy access for insects and fungi to interior pole locations where preservatives may not have penetrated.
- Penta-treated poles impart some corrosion resistance to metal hardware because of the presence of the carrier oil. CCA treated poles require galvanized or stainless steel hardware because CCA enhances corrosion of unprotected metal.
- Penta-treated poles exhibit reduced tendency to smolder after a fire (compared to CCA).

Therefore, CCA and creosote cannot substitute for penta in cross-arms manufactured from Douglas-fir or southern pine. Only penta is suitable for this use. Furthermore, in western states, Douglas-fir is the primary specie used for utility poles. As described above, CCA is a poor substitute for treatment of Douglas-fir.

Chromated Copper Arsenate (CCA)

CCA History

CCA, a waterborne preservative consisting of chromium, copper, and arsenic, was developed in India in 1933 and the patent rights were sold to Bell Telephone. The copper component of CCA is directed at repelling fungi. The arsenic component is meant to repel insects and copper tolerant fungi. Hexavalent chromium helps minimize corrosion of treating plant equipment. The chromium also supports fixation of copper and arsenic in the wood (Zahora, 1994).

The use of CCA for pole treatments rose sharply in the 1980s because it cost less than penta and lacked the “oily” feel.

As a result of regulatory issues, availability of alternative preservatives, consumer demand, market issues, and concern over alleged risks to the public, manufacturers of CCA-treated lumber for residential applications voluntarily halted production and sale of CCA-treated wood to public consumers at the end of 2003 (with a few exceptions for special uses). However, its use for industrial treatment of wood poles is unchanged.

CCA has an increased capacity for causing corrosion of wood pole hardware. Therefore, galvanized hardware must be used on CCA-treated poles. The utility industry, in general, has already made a complete shift from ungalvanized hardware to galvanized hardware, whether they are using creosote, penta, or CCA-treated wood.

CCA Fixation

When CCA treatment is properly conducted, the dissolved chemicals, in large part, precipitate and/or bond chemically with the wood by reduction. This process is called fixation. Since the chemical preservatives are waterborne, they remain in solution until fixation occurs in wood cells.

The fixation of CCA in wood is a chemically complex process that is not generally well understood. As a chemical reaction, its rate increases with temperature. During fixation, following impregnation with the treating solution, chromium undergoes conversion from the hexavalent (Cr^{VI}) state to the trivalent (Cr^{III}) state. In general, fixation is thought to be complete when the conversion from hexavalent to trivalent chromium has ceased (Cooper, Jeremic and Taylor, 2001). Hexavalent chromium is the most toxic form of the metal. Trivalent chromium is less toxic.

According to Cooper (2002), chromium fixation takes longer than fixation of arsenic and copper. In a relative sense, it is also easiest of the three metals to monitor. It is a good indicator of complete fixation because of these characteristics.

The length of the fixation period is temperature sensitive and can last from several hours to two months, depending on the temperature. Cooper reported that maximum fixation of CCA components in southern pine at 21° C was 15 days. He cautions that "dry" wood is not necessarily an indicator of wood with complete fixation. Improper fixation can result in significantly increased leaching of all CCA components.

Cooper, Jeremic and Ung (2004) confirmed the efficacy of chromium fixation in laboratory tests. The authors found that Cr^{VI} in the leachate was near or below a detection limit of 1 part per billion (ppb), compared with total Cr concentrations from 200 to 2700 ppb. The authors concluded there is little health or environmental risk from hexavalent chromium leaching from properly fixed CCA-treated wood.

CCA Manufacture

Liquid chromic acid (CrO_3 in water solution at 60 percent concentration), arsenic acid (As_2O_5 in water solution at 75 percent), and copper oxide are mixed for approximately two hours to form a concentrate. The concentrate is allowed to settle, and then it is filtered prior to use (Environment Canada, 2002).

CCA Regulatory Status

Chromium, copper, and arsenic are EPA Restricted Use Pesticides (EPA, 2004). EPA determined (2008) that chromated arsenicals were eligible for reregistration, provided that the prescribed risk mitigation measures were adopted and labels were amended accordingly. Manufacturers and marketers responded positively and full re-registration was nearly complete in summer early 2010.

CCA Supply and Cost

Supplies of copper, arsenic, and chromium appear to be adequate for generation of waterborne preservatives for many years. Copper is a driving force behind the cost of CCA. So is arsenic, which is relatively inexpensive (in 2010). When global demand for copper is high, the price of CCA is likely to behave in kind. It may also be counterbalanced by the lower cost of arsenic and the fact that it is water-borne, not oil-borne.

In 2004, the estimated cost of a Class 4, 40-foot southern pine pole at a 0.60 pcf retention of CCA-C was $177 (Surrency, 2004). In 2007, the same pole cost approximately $187 (Healy, 2007). Softening agents, which enhance climbability, can be added for approximately $20 more. In 2010, a southern pine pole treated with CCA to the same retention would cost approximately $272 (Leigh, 2010).

CCA Effectiveness

Like creosote and penta, the effectiveness of CCA as a preservative is apparent in the field, though CCA has not been widely used for as long as creosote or penta.

One EPRI utility member reported the results of an unpublished study of 20-year-old, in-service CCA-treated distribution poles. The study was conducted in 1992. Most of the 200 poles were treated with CCA-C. None of the inspected poles was visually degraded by decay of any kind.

Hot-dipped galvanized steel hardware is recommended for use with CCA treated wood because CCA accelerates corrosion in untreated metal connectors and fasteners. In general, galvanized hardware is used throughout the industry, regardless of the type of preservative because the slight additional cost (over non-galvanized steel) is offset by the extended performance.

CCA Environmental Studies, In-Service Poles

Studies of CCA leaching specifically at in-service utility poles were not located. Studies of CCA loss from southern pine stakes do exist. However, these were not reviewed or summarized here because the findings cannot be directly correlated with in-service poles.

CCA-Treated Pole Recycling/Disposal

Bench scale processes to liquefy wood and separate the treatment chemicals have been conducted with some success. On an industrial scale, however, these methods require use of massive quantities of acids and solvents.

In general, combustion of CCA poles is not a viable option because the resulting ash generally fails the TCLP test, and emissions to air could also be an issue. There are nonetheless several municipal incinerators that accept CCA-treated wood. The Lancaster County Solid Waste Management Authority operates one such incinerator in Lancaster, Pennsylvania. At this facility, CCA-treated wood poles are fed into the waste stream on a measured basis. The total volumes of resulting ash and/or emissions apparently remain within the criteria of federal and/or state operating permits (Weaver, 2010).

A French company (Thermya, in D'ornon France) claims to have developed a successful, permitted (in France) low-temperature thermal process that separates and removes the metals from CCA-treated wood. The company also claims that this method can be applied to penta and creosote treated wood with success. The low-temperature (200 to 400 degrees F), low-oxygen pyrolysis process generates a bio-fuel (a charcoal-like end product). The process has been commercialized in several countries, including the US, but only Thermya continues to claim that metals can be fully reclaimed from the process.

Regardless, CCA-treated poles disposed by the end user are exempt from classification as a federal hazardous waste; therefore, landfilling as a non-hazardous waste is an option. Anecdotal evidence suggests that some utilities nonetheless use more expensive hazardous waste landfills, as this method is regarded as generating less liability. However, based on discussion with a commercial hazardous landfill operator (Long, 2010), disposal of CCA-treated poles may cost as much as $329 per yard.

