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STOCKHOLM CONVENTION

GUIDANCE ON ALTERNATIVES TO PENTACHLOROPHENOL (PCP)

2021

UN environment programme

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ACKNOWLEDGEMENT

The European Union, the Governments of Germany and Sweden are gratefully acknowledged for providing the necessary funding that made the production of this publication possible.

The feedback from Parties and observers to the Stockholm Convention on Persistent Organic Pollutants is highly appreciated.

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Recommended citation: UNEP (2021). Guidance on alternatives to pentachlorophenol. Revised from document UNEP/POPS/COP.8/INF/20. Secretariat of the Basel, Rotterdam and Stockholm conventions, United Nations Environment Programme, Geneva.

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1. POLICY PLANNING FOR EMISSION CONTROL AND PHASE-OUT OF PCP USED FOR UTILITY POLES AND CROSS-ARMS

Planned approach for management of PCP

Pentachlorophenol (PCP) and its salts and esters are listed under Annex A to the Stockholm Convention, with specific exemptions for the continued use of PCP for utility poles and cross-arms. Manufacturing of PCP is limited to only a small number of countries, with the use of PCP for treatment of timber also limited to a smaller number of nations. However there are also a number of former uses for PCP, and continued legacy issues from timber treated with PCP. In order to manage PCP at national level it is necessary to understand what are the issues relevant to a given country at national level, what control measures are needed, what form of stakeholder engagement is needed, and what activities should be undertaken to help minimize releases to environment and, therefore, human exposure.

Figure 1 provides an illustrative set of steps which could be used to help understand the main issues, establish contact with the relevant Parties and undertake work to further control and minimize emissions, as well as facilitating the phase-out of PCP and transition to safer alternatives (both chemical and non-chemical). The remainder of this chapter looks at each of these steps in turn.

Figure 1: Planning process for management of PCP and transition to alternatives

Step 1	Identification of issues at national level
Step 2	Engagement with Industry / Agencies / NGOs
Step 3	Review and Development of Control Options
Step 4	Development of Control Plans
Step 5	Awareness Campaigns
Step 6	Monitoring / Compliance / Feedback
Step 7	International Activities

Step 1: Identification of issues at national level

The first step within the planning for management of PCP is to better understand the key important issues at national level. For example, where only a limited number of nations manufacture PCP or make use of PCP based products for timber treatment, the emissions associated with these activities may not be directly relevant for a given nation. However, import of previously treated timber may be an issue, as may handling of waste legacy aspects of treated timbers, former sites of manufacture, or even former uses. Therefore, the first step is to understand which issues are of key importance.

The Development of emission inventories (as detailed in chapters 2, 3, and 4 in this guidance document) provides a valuable tool to help provide an evidence base for what the key issues are likely to be. Additionally, it will be necessary as part of this inventory development work to gather data from a variety of sources and engage with relevant industry groups, regulatory agencies and NGO stakeholders (see chapter 3). The completion of this first stage should help the policy maker fully understand what the main issues are and where further control and work is needed. They should also inform the policy maker on how and where PCP is being used within their nation and by which industry sectors including the full life cycle (i.e. waste handling aspects should also be included).

Step 2: Engagement with Industry / Regulatory Agencies / NGOs

The second step involves the early preparatory work for development of control options for PCP, and the work needed to support the phase-out of PCP in favour of safer options. The completion of the first step will have identified a set of key issues which need to be addressed. As part of the emission inventory work specific stakeholders may have already been contacted to provide data. This second step has a different focus to the stakeholder engagement. The contact in this case could be used to help serve the following purposes:

- Establishment of working groups between regulatory officials and industry representatives, to help understand the key obstacles to phase-out of PCP for safer alternatives. This would provide a mixture of policy and regulatory expertise with technical expertise from industry on how PCP is used and what the possible options for phase-out might be;

- Additionally these kinds of working group can prove useful to help identify and manage key priorities for existing use. For example if the risk of human exposure from manually treating activities is identified as high risk, the working group can be used to communicate to industry the urgency with this issue and need to move to automatic / closed systems of treatment;

- Establish key contacts for government departments and regulatory agencies. One of the key issues for managing PCP will be awareness. Establishing communication routes and training on key information to enforcement agencies will help establish a more effective control, while providing valuable feedback loops on information from those agencies carrying out enforcement;

- Finally contact with a wider audience such as NGOs and the public can be used to help gather feedback on what others perceive as being the priority issues for management. This could be conducted as targeted consultation, public surveys (as part of the work linked to national implementation plans), or as part of the awareness campaigns in step 5.