Based on an EPRI study, landfill disposal costs ranged from $3 to $100 per ton, with higher costs associated with limited space at northeast landfills and at landfills where poles were considered a distinct category of waste. (EPRI, 2001). More recent estimates (Fogarty, 2010) for non-hazardous landfill disposal ranged from $30 to $70 per ton, depending on the type of processing (cut to short lengths or chipped).

Secondary use via sale or donation to the public has been a successful, effective means to manage poles removed from service. Utilities engaging in this management option typically provide use and handling information to the secondary user.

Recycling of CCA-treated Class 4, 40-foot southern pine poles into lumber via sawmilling is not regarded as economically feasible, primarily because CCA-treated lumber markets are much reduced (CCA-treated lumber sales to homeowners is only allowed in rare and specific instances) and because effective environmental controls (sawdust capture) are expensive.

CCA Advantages, Disadvantages, and Unique Characteristics

The surface of CCA poles is dry and "clean" compared with creosote and penta poles. There is no odor associated with a dry CCA-treated pole. CCA is generally less expensive than creosote or penta.

The relatively dry surface of a CCA-treated pole is harder than the surface of a pole treated with oil-borne preservatives. This affects their climbability, which requires greater force for a climber to seat the gaffs. Softening agents have been developed to counteract this effect, but they add approximately $20 to the cost of each pole. Otherwise careful gaff maintenance and sharpening can overcome this difficulty, so additional but limited training may be required for linesmen. With many utilities this is not an issue, as climbing has been replaced with the use of hydraulic bucket lifts.

While CCA-treated poles are still available to utilities for commercial and industrial use, public perception may be a factor in utility decision-making. The desire to purchase and use CCA-treated poles may be suppressed and is regarded as a potential disadvantage.

From an operational and functional perspective, CCA-treated wood poles are often desired for use by utilities for several specific reasons, as follow:

- CCA-treated poles are specified for locations where a dry, residue-free surface is required (Lebow and Tippee, 2001), and/or odors are not acceptable. For example, in urban areas where sidewalks are common and poles are set through the sidewalk into the ground. In this setting, CCA-treated poles cannot be replaced by penta or creosote-treated poles because of infrequent but possible "bleeding" that causes oily staining at the base of a pole. Use of CCA is also specified frequently for residential areas, where human contact with the wood surface is more likely than in rural areas and staining/odors may be a concern.
- In areas with high soil moisture, where the water table is high, or water is perched at a shallow depth, CCA-treated poles are specified over penta or creosote-treated poles because the CCA preservatives are "fixed," or chemically bonded within the wood (Lebow and Tippee, 2001). Proper fixation minimizes the risk of leaching. Long-term subsurface saturation is less likely to deplete the CCA preservatives, shortening service life, and increasing the risk of early pole failure and unplanned electrical outages.

- CCA-treated poles are also sometimes specified in areas that experience occasional freshwater flooding, because the CCA is fixed, and penta-treated wood is not adequately protected. In this environment, creosote and penta poles may cause a sheen on the water (Lebow and Tippee, 2001).

5
ALTERNATIVE OIL-BORNE PRESERVATIVES

Copper Naphthenate

Copper naphthenate (CuN) has been available and used for a number of years for preserving lumber and poles. However, its use as a preservative for wood utility poles has not been widespread.

Copper Naphthenate History

CuN was developed as a biocide in the late 1800s. It was standardized by AWPA in 1949. It did not gain wide use for pressure treatments until the late 1980s, when its general-use classification as a non-restricted use pesticide stimulated interest (Brient, Freeman and McIntyre, 2003).

Atypical failures (rot and breakage well above the groundline) of southern pine poles treated with CuN occurred in several Midwestern states in the 1990s. These incidents resulted in significant concerns about the quality of the preservative. According to several sources, the causal deficiencies have been addressed and CuN should be considered as an option for utilities seeking alternatives to creosote, penta, and CCA. CuN solutions have also been developed using water as the carrier, though for poles, the oil-borne solution is most common. AWPA published a standard for water-borne CuN use for poles in 2007.

Copper Naphthenate Manufacture

CuN is the reaction product of copper compounds with naphthenatic acids, which are naturally occurring carboxylic acids recovered from petroleum distillates (Brient, Freeman and McIntyre, 2003). It is diluted in organic solvents such as diesel fuel or mineral spirits to facilitate penetration into the interior of the wood (Brient, et al., 2000).

As of 2001, there were 31 operating treatment plants using CuN in various petroleum oils in the United States. Over 2.5 million pounds of CuN concentrate were estimated as being sold into the United States wood preservation market as of that date (Freeman and Brient, 2001). More recent information is not available.

Copper Naphthenate Regulatory Status

CuN is a non-restricted use wood preservative. It can be purchased in off-the-shelf formulations, such as Cuprinol®.

Copper Naphthenate Supply and Cost

The principle components consist of copper and naphthenic acids. The current and future supply of copper is good . The supply of naphthenic acids is a function of petroleum supplies. In 2007, The approximate price for a CuN treated southern pine pole, Class 4, 40-foot, 0.08-pcf retention, is $190-210 at the treatment plant (Freeman, 2007).

The cost of a Douglas-fir treated with CuN in 2010 is approximately $300 to $320 (Laughlin, 2010).

Copper Naphthenate Reputation

As mentioned above, a significant number of CuN treated poles experienced premature (in-service for just a few years) and atypical failures in several Midwest locations in the late 1980s and early 1990s. Smith (2002) noted that the experiences of several dozen individual utility companies were dramatic – failure rates for copper naphthenate treated poles ranged from five to fifty percent.

A number of studies and papers have described the likely causes and solutions, as follow:

- Prior to the mid-1990s, not all poles were sterilized before pressure treatment with preservatives. This presented a potential for active decay in a pole that might not be halted during treatment. Pole sterilization methods today should prevent incipient and on-going decay.
- "Problem" poles were treated at only two locations. Poles with premature and atypical decay could not be a function of overall copper naphthenate inadequacy if other CuN treaters produced poles that performed normally.
- High water content in the CuN "work" solution might have contributed to the problem. Currently acceptable treatment solutions are formulated so that water separates in less than five minutes. This allows emulsion problems to be identified and rectified before pole treatment.
- It is possible that synthetic naphthenic acids were used in past practices. Synthetic acids are regarded as substandard. Manufacturers are now required to certify that synthetic acids are not used.
- Past chemical manufacturing may have resulted in the presence of solids in treatment solutions. Copper naphthenate produced today is filtered before use.

Copper Naphthenate Effectiveness

According to Freeman and McIntyre (2002) over 1.3 million poles have been treated with CuN since 1988. Fewer than 5,000 have been cited as having early decay problems – less than 0.4 percent.

A similar perspective is supplied by the results of a nationwide survey of CuN poles treated from 1988 to 1999. 307 poles were sounded and bored and only 2 poles— both from the 1990-1994 era—had early decay (Barnes, et al., 2000).

One EPRI sponsored test program demonstrated the 14-year performance of CuN at 0.05 pcf retention to be equivalent to 0.40 pcf pentachlorophenol. This equivalence rating was a positive conclusion, given that the decay hazard at some of the test sites was extreme, where untreated poles typically fail in 4-5 years (McIntyre and Freeman, 2002).

Copper Naphthenate Environmental Studies, In-Service Poles

In a study conducted in Washington State by Brient (2002), 14 CuN treated poles continued to retain copper at levels at or above the minimum recommended retention for that AWPA Deterioration Zone after 8 to 14 years in service. No sign of decay or insect attack was observed in any of the poles.

Copper levels in soil 4 inches from the poles averaged 220 and 1124 mg/kg at the two sites studied. These concentrations were less than half the 2960 mg/kg cleanup level for copper calculated from the Washington State Cleanup Levels and Risk Calculations (CLARC), Method B, based on direct ingestion of soil from unrestricted (residential) land uses.

Total petroleum hydrocarbon (TPH) levels in soil collected from one site where CuN poles were the original installation averaged an order of magnitude below the Method A cleanup level of 2000 mg/kg listed for diesel range organics. TPH in soil collected near ten poles at another site averaged above the Model Toxic Control Act (MTCA) Method A residential cleanup level, but this site previously held poles treated with creosote.

Copper Naphthenate-Treated Pole Recycling/Disposal

Little specific information regarding recycling/disposal of CuN treated poles is available (EPRI, 2001). However, secondary use via sale or donation to the public is a viable option, as is the case for other used, treated wood poles.

Incineration/combustion may be an option, because all traces of the oil carrier should be destroyed during combustion. Merichem Company, a manufacturer of copper naphthenate, states at its web site that copper naphthenate-treated wood can be incinerated or landfilled, but that the treatment solution should not be disposed in an aquatic environment (Merichem, 2010).

Boilers permitted to combust treated wood are present in just ten states. Combustion costs ranged from $8 to $30 per ton, excluding shipping costs (EPRI, 2001).

While copper is not on the TCLP metals list, and resulting ash would not test as “hazardous” for copper, the resulting ash is nonetheless expected to contain an elevated level of copper. This could be an issue with respect to ash disposal and potential leaching of copper. Even if incineration was possible, loading/shipping costs may be high because the poles are frequently cut into many pieces during removal from service, and long distance trucking may be necessary. Furthermore, any metal in the pole (nails, old hardware) may require removal before incineration. The labor and logistics can become expensive.

Landfill disposal costs range from $3 to $100 per ton, with higher costs associated with limited space at northeast landfills and at landfills where poles were considered a distinct category of waste (EPRI, 2001). More recent estimates (Fogarty, 2010) for non-hazardous landfill disposal ranged from $30 to $70 per ton, depending on the type of processing (cut to short lengths or chipped).

Recycling of Class 4, 40-foot southern pine poles into lumber by sawmilling may be economically feasible. Based on the apparent success of sawmills in Georgia and Texas the same should be applicable to CuN-treated poles, especially given the non-restricted nature of the preservative.

Copper Naphthenate Advantages and Disadvantages

CuN treated poles are conveniently handled and managed by utility personnel who are already accustomed to working with wood. The slightly oily surface, similar to that of a penta treated pole, might be regarded as less than ideal.

CuN is not a restricted use pesticide. This is a primary advantage compared to the three common preservatives.

While some linemen and engineers have concerns that a pole with high levels of copper may be more conductive than other treated poles, Freeman (2001) reported no increased conductivity of poles treated with copper naphthenate. Freeman also reported that gaff penetration in copper naphthenate treated southern pine poles required less force for gaff "seating" than was required in penta-treated southern pine.

Aquatic environments are particularly sensitive to copper. It is important to manage the use and disposal of CuN treated wood with respect to potential leaching and migration in soil and aquatic systems.

6
ALTERNATIVE WATERBORNE PRESERVATIVES

This section of the report provides information on alternative waterborne wood preservatives that are less widespread than CCA-C, or are not typically used on southern pine distribution poles.

Ammoniacal Copper Zinc Arsenate (ACZA)

In the late 1970s, researchers found that aqueous ammonia solutions could be used to solubilize metals in water solutions. In this process, the components complex with the ammonia and remain soluble in the alkaline treating solution. During pressure treatment of wood, the solubilized cationic metals become fixed as ammonia volatilizes from the wood; dissipation of free ammonia is necessary for the best copper fixation. Aqueous ammonia solutions (primarily ammoniacal copper zinc arsenate) typically provide better penetration in hard to treat species such as Douglas-fir (Zahora, 1994) because the ammonia helps dissolve extractives.

ACZA History

ACZA is linked to the origin of ammoniacal copper arsenate (ACA), which was developed at the University of California in the 1930s.

Several studies in the 1970s and 1980s demonstrated that adding zinc to the formulation would reduce leaching of arsenic. This finding led to the development of ACZA in 1983 by J.H. Baxter and Company, where half the arsenic in ACA was replaced with zinc (Richardson, 1993).

The ACZA treatment industry evolved in the western United States for use in Douglas-fir transmission poles. There is little or no demand for distribution poles treated with ACZA.

The southern pine treating industry in the southeastern United States is not likely to make investments (roughly $200,000 to convert a plant for ACZA) and offer southern pine poles treated with ACZA as long as CCA remains an option.

ACZA Manufacture

Copper and zinc in dry powder form is mixed with arsenic pentoxide (a liquid arsenic acid). These components are then dissolved in aqua ammonia, with the addition of ammonium bicarbonate to solubilize the metallic oxides (Baileys, 2002).

Aqua ammonia is manufactured by reacting anhydrous ammonia with water to form a solution that is approximately 30 percent ammonia by weight. Aqua ammonia is manufactured from anhydrous ammonia. Anhydrous ammonia is manufactured from fixed nitrogen.

ACZA Regulatory Status

ACZA is an arsenical mixture and is therefore classified as a Restricted Use Pesticide (EPA, 2004). EPA determined (2008) that currently registered uses of chromated arsenicals are eligible for reregistration, provided that risk mitigation measures were adopted and labels were amended accordingly. Manufacturers and marketers responded positively and re-registration of ACZA was nearly complete in early 2010.

ACZA Supply and Cost

ACZA consists of aqua ammonia, copper, zinc, and arsenic. Copper and arsenic are addressed in earlier sections of this report.

The cost of ACZA treated distribution poles is unknown because there is no known demand for them.

ACZA Effectiveness

Specific studies of longevity of ACZA-treated poles were not located. However, anecdotal evidence and continued use of this preservative strongly suggest adequate performance.

ACZA Environmental Studies, In-Service Poles

Morrell, Keefe and Baileys (2003) investigated levels of copper, zinc, and arsenic in soil around nineteen ACZA-treated Douglas-fir transmission poles in the states of Florida, Virginia, and New York.

The study concluded that concentrations of copper, zinc, and arsenic were elevated in soils immediately adjacent to the poles. The affected zone was generally confined to within approximately one meter of the pole, with rapid declines in concentration beyond 0.3 meters and in deeper zones. Copper and zinc concentrations were generally higher than arsenic concentrations. The evaluation of “background” arsenic concentrations revealed arsenic in most cases was present at less than 0.1 mg/kg.

The researchers did point out that all the poles, which had been installed between 1991 and 1998, had received preservative treatment before AWPA promulgation of more stringent treatment and post-treatment fixation standards designed to prevent overtreatment.

Brooks (2000) reported no significant adverse effects to the biota in the area of boardwalks constructed of wood preserved with CCA-C, ACZA or ACQ-B at the Wildwood Wetland Recreational Area in Oregon.