The completion of this second step is intended to inform the key issues, and technical / socio-economic obstacles that may be presented in managing the control and phase-out of PCP. Further guidance on the potential likely issues that might present obstacles to phase-out and transition are given below:

- The availability and applicability of alternatives varies by region. There may not be economically viable non-chemical alternatives to PCP in some regions, for example where there is limited infrastructure for steel or cement production. Additionally, climatic conditions (i.e. particularly low or high temperatures/ humidity) may render some chemical alternatives less effective than PCP;

- The existence of poorly documented and regulated secondary markets. Even if PCP use in industry is restricted or prohibited, materials such as utility poles or railroad ties may be sold for reuse, where they may be installed in residential settings such as for garden borders (USA 2013). Such items can continue to leach PCP into the environment for many years. It is likely to be difficult to identify and control use of PCP-treated wood for such uses;

- Socio-economic impacts. The majority of the socio-economic impacts of a PCP prohibition would fall on those other countries still using PCP in wood preservation. There would be limited or no costs for countries that have already prohibited use. The main cost elements associated with a prohibition on use would include:

  - Differences in costs for purchasing and processing the alternatives in manufacture of utility poles and other products (see the section on 'information on alternatives'). Alternatives with a higher initial purchase price may actually be more cost effective over the life of the product when durability and other factors are taken into account;

  - Changes in material and labour costs due to a different frequency of replacement of e.g. utility poles (wooden poles treated with less efficacious preservatives would need more frequent replacement; steel and concrete poles may need less frequent replacement, dependent on application);

  - Changes in the associated equipment needed to install, inspect, and maintain utility poles made of alternative materials (e.g., steel). The resulting effects on worker safety have not been quantified for either PCP-treated poles or for alternatives;

– Costs for wood treaters and manufacturers associated with loss of revenues and potentially costs associated with loss of residual value of their capital equipment, offsets by potential gains by other treatment. Arrangements should be made for industry to work with government to identify suitable options to gradually eliminate PCP, without causing excessive economic impacts. A region-specific cost benefit analysis of options should be developed.

Step 3: Review and Development of Control Options

The third step in the planning process is the review and development of control options, following the identification of key issues (step 1) and further engagement with key stakeholders to better understand the socio-economic and technical issues (step 2). This next step is intended to develop possible control options to manage the existing use of PCP and to aid the phase-out of PCP for safer alternatives. At this stage the development of control options should aim to encompass all possible viable options (the selection of control options / filtering of options happens in the next step, Step 4). This process could include policy options such as a restriction on the re-use of treated timber for applications other than the original use, or it could include technical control options, such as labelling for timber treated with PCP to ease identification at end of life.

As part of the development of control options it will be necessary to undertake a feasibility assessment or cost-benefit study to help identify which options are likely to provide the best benefit against cost. This can also be used to filter out those options which are less likely to prove useful. Specific control options will be dependent on the outputs of the first two steps detailed here. However some example control options (both policy based and technical) could include the following.

Possible Policy control options

- Restrictions placed upon industry to prevent the re-use of treated timber for other applications (e.g. domestic) beyond the original use;
- Waste is often dealt with regionally rather than at a country level. National authorities should, therefore, co-ordinate with regional authorities to ensure that appropriate disposal procedures are adhered to, and that PCP-containing wastes are clearly identified. Guidance and awareness documents can also be provided online, such as the materials developed by the USEPA.[1] These provide information to the public and industry about how to dispose of PCP products correctly, and who to inform in relation to their disposal;
- Policy options aimed to support innovation and development of alternatives to PCP that could be brought to market. These could include:
  – Financial incentives for development of commercially ready alternatives to PCP which are demonstrated to be safer;
  – Establishment of innovation networks to help industry support one another with management and development of PCP alternatives for specific applications. For example, European Enterprise Network for SMEs: https://een.ec.europa.eu/ or the ITF innovation network: https://network.itfenergy.com/;
  – Establishment of communication channels to provide information on innovation and case studies of how technological advances have been made. For example similar to the Subsport innovation portal: http://www.subsport.eu/;
  – The Stockholm Convention details time-limited exemptions for the continued use of PCP in utility poles and cross-arms. Working with industry groups it could be possible to set phase-out dates after which the use of PCP is prohibited.

Possible Technical control options

- The labelling, or branding (as practised in Canada US) of new PCP-treated wood would help to facilitate proper environmentally sound management of stockpiles and wastes. Branding would be preferred, as it has the potential to last longer. There should also be multiple brands, so that the mark can be identified even if the utility pole is dismantled;

[1] https://www.epa.gov/ingredients-used-pesticide-products/pentachlorophenol.