ACZA-Treated Pole Recycling/Disposal

Currently, there are no known southern pine ACZA distribution poles in-service, so there are no data on disposal methods. ACZA is rarely used with Douglas-fir distribution poles and no information on recycling them was located.

ACZA Advantages and Disadvantages

Little re-training is required for line crews who may have developed most of their experience working on poles treated with other water-borne preservatives.

There is no chromium in ACZA. Substantially more copper is present in ACZA than in CCA. Copper must be carefully managed with regard to aquatic environments. ACZA contains about one-third the arsenic found in CCA.

ACZA solutions can be heated and remain heated for longer periods than other solutions. This provides an advantage during pole treatment that ensures deep penetration (though this should not be a significant issue with southern pine) and contributes to sterilization of wood (Baileys, 2002).

Hot-dipped galvanized fasteners or hardware should be used when in contact with ACZA treated wood. The galvanic coating is sacrificed in order to afford protection to the rest of the metal over time. Surface corrosion of hardware within a few years of service is common. However, several tests have indicated that this initial corrosion rate is not sustained over a long period.

Testing of the metal oxides used in ACZA by applying voltage to compressed pellets of the dry powder indicate these components are non-conductive.

Ammoniacal/Alkaline Copper Quaternary Compound

ACQ History

Research of quaternary compounds and copper mixtures was first conducted in New Zealand in the 1970s. ACQ has been widely used for many years in Europe and Japan (Preston, 2004).

There are multiple formulations of ACQ. The various formulations allow flexibility in achieving compatibility with a specific wood species and application. When ammonia is used as the carrier, *ammoniacal* copper quat (Type B) has improved ability to penetrate into difficult-to-treat wood species, such as Douglas-fir. However, if the wood species is readily treated, such as southern pine, an alkaline carrier can be used to provide a more uniform surface appearance. However, AWPA (2010) has only standardized ACQ Type B for use to treat wood distribution poles.

While the AWPA has standardized the use of ACQ for pole treatment, there is no known demand from utilities for ACQ-treated poles.

ACQ Manufacture

Copper amine and copper ammonia solutions are produced from various copper sources depending on the available technology. Quaternary compounds are manufactured from long chain amines that derive from natural or synthetic sources (Preston, 2004).

ACQ Regulatory Status

ACQ and its components are EPA registered biocides. ACQ does not contain any restricted use pesticides.

ACQ Supply and Cost

Copper is the primary component of ACQ.

ACQ is readily available in the United States. Supply is more than adequate for the pole markets as ACQ is the dominant preservative in United States lumber treatment markets, now that CCA is no longer available for residential public use. The cost is approximately 15 to 20 percent higher than CCA (Fowlie, 2002). There is no known current demand for poles treated with ACQ.

ACQ Effectiveness

No studies of in-service performance of ACQ-treated wood poles are available. However, ACQ is presented by manufacturers as providing equivalent performance to CCA across a broad range of above ground and ground contact applications, based on stake and lumber tests. In addition, based on on-going use in Europe and Japan, its effectiveness in exterior use lumber is good.

ACQ Environmental Studies, In-Service Poles

There are no known studies of leaching/migration of ACQ from poles or stakes.

ACQ-Treated Pole Recycling/Disposal

There are no known ACQ-treated poles in service, so disposal issues are not currently an issue. However, burning of ACQ-treated poles is not recommended because the ash will have an elevated copper content. Landfilling is not restricted by federal law.

ACQ Advantages and Disadvantages

Climbing ACQ-treated poles is expected to be similar to climbing of CCA poles – the wood is somewhat harder than a pole treated with oil-borne preservatives.

ACQ treatments accelerate corrosion of metal fasteners relative to untreated wood and wood treated with CCA. The providers of ACQ treated wood indicate in product literature that galvanized hardware, coated to meet the ASTM A-153 standard, is adequate. However, the same literature frequently states that stainless steel will provide “optimal” performance. The cost of stainless steel hardware is approximately 50 to 300 percent more than galvanized steel hardware, depending on the function of the specific hardware required. Aluminum hardware should not be used at all, as it corrodes quickly in the presence of copper (Morrison, 2004).

The short history of use of ACQ to treat poles is a disadvantage in that ACQ has not developed a reputation, good or bad, as a pole preservative. Significant shifts to this preservative for pole treatment are unlikely in the absence of additional field data, the higher costs associated with the stainless steel hardware, and the continued availability of other well known preservatives that are less expensive and well-proven.

Copper Azole

Copper Azole History

Development of copper azole began in New Zealand in the 1980s. It has been used for wood treatment since 1992. It is copper based to repel most insects and fungi.

Tebuconazole, the co-biocide, was developed by Bayer Corporation in the mid 1980s, and belongs in the group known as triazoles. Tebuconazole has been widely used in agriculture as a fungicide.

AWPA (2010) has standardized three formulations: copper azole Type A (CBA-A), copper azole Type B (CA-B), and copper azole Type C (CA-C). Type A contains approximately one half the copper (45%) found in Type B. In Type A, boron is used as part of the formulation. Type C is nearly approximately 95% copper. AWPA has standardized all three formulations for use in southern pine, but not Douglas-fir.

No copper azole treatment of wood poles for utility use is known to be occurring in the United States.

Copper Azole Manufacture

Relevant information regarding the manufacture of copper azole was not readily available, probably because it is not in use for pole treatment.

Copper Azole Regulatory Status

Copper azole is an EPA registered biocide. Copper azole does not contain restricted use pesticides.

Copper Azole Supply and Cost

No information on the supply and cost of tebuconazole was located. However, tebuconazole is present as less than 4 percent of the preservative mixture. Given its continued use in agriculture, supply and prices are expected to be adequate and acceptable.

There are no known pole treaters currently using copper azole. Therefore, treated pole prices are not available. However, the cost is expected to be “high”, given the level of copper that is required in the preservative.

Copper Azole Effectiveness

There are no known published data on CBA-A, CA-B, or CA-C effectiveness in poles. Neither of the three types are recommended by AWPA (2010) for Use Category 4C (tropical and semi-tropical regions). Neither are standardized by AWPA for wood species other than southern pine and western red cedar.

Fox and Williams (1994) reported on an earlier formulation that included boron. Their studies demonstrated good results compared with CCA and ACZA, though they were relatively short duration field tests with stakes.

Copper Azole Environmental Studies, In-Service Poles

There are no known published data on leaching/migration from pole or stake tests.

Copper Azole-Treated Pole Recycling/Disposal

There are no known copper azole-treated poles in service, so disposal issues are not currently relevant. However, burning of ACQ-treated poles is not recommended because the ash will have an elevated copper content. Otherwise, landfilling is not restricted by federal law.

Copper Azole Advantages and Disadvantages

The primary disadvantages of copper azole are lack of use history in wood poles, assumed higher costs, and relatively high levels of copper, compared to both the common and alternative preservatives. Relevant field performance studies and information about the long-term fate and behavior of tebuconazole are lacking.

Pole users may be compelled to use stainless steel to extend the life of hardware. The cost of stainless steel hardware is approximately 50 to 300 percent more than galvanized steel hardware. Aluminum hardware should not be used at all, as it corrodes quickly in the presence of copper (Morrison, 2004).

The primary advantage of copper azole is that it is not a restricted use pesticide.

Other Alternative Preservatives

According to Freeman (2006), bringing a new pole preservative to market requires an investment of six to seven years and approximately $500,000. The time and money is required to support development, field trials, data reduction and numerous submissions and presentations, EPA approval, and (though not required by law) AWPA approval and standardization. There is no guarantee that a new preservative with excellent performance and little potential environmental impacts will make it through all these challenges.

The following text provides brief information about new developments that may have potential as future pole preservatives but face the challenges identified above.

Molybdenum and Tungsten

Cowan and Banerjee (2005) reported studies in which CCA formulations were changed by replacing arsenic with molybdenum and tungsten, treating wood with the new solutions, and evaluating resistance of treated samples to a brown-rot fungus. The researchers found that component leaching was similar to that of CCA-treated wood (minor), but that the woods treated with the molybdenum and tungsten mixes had the same or better resistance to brown-rot fungus than CCA-treated wood.

Polyxylenol Tetrasulfide (PXTS)

PXTS is an oligomeric compound with fungicidal, insecticidal, and termiticidal effects. Based on available data (Freeman et al., 2004), it is less toxic to wood decaying fungi than CCA, but more toxic than creosote. It is less corrosive than CCA to galvanized metal, but more corrosive to brass and mild steel than CCA. PXTS is already registered by EPA for use as a wood preservative. While AWPA has standardized PXTS as an oil-based preservative for use in pressure treatment processes (AWPA, 2007), it is not standardized for use in poles. The patent for PXTS is currently available. Freeman (2006) predicted that PXTS would be approved by AWPA for use in poles by 2009. However, this has not occurred.

Bis-(N-cyclohexyldiazeniumdioxy)-Copper Complex

Bis-(N-cyclohexyldiazeniumdioxy)-Copper Complex has two different acronyms: Cu-HDO and CX-A. AWPA (2007) uses the CX-A acronym. CX-A is a water-borne copper diazineum compound with 5% boric acid, registered by EPA in 2005. The copper component is responsible for aquatic toxicity, but it otherwise has low soil mobility. It has been used in Europe for a number of years (LeBow, 2004). Currently, CX-A is standardized for use in sawn products by AWPA, but not for use in poles.

Micronized Copper

"Micronized" copper is created by mechanical grinding of water or oil insoluble copper compounds (usually copper carbonate), such that 90 percent of the resulting particles are 1000 nanometers or less in size. At this size, particles are "carried" (water or oil-borne) into wood without blocking the passageways in the cells (Freeman and McIntyre, 2008). Electron microscopy and x-ray microanalysis confirm a good distribution of copper within the cells, similar to the distribution resulting from pressure treatment with dissolved copper. Reactive fixation of copper was not significant. The primary mode of copper retention in wood cells was deposition. Leaching tests indicate that copper loss from micronized formulations is approximately 25 percent of copper leaching from dissolved formulations.

Micronized copper formulations have not been standardized by AWPA. International Code Council Evaluation Services (ICC-ES) has issued Evaluation Services Reports (ESR) for certain formulations. ESRs indicate that products are satisfactory for building code regulated uses.

There is no known use of these formulations for wood pole treatment. But there are many potential advantages. Copper retention levels are generally less than dissolved copper treatment solutions. Leaching is expected to be less. Manufacturer stake tests indicate efficacy similar to dissolved copper formulations such as CCA.

Some of the current branded formulations have attained an Environmentally Preferred Product status from Scientific Certification Systems (SCS). SCS is a third-party certification services and standards development company. MicroPro has also earned a National Association of Home Builder's Green Approved Product certification.

Sodium Silicate

TimberSIL™ is the trade name for a product developed to infuse wood with sodium silicate (glass). The owners of the process claim that it is completely non-toxic and that the sodium silicate acts as a physical barrier to fungi and insects (2010). The makers warrant that TimberSIL™ treated wood will perform acceptably for 40 years, even in ground contact, and allow transfer of the warrantee.

The TimberSil™ product is in accordance with 40 CFR 152.10, as a “barrier” product. It is not a pesticide and does not have to be registered under FIFRA. EPA determines a product to be a barrier if the following are true:

- The product is not intended to prevent, destroy, repel, or mitigate a pest, or to defoliate, desiccate or regulate the growth of plants.
- The product does not make a pesticidal claim on the labeling or in connection with sale and distribution.
- The product is intended to exclude pests only by providing a physical barrier against pest access, and contains no toxicants.

Because TimberSil™ is not a chemical preservative, AWPA has no role in standardizing it. TimberSil™ is currently marketing treated lumber and marine piles. Company representatives say they are interested in marketing wood utility poles. Representatives indicate that a TimberSil-treated 40 foot southern pine pole would sell for approximately $500.

Summary of Common and Alternative Wood Preservatives

Table 6-1 summarizes relevant characteristics of common and alternative wood preservatives. Molybdenum and tungsten, PXTS, Cu-HDO, and TimberSIL™ formulations are not included because they are not approved by EPA, commercially available, or standardized for wood pole use by AWPA.

Table 6-1
Summary of Relevant Characteristics of Common and Alternative Wood Preservatives

	Creosote	Penta	CCA	CuN	ACZA	ACQ	CA-B
Supply	Good	Good	Good	Good	Good	Good	Uncertain
Pole Cost – Southern Pine	~$377	~$308	~$272	~$200	$410	~$220	Uncertain
Pole Cost – Douglas-fir	~$205	~$300-$320	NA	~$300-$320	NA	NA	NA
Efficacy	Good	Good	Good	Good	Good[1]	Good[2]	Uncertain
Regulatory Status	RUP	RUP	RUP	Non-RUP	RUP	Non-RUP, Biocide	Non-RUP, Biocide
Recycle/ Disposal	Landfill, Incinerate, Re-use	Landfill, Incinerate, Re-use	Landfill, Re-use	Landfill, Re-use	Landfill, Re-use	Landfill, Re-use	Landfill. Re-use (assumed)
Advantages	Known properties, Climbable	Known properties, Climbable	Known properties, Climbable, Cost	Known properties, Climbable	Known properties, Climbable	Known properties,Cli mbable	Uncertain
Dis-advantages	Leaching	Leaching, surface may be “dirty”	Leaching	Leaching	Leaching	Leaching, Cost, Corrosive	Leaching (assumed) Cost, Little historical record

1. Based on ACZA use in Douglas-fir transmission poles. No known current use in southern pine distribution poles.
2. Based on ACQ use in Europe and Japan, primarily in lumber. No known current use in southern pine distribution poles.

7
ALTERNATIVE POLE MATERIALS AND SPECIES

Thin-Walled Steel

Steel distribution structures are hollow, with wall thicknesses that range from 1/8-inch to 5/32-inch. These are referred to as “thin-walled” steel (EPRI, 1997).

Thin-Walled Steel Manufacture

Steel distribution poles are manufactured under controlled conditions using hot-rolled steel sheets that meet ASTM standards. Holes are usually drilled or gas cut at the plant, as required. Components for attachment and connections required for hardware may also be shop welded on the pole (NRECA, 1999).

Steel poles are subjected to abrasive cleansing to remove welding slag and other unwanted material prior to galvanizing. Then, most poles receive a “hot dip” galvanization, to help prevent corrosion when in use.