- Pressure-treated wood at the end of its service-life will still contain some PCP, although there are some indications that the amount remaining will be relatively low (USA 2014). Incineration can lead to the unintentional production of dioxins and furans. The BAT/BEP guidelines (UNEP 2007)[2] and provisions of Annex C to the Stockholm Convention provide information on the appropriate elimination or disposal technologies to be used;
- Identification of key restriction measures to limit the release of PCP from treated timber and potential exposure to both workers and the environment. For example, a restriction meaning that all timber treatment must be completed as an automated process with manual activities for movement of recently treated wood banned would minimise exposure in application of PCP to materials. Restrictions placed on timber treatment facilities to limit the 'dripping / leaching' from recently treated timber may also be relevant. This could take the form of additional drying before the timber is sent for use;
- Additional training for enforcement agencies, particularly within the waste sector to help identify and manage treated wood more easily. This could also include obligations for monitoring of waste timber to clarify PCP content before wood can be reused / recycled.

Step 4: Development of Control Plans

The previous step should provide an exhaustive list of possible viable control options to help manage and minimize the emissions from existing use of PCP; as well as promote the phase-out of PCP for safer alternatives (both chemical and non-chemical). The preceding step is intended to develop a list of all available options for control, minimization and transition to alternatives. As part of the preceding step it is also necessary to assess these options and identify which ones have the best potential benefit to achieve these goals.

The next stage in this process is to develop a plan of integrated options based on this list which should work together to help manage, control and minimize emissions and facilitate the transition of PCP for safer alternatives. These control plans should form part of the national implementation plan for POPs in order to document them publically and also to allow for other ongoing work on other POPs to be taken into consideration.

In developing these control plans it will also be necessary to set achievable targets over an appropriate timescale and to put in place mechanisms to assess how successful each option has been. In practice the development of plans should be seen as an evolution, with the possibility for further tailoring or amendment of options depending on the outcome of other work or changes occurring within given nations.

Step 5: Awareness campaigns

The preceding two steps detail the activities that could be undertaken to identify possible options for the control of PCP to manage emissions and facilitate the transition to safer alternatives. An additional important step to these options will be to ensure that the work undertaken is done so in a transparent fashion and with emphasis made to help raise awareness within all key stakeholder groups. Raising awareness of the key issues surrounding PCP and the need for control will help ensure that the control options utilised are as effective as possible and that all key stakeholders remain engaged with the process.

In particular ensuring a high level of communication with industry will be of importance to help ensure that they remain compliant and are part of the overall process to aid transition to safer alternatives.

Awareness campaigns can be conducted in a variety of ways and should be tailored to best meet the needs of the target groups receiving the information. For example, public awareness campaigns on the safe management of waste wood should be communicated in non-technical language in an easy accessible fashion (e.g. national leaflet campaign, radio campaign, website etc.). Awareness campaigns targeted at industry for the safe treatment and management of timber would use more technical language, and would likely take the form of guidance on how they need to ensure they remain compliant (e.g. industry helpline; regulatory website, training/communication from agency enforcement officers during site visits).

[2] http://chm.pops.int/Implementation/BATandBEP/BATBEPGuidelinesArticle5/tabid/187/Default.aspx.

For example the US EPA website specifically provides information for the general public on PCP, and management of treated timber in a non-technical format: https://www.epa.gov/ingredients-used-pesticide-products/pentachlorophenol

Step 6: Monitoring / Compliance / Feedback

The next step is intended to focus on the control options which have been implemented and to monitor their rate of success. As highlighted, the development of options should be seen as an evolution, with the possibility for further tailoring or amendment dependent on how existing control options work and changes at national level affect the use and emission of PCP. In order to capture this information it will be necessary to develop mechanisms to ensure compliance with existing control options (e.g. labelling and waste handling) as well as feedback on how successful these options have been.

The use of stakeholder engagement in step 2 such as industry working groups and communication with enforcement agencies could be used to provide information on compliance and feedback on how successful the options within the control plan have been.

One additional element may be the need for additional monitoring. The guidance in chapter 4 on development of emission inventories includes details on the need to reduce uncertainty in emission estimates and fill data gaps where read across or default data has been used. Additionally chapter 2 and 4 have also highlighted the possibility for 'hot spots' at former sites of manufacture and use.

The use of environmental monitoring programmes to assess ambient concentrations of PCP in the natural environment will also be important to help track progress against the objective of reducing emissions to the natural environment, as well as ensuring the correct issues are being targeted. The development of monitoring programmes is potentially expensive, and should, therefore, be developed in line with the preceding steps to ensure that monitoring is as targeted and risk-based as possible.