“Weathering” steel that meets ASTM standards is another type of steel used for manufacture of distribution poles. This type forms a hard, brown patina of protective oxide (different from typical rusting) that protects the pole (ASCE, 1990) and is considered by some as more attractive than galvanized steel. In addition, its purchase price is typically less than a galvanized pole because no galvanization is necessary (Blacketeer, 2004).

Steel poles manufactured from new (non-recycled) steel require approximately 5 times more energy to manufacture than do wood poles (EPRI, 1997). If recycled steel is used, approximately two and one-half times as much energy is required (SAEFL, 1998). The Iron and Steel Institute reports that most steel poles made in the United States use nearly 100 percent recycled material.

Thin-Walled Steel Supply and Cost

The price of steel rose throughout the 2000s, primarily because of industrial development in China. This occurred at the same time that the coke supply dropped, further limiting the supply and escalating the price. World steel demand and prices hit a historic peak in 2008, dropping rapidly thereafter (OECD, 2009). Prices bottomed out in the summer of 2009 and have been slowly rising since then, primarily due to demand in China (MEPS International, 2010).

According to Snyder (2004), the United States consumption of steel was about 120 million tons per year. Snyder estimated that if all United States utilities began using steel for new or replacement wood poles, only 1 million additional tons of steel would be required to meet the annual demand. This is less than a 1% increase in the volume of raw material, and is not typically expected to have a significant effect on priceZinc supplies and related cost information are described in the section on ACZA.

Valmont Newmark (Valmont, 2010) reported the costs of Class 4, 40-foot galvanized and weathering steel poles. The costs were at the point of manufacture, and based on the purchase of 100 poles. The galvanized poles, weighing 439 pounds, were $715 each. The weathering steel poles, weighing 411 pounds, were $680 each.

Thin-Walled Steel Effectiveness

Field performance studies of steel distribution poles could not be found. Therefore, direct embed, in-service steel pole effectiveness is assumed as a function of the known properties of steel and inferred from information about recent direct embed steel pole projects.

Thin-Walled Steel Pole Use

The weight of thin-walled steel distribution poles is roughly half the weight (500 pounds) of an equivalent wood pole. This results in the ability to transport more poles in one load, and reduces worker effort in guiding poles into place. Transporting, lifting, and moving steel poles require greater care than wood because chips, dents, or cracks in a steel pole could result in early failure from corrosion or buckling. Steel poles should not be handled with chains or pushed over rough ground (EPRI, 1997).

Steel alone is inherently conductive, and Donohoe (1999) has demonstrated that direct embedded steel poles (without galvanization on the butt) are generally adequately grounded. Galvanation and protective coatings reduce pole effectiveness as a ground.

Thin-Walled Steel Pole Recycling/Disposal

The Steel Recycling Institute (Crawford, 2004) indicates that in the current steel market, it is easy to dispose of steel poles via recycling at local ferrous scrap yards. They in turn feed steel mills throughout the United States and some export markets. Poles delivered to scrap yards may require cutting into halves or quarters, but utilities can normally expect to be paid for the scrap.

Pay rates will vary with location, and negotiation of contracts between utilities and scrap yards may result in favorable terms for utilities.

Based on the information above, it is probable that public donation is a good option as well. Consumers will find a use for steel poles as they have for wood poles, even if the use is turning the poles in for scrap recycling.

Thin-Walled Steel Advantages and Disadvantages

Steel is not degraded by decay, fungi, insects, or woodpeckers. Steel is effective at withstanding weathering, ultraviolet degradation, and short-term fire. However, it is subject to corrosion, primarily below groundline (EPRI, 1997).

Thin-walled steel poles do not contain preservatives and are recyclable. The current market for steel scrap is good. Most recyclers are currently paying for steel scrap. While the payment is far less than the original cost of the pole, it is still an improvement compared to paying to dispose of the pole. Thus, secondary use of steel poles is less likely to occur than for used treated wood poles.

Thin-walled steel poles are lighter than equivalent wood structures, so transport of steel poles is cheaper (more poles per shipment). In some respects, installation is easy because steel poles are lighter than most alternatives. More careful handling is required during transport and installation to avoid cracks, chips, or dents in the poles.

Steel poles have lesser insulation characteristics than wood and additional insulation is frequently needed. Furthermore, most steel poles require butt coatings so the pole itself is not an adequate ground.

Steel poles may buckle under overloads, as opposed to breaking. Once this occurs, the pole must be replaced. However, there is a potential advantage to this type of buckling (without breakage): electricity may continue to flow until an outage can be managed during pole replacement.

Steel poles are significantly more expensive than treated wood poles. In addition, steel poles cannot generally be used on a “one-for-one” replacement basis for wood poles, complicating the ability to use steel poles as a replacement in a predominantly wood distribution system.

The production capabilities of steel pole manufacturers are currently limited: a conservative estimate of production of steel distribution pole production from the entire industry suggests a maximum output of 200,000 poles per year. The utility industry purchases approximately 2 million replacement poles annually. Steel pole output, however, is a function of limited demand. If utilities ordered more steel poles, producers would respond with increased production.

Fiberglass Reinforced Composite (FRC)

The development of FRC began during World War II with the manufacture of the B-17 Bomber. FRC continued to be used for aircraft manufacture, and a Boeing 777 commercial jetliner reportedly consists of more than 25 percent FRC.

The oldest known FRC poles were manufactured by Gar Wood Industries in 1954. In 1968, South Carolina Gas and Electric contracted with Shakespeare to manufacture FRC poles for installation on a coastal island. In 1981, in Alameda, California, Shakespeare manufactured 800 poles that were installed in back yards and hard to reach places (Derrick, 1997).

FRC Manufacture

The primary raw materials used to manufacture fiberglass are sand, feldspar, sodium sulfate, and boric acid. These materials are heated in a furnace to temperatures as high as 1700 degrees Celsius and transformed into molten glass. The molten glass can then be transformed into fibers by a variety of processes.

FRC Pole Physical Properties

FRC poles have good insulation properties, good fire resistance, and good corrosion resistance. Fiberglass is prone to ultraviolet (UV) degradation, but additives are used to minimize this. A class 4, 40 foot FRC pole weighs approximately 370 pounds.

“Blooming” may occur on in-service FRC poles, where the resin is degraded and glass fibers are exposed. If this occurs, or if the surface is damaged, epoxy fillers and urethane finishes should be applied. In extreme temperature regimes (freeze/thaw), FRC may eventually crack. The extreme temperatures caused by fire may also cause resin decomposition.

FRC Supply and Costs

Sand, feldspar, sodium sulfate, and boric acid are all common materials of relatively low cost.

Boron, the raw material from which boric acid is produced, is widely available and supplies are expected to be adequate for the foreseeable future.

Powertrusion Products (2010) reported the approximate cost of a Class 4, 40-foot FRC pole was about $1070 for 60 or more direct embed poles at the point of manufacture. FRC pole producers either did not know, or would not comment on their annual production abilities. They did indicate that production of five to six thousand FRC poles per year was possible.

FRC Use

Shipping of FRC poles will generally be limited by volume, as a full truckload will weigh less than allowed by highway laws. However, because an undamaged surface condition is crucial for good field performance, special measures may be required during trucking, such as blocking and/or full length wrap (EPRI, 1997).

FRC distribution poles are direct embed, as are wood poles. Care must be exercised during installation to avoid damaging the surface of the pole, thereby weakening and/or exposing resin and fibers to UV light, which degrades the FRC. FRC itself is fairly non-conductive, but grounding is required as necessary for pole hardware.