The outputs from monitoring, compliance work and feedback from stakeholders, can be used to help further tailor the understanding on key issues, and the work carried out in the preceding steps, in order to further develop planning.

Step 7: International Activities

The final step includes the broader international focus of work on POPs under the Stockholm Convention, and related work under the Basel and Rotterdam Conventions. The preceding steps have detailed the logical process that can be used for planning when assessing the key issues and potential options for control of existing uses of PCP and transition to safer alternatives. However, where PCP poses international issues (in part because of its ability to undergo long range transport), it is also important to give consideration to some international activities which can also be used to help control the movement of PCP and PCP treated timber.

PCP is listed under Annex III of the Rotterdam Convention, meaning that prior informed consent is required before PCP can be transported across politically boundaries as a commercial good. Chlorophenols are also listed under Annex I of the Basel Convention, meaning that waste contaminated with PCP also requires prior informed consent before crossing political borders for final destruction. Notification should also be provided to the Secretariat of the Basel Convention from national level of what wastes have been granted consent.

The Stockholm, Basel and Rotterdam Convention already enforce a number of control measures for the movement of PCP, PCP treated goods and wastes contaminated by PCP. However, additional international activities could include bilateral exchanges to help ensure that national planning is in alignment with neighbouring nations. This is particularly important where integrated markets exist for the supply and use of PCP and PCP treated timber. It may also be possible to make use of national planning and proposed monitoring programmes to share efforts and resource burdens with neighbouring nations to maximise the benefit of such monitoring programmes.

These aspects promote the need for communication and knowledge exchange between partnering nations to help establish the best possible use of resources. Equally the Stockholm Convention regional centres provide a valuable focal point for awareness raising and information exchange.

2. CHEMICAL ALTERNATIVES TO PCP

Introduction

Chemical alternatives to PCP are substances which offer the same uses as PCP, but have a reduced potential for environmental harm. The key use of PCP is for industrial wood treatment (POP RC, 2014). This section, therefore, explores alternative chemicals that may be used for this purpose. A number of accepted wood preservation chemicals exist with potential to replace PCP dependent on the specific application. The US EPA (2008) and Environment Canada (2004) have identified the following key substances that are mass produced as wood preservatives (in addition to PCP):

- Chromated copper arsenate (CCA);
- Creosote-based products;
- Ammonical Copper Zinc Arsenate (ACZA); and
- Additional preservatives including Ammonium Copper Quaternary (ACQ), Copper Naphthenate, copper azoles and azoles/permethrin.

This section provides a breakdown of each alternative with an analysis of its technical feasibility, highlighting its potential strengths, weaknesses and risks to health and the environment.

Chromated Copper Arsenate (CCA)

CCA is a product made up of active ingredients in a ratio of 5:3:2 for chromic acid, arsenic acid and cupric oxide, respectively (POP RC, 2014). The product is widely used in North America and is recognised as the main preservative wood treatment product in the USA for industrial use, with 44% market share (US EPA 2008). It is also widely used in Canada and New Zealand (Canada, 2014; POP RC, 2014). While CCA is widely used for wood treatment, it was voluntarily removed from use on wood intended for the domestic/residential (e.g. homeowner) use market in 2003 in both the USA and Canada due to public health concerns about the leaching of arsenic. It is now limited to use on wood intended for industrial applications and handled by professional users (Environment Canada, 2013; US-EPA, 2008). However, the US EPA have stated that the restrictions were just a precaution, and that CCA-treated domestic/residential structures should remain in place as they pose no significant threat to health if applied properly. Similar restrictions have been imposed in other regions, such as the EU (European Commission, 2003). In this region, Copper Chrome Arsenic (CCA) approval ceased in September 2006. Wood already on the market treated with CCA can still be sold and used for permitted uses (not inside buildings for example).

CCA is typically used in a pressure treating process for wood following a similar process to PCP and creosote, although CCA is used at lower application temperatures: 65ºC compared to 100ºC for PCP and Creosote (Becker *et al.*. 2008a). On completion of pressure treating (for all preservative types) it is necessary to include a drying cycle. It is, however, not appropriate to use kiln drying for CCA (air drying is preferred) as there is the potential to release chromium to air (Becker *et al.*. 2008a). The pressure treatment process, when correctly applied, provides high fixation rates for CCA with the metal components tightly bound to wood (Environment Canada 2004).