In-service FRC failures are usually caused by ultraviolet radiation, delamination of fiberglass layers, overloading, or vehicle impacts (EPRI, 1997). FRC manufacturers claim that UV inhibitors and below surface veils prevent UV degradation.

A Class 4, 40-foot FRC pole weighs approximately 475 pounds. This enables hand carrying to tight or difficult spots, and lighter helicopters may be used when remote or difficult installations are required.

FRC Effectiveness

As with thin-walled steel, FRC poles cannot be degraded by fungi or insects. FRC poles are also impervious to woodpeckers.

There are no known field studies of in-service, direct embed, FRC distribution poles that evaluate performance, wear, blooming, and/or longevity. FRC pole manufacturers, however, indicate that 40 years is a minimum life span, with little or no maintenance. For example, Derrick (1997) reported that FRC poles installed in Hawaii in 1953 are still in service and performing well. A survey of utility personnel revealed a “perceived” lifespan of 43 years for FRC poles (EPRI, 1997).

FRC Pole Recycling/Disposal

Because fiberglass is not biodegradable, proper management should ensure a long lifespan. Eventually, however, even fiberglass poles will be removed from service. Assuming that some portion of its length is stable and retains its former hollow shape, it is likely that recycling through donation is a good option.

Fiberglass can be recycled, but there are few facilities that accept fiberglass. Otherwise, FRC can be disposed in landfills as non-hazardous solid waste. Landfill disposal is likely to be a cost activity based on weight or volume. The volume of FRC can be manipulated and reduced via cutting and/or crushing.

FRC Advantages and Disadvantages

FRC poles have good insulation properties, good fire resistance, and good corrosion resistance. Fiberglass is prone to ultraviolet (UV) degradation, but additives are used to minimize this.

"Blooming" may occur on in-service FRC poles, where the resin is degraded and glass fibers are exposed. If this occurs, or if the surface is damaged, epoxy fillers and urethane finishes should be applied. In extreme temperature regimes (freeze/thaw), FRC may eventually crack. The extreme temperatures caused by fire may also cause resin decomposition.

FRC poles do not leach chemicals. They are lightweight and strong. Insulation and grounding requirements are essentially the same as wood. They are available in several colors. They are not susceptible to degradation as a result of fungal, insect, or woodpecker attack. On a class-by-class basis, an FRC pole is more reliable than an "equivalent" wood pole for certain properties.

Disadvantages include higher initial costs. While in-service use is generally innocuous with respect to environmental concerns (leaching and migration), at the point of manufacture VOCs and other generated wastes are a disadvantage.

FRC poles are not as forgiving as wood. They are more easily damaged than wood, in ways that reduce strength more easily than wood. The surface of FRC must be carefully protected during transportation and installation.

FRC poles are significantly more expensive than treated wood poles. In addition, the production capabilities of FRC pole manufacturers is limited: manufacturers indicate that production of five to six thousand poles per year was possible, while the utility industry purchases approximately 2 million replacement poles on an annual basis.

Spun-Cast Concrete

Concrete poles have traditionally been used for transmission structures and specialty needs, primarily because they are heavy (approximately 3,600 pounds). By itself, concrete has relatively high compressive strength properties. However, tension strength is low. To address this shortcoming, manufacturers add tensioned steel tendons within the concrete. The capacity of prestressed hollow spun-cast concrete poles in a Grade C distribution setting depends on the specified concrete strength, the quantity of internal prestressed tendons, and the wall thickness (NRECA, 1999).

Spun-Cast Concrete Manufacture

Prestressed hollow-spun concrete poles are manufactured in a controlled environment, so that a higher confidence level in predicted strength can be achieved. Prestressing is accomplished by tensioning steel tendons in a round tapered mold. Concrete is added to the mold, and then the mold is spun at a high rate. This forms a tubular wall around the steel tendons, resulting in a pole that efficiently withstands column buckling and bending.

Production of concrete poles requires approximately eight times as much energy as production of wood poles (EPRI, 1997). Most of this energy is used to render limestone (in kilns) into the powder commonly referred to as “Portland” cement. Fly ash (a by-product of coal combustion) is sometimes mixed into cement as a way to recycle the fly ash. When mixing is properly conducted, according to *The Sustainable Design Resource Guide* (2004), the concrete is smoother, denser, more workable, and less permeable. According to Headwaters Resources (2007), a commercial marketer of coal combustion by-products, concrete containing appropriate quality fly ash is easy to work because the ash creates a lubricating effect - fills forms more completely, and 10 percent less water may be used.

Spun-Cast Concrete Pole Properties

Concrete has hygroscopic characteristics. Freeze/thaw cycles can cause degradation. Concrete is also subject to degradation in saltwater regions along coastlines, because salt reacts with lime in the cement and neutralizes bonding (EPRI, 1997), though additives may retard this potential. Cracking, though rare, is of great concern because it may ultimately cause exposure of steel tendons (EPRI, 1997).

Spun-Cast Concrete Pole Supply and Cost

The main components of concrete are limestone (heated in a kiln and in powdered form), aggregate (sand and/or gravel), and water. These materials are common and supplies are abundant and expected to be adequate for many years.

In 2005, a spun-cast concrete pole intended to be “equivalent” to a Class 4, 40-foot wood pole cost about $1500. One manufacturer stated that they could produce about 500 of these poles per year. In 2010, a pre-stressed concrete pole at point of manufacture cost about $760 (Rice, 2010), with the ability to produce about 3000 poles in a year.

Spun-Cast Concrete Effectiveness

Prestressed hollow-spun concrete is more durable, heavier, and stiffer than wood. It is not subject to biodegradation from fungi, insects, or woodpeckers. It does not twist or warp. However, concrete degradation, cracks, and internal corrosion must be monitored.

There are no know studies of distribution sized concrete pole performance, but reinforced concrete structure performance is well known, with life spans in excess of 40 years. A survey of utility personnel revealed “perceived” life spans of spun cast concrete poles of 48 years (EPRI, 1997).

Spun-Cast Concrete Pole Use

Although prestressed hollow-spun concrete poles are sized to ultimate design conditions, the allowable capacity of a concrete pole also needs to be checked under “working” stress levels so that concrete cracking would be limited (NRECA, 1999).

The most severe trucking limitations are encountered with concrete poles. Careful blocking is required, and concrete poles are significantly heavier than all other poles discussed in this report. As a result, more powerful equipment than is required for wood poles may be necessary. The weight of concrete poles is also likely to increase installation time and fatigue of the workers.

NESC® (2007) does consider a direct-embedded concrete pole with reinforcing steel or prestressed strands to be an adequate existing ground electrode.

The hardware on concrete poles requires grounding the same as hardware on wood poles. If an external groundwire is unacceptable, an internally embedded groundwire (along the tendons) may be used if its size is at least #2 American Wire Gauge (AWG).

During installation, lift points designated by the manufacturer should be used to avoid causing stress cracks; tendons in concrete poles do not usually corrode unless the surrounding concrete is cracked.

Field drilling of concrete should be avoided at all costs because of the potential of exposing the tendons, but also because the tendons themselves may be damaged and weakened by drilling (EPRI, 1997). If there is no alternative, the manufacturer should be consulted.