CCA has both strengths and weaknesses in treatment of wood compared to PCP. CCA is recognized as producing a clean, dry, odour free finish which is easy to paint. Conversely, as PCP is an oil-based wood treatment, PCP-treated wood can 'bleed' and typically has a phenolic odour (GEI 2005). This makes CCA-treated wood more applicable to public locations such as pavements or pedestrian areas. The high fixation rates for CCA also mean it is suitable for use in areas with high moisture soil content or high water table. However, CCA treatments can have an effect on moisture content of wood leaving them particularly dry. This has previously caused additional problems for climbing utility poles, now overcome with the use of softeners (Canada 2014). For hot dry climates the use of CCA can also be an issue for shrinking, cracking or warping of wood. This is particularly an issue for load-bearing structures such as cross-arms for utility poles (GEI 2005). The use of oil-based preservatives such as PCP and creosote provide an additional 'suppleness' to wood which can protect against warping and cracking in hot dry climates. CCA is also recognized as being corrosive to some metal types meaning that galvanized metal fastenings should be used in combination with CCA applications (UNECE 2010). This approach is taken as the industry standard in the USA (Becker *et al.*, 2008).

The ICC (2014) and ACAT/IPEN (2014) have both raised concerns regarding CCA's environmental and human health impacts, noting that CCA contains highly toxic and carcinogenic substances with concerns for these substances reaching the natural environment. CCA contains two carcinogens, hexavalent chromium (CrVI) and arsenic, along with copper which is highly toxic to aquatic organisms (CDC 2013, USEPA 2013, USEPA 2008d). However, post fixation, in service CCA treated wood does not contain hexavalent chromium, but rather trivalent chromium (USEPA 1998). Trivalent chromium is classified as a group 3 ("Not classifiable as to its carcinogenicity to humans") carcinogen while hexavalent chromium is group 1 ("Carcinogenic to humans") (IARC 2014*)*. Furthermore, KMG (PCPTF-KMG 2014) notes that CCA is no longer authorized for use in the European Union under the Biocidal Products Regulation.

Health Canada's Pest Management Regulatory Agency (PMRA), who carried out a joint risk assessment with the US EPA for heavy duty wood preservatives, notes that the original assessment for CCA is expected to have overestimated risk, and that wood treatment facilities following the TRD (labelling, storage, risk management plans) would greatly reduce the risk of exposure and environmental loss. The same document also states that CCA used in freshwater conditions has a low potential for leaching and that any material lost from utility poles in submerged conditions is retained in the sediment at the foot of the pole with minimal risk for exposure to aquatic species (PMRA 2011 and US EPA 2008c). Laboratory studies by Kamchanawong (2010) and Mercer (2012) assessed the leaching potential of CCA within hypothetical environments that simulate unlined landfill conditions; For the Kamchanawong this was under tropical conditions. The results of these studies highlighted potential for leaching which in real world environments may cause a concern for groundwater. However, the environmental relevance of these studies is unknown. In Canada and the USA, registrants voluntarily withdrew consumer (i.e. non-industrial) uses of wood treated with CCA as of 2004. These uses are, therefore, prohibited in Canada and the USA, as is export of wood for these purposes (US EPA 2014, US EPA 2003, PMRA 2002, and PMRA 2006).

It is difficult to treat certain wood species used for utility poles with CCA due to the inability of the treatment to penetrate blocked wood pores. In addition, CCA-treated utility poles are more difficult to climb. (UNECE 2010).

In Sri Lanka, copper chromated borate (CCB) is used as an alternative to CCA within specific applications but not on utility poles (Sri Lanka 2014).

Creosote

Creosote is produced from the distillation of coal tars and contains between 200-250 chemical species, although 85% of these are polycyclic aromatic hydrocarbons (PAHs) (Environment Canada 2013) with a large number of toxic substances contained in creosote including PAHs, phenol, and cresols. Creosote is a widely-used preservative for wood with proven efficacy, although it has negative environmental and health consequences. Efficacy studies show that creosote is effective against a broad spectrum of harmful organisms, including wood rotting fungi, against wood rot in soil and water contact, against insects, and against marine borers (Sweden 2014). Creosote is widely used in the USA with 16% of the utility pole market (Becker *et al.*., 2008) and 31% of all wood in the USA (Vlosky 2009) as well as Canada (2014) and Sri Lanka, although information from Sri Lanka suggests service life is 30 to 50 years under harsh tropical climates (Sri Lanka 2014). In the EU, creosote is extensively used across the EU Member States, and according to the European Electricity Industry Association, Eurelectric (2010), about 1 million m^3 of wood were treated with creosote each year. Creosote is of particular use in railway ties and cross-arms for utility poles (UNECE 2010) and in the EU the majority of creosoted wood is accounted for by these uses (WEI-IEO 2008).

Creosote, like PCP, is an-oil based product used within industrial pressure, immersion or vacuum treating of wood. In Canada, it is also used as a brush