Spun-Cast Concrete Pole Recycling/Disposal

Concrete poles can be recycled, but not as easily as steel, because appropriate facilities are comparatively rare. Their weight is likely to be a disadvantage with respect to public donations. Unusable concrete poles are usually discarded in non-hazardous landfills.

Spun-Cast Concrete Advantages and Disadvantages

Spun-cast concrete poles are engineered structures, with much less variance in physical characteristics than wood poles. They are impervious to UV degradation, fungi, insects, and woodpeckers. They do not twist or warp. They stand up well to short duration fires. Since they do not contain preservatives, concerns associated with leaching of chemicals are not an issue. Although concrete poles may require more effort to haul and set, they are still desirable in locations where little future maintenance is required.

Concrete pole manufacture is the most energy intensive process for pole manufacturing.

Plastic

Compared with FRC, steel, and spun-cast concrete, there is little readily available information about plastic utility poles.

One vendor was located in 2005 who was fabricating plastic poles for one electric utility company. The poles required internal steel skeletons or solid spines because the hardened plastic formulation alone was not strong enough for use as a distribution structure. The utility purchaser saw no advantages because the plastic pole was susceptible to some of the same disadvantages as concrete. By 2010 the vendor was apparently out of business.

Fly Ash

Fly ash is one of the by-products of coal combustion. It is a powdery material consisting of silicon, aluminum, iron, and calcium oxides. EPA (2007) also estimates that approximately 35% of the fly ash generated each year is recycled in various ways.

Fly ash products can supplement or replace Portland cement, a primary ingredient in concrete, to reduce raw material costs and strengthen the concrete. The use of one ton of fly ash in concrete manufacture offsets generation of approximately 1 ton of carbon dioxide during cement production.

Use of fly ash to manufacture poles has been evaluated by Chugh and Ma (2006). These researchers concluded that an FRC pole could be manufactured using fly ash polymer. They estimated (in 2003 dollars) that with a capital investment of $575,000, Class 3, 35-foot poles could be manufactured at a cost of approximately $385 each, at a rate of 800 poles per month. With a retail cost of $482 per pole, the payback period would be 4.1 years. Strength testing was performed on scale “model” poles that were expected to behave in a scaled manner and concluded that full-size, street-ready FRC/fly ash poles would meet or exceed the ANSI strength requirements for wood poles. They also concluded that these poles would be moisture, UV, and decay-resistant.

Discussion with existing commercial concrete pole manufacturers indicates that the investment to retrofit existing concrete pole plants is too high (Valmont, 2010).

American Chestnut (*Castanea dentata*)

Twenty five percent of the eastern United States forest resource was once comprised of American chestnut. Its wood is naturally decay resistant. Anecdotal information and some physical evidence indicate that American chestnut was one of the first wood pole species used in the United States to support telegraph and electrical wires. These poles reportedly lasted 25 years in service (without preservative treatment), and creosote butt treatments were sometimes used to extend their service lives.

However, circa 1904, a blight (*Cryphonectria parasitica)* was inadvertently imported from Asia. The American chestnut was not resistant to the blight and by 1940, most American chestnut trees were dead. Sprouts continually rise from the stumps, but these rarely attain a girth of more than a few inches before the blight causes fatal girdling.

Efforts to develop blight resistant strains of American chestnut have been underway for a number of years. Resistant strains are already being planted in silvicultural clearcuts (Anagnostakis, 2005) in state forests (full sunlight promotes best growth).

American Chestnut Physical Properties

Table 7-1 presents several physical properties of American chestnut wood in comparison with the common North American pole species wood (the properties below are not based on destructive testing of poles).

Table 7-1
Selected Physical Properties of North American Species

	Southern Pine	Douglas-Fir	Western Red Cedar	American Chestnut
Weight (dry) (lbs/ft^3)	24 - 40	31	24	32
Specific Gravity	0.55	0.48	0.32	0.43
Hardness (psi)	319 - 942	616	337	432
Modulus of Rupture (dry) (psi)	11,292 – 14,117	12,238	8,271	9,335
Modulus of Elasticity (psi, 10^6)	1.87	1.75	1. 11	1.23

The Wood Explorer, 2005; Chudnoff, 1995
lbs/ft^3 - pounds per cubic foot; psi - pounds per square inch

American Chestnut Potential as Wood Poles

American chestnut has several characteristics that suggest good potential for future wood pole use. Historic technical reports, coupled with anecdotal information, clearly demonstrate its previous wide use in this capacity. Furthermore, physical properties data suggest adequate strength for this purpose.

Several issues must be addressed before concluding that American chestnut can serve as a major alternative to currently available choices. These issues follow.

Quantitative studies of decay-resistance of American/Chinese chestnut strains were not located. Decay-resistance is expected to be similar to pure American chestnut, but this has yet to be confirmed.

If decay-resistance is not generally good enough to provide an in-service, consistent lifespan of 25 years or more, research will be required to determine the most effective preservative and treatment system.

American chestnut will most likely require ANSI and NESC® approval, based on destructive testing.

Assuming that strength and decay-resistant properties and growth rates are acceptable, a valid silvicultural system for production is necessary – determining whether plantations are required or desired is a primary question.

Tropical Hardwoods

Some tropical hardwood species are known to have inherent decay-resistant properties. Seven tropical hardwood species native to South America were evaluated with respect to physical properties, decay resistance, strength, availability, and tropical forest management.

Two or three species could serve well as pole structures that do not require preservative treatment. However, supplies are generally poor and verification that forests of origin are responsibly managed is difficult.

ANSI recently acknowledged (2009) that two tropical hardwood species (*Abiurana* and *Mata Mata*) are generally suitable for use for use as untreated utility poles, and created a separate standard (ANSI 05.2.2009) to address them. The standard requires that these tropical hardwood poles be harvested from certified, sustainably managed forests.

Summary of Pole Materials and Species

Table 7-2 below provides a summary of the relevant alternative pole materials and species.

Table 7-2
Summary of Relevant Pole Materials and Species

	Southern Pine	Thin Walled Steel	FRC	Spuncast Concrete	American Chestnut	Brazilian Hardwoods	Guyana Hardwoods
Supply	Good	Good	Good	Good	Uncertain	Uncertain	Uncertain
Material Cost	~$205 - $320	~$680 - $715	$1,070	~$760 - $1500	Uncertain	Unknown	Unknown
Performance	Good	Good	Good	Good	Uncertain	Good reputations	Good reputations
Weight lbs/kg) air dry	1,090/ 495	440/ 200	475/ 215	2,950/ 1,340	630/ 285	~1,260/ 570	~1,260/ 570
Recycle/ Disposal	Landfill, incinerate, Re-use	Landfill, recycle, Re-use	Landfill, recycle, Re-use	Landfill, recycle, Re-use	Landfill, incinerate, Re-use, resaw	Landfill, incinerate, Re-use, resaw	Landfill, incinerate, Re-use, resaw
Advantages	Known properties, climbable, sustainable	Known properties, flame and decay resistant	Known properties, flame and decay resistant	Known properties,	Potential for less preservative treatment, sustainable	Potential for little or no preservative treatment, strong	Potential for little or no preservative treatment, strong
Disadvantages	Decay prone	Corrosion, insulation, cost, short use history, limited availability	Cost, short use history, limited availability	Weight, cost, short use history, limited availability	Not yet available, little performance data	Uncertain supplies, little performance data	Uncertain supplies, little performance data

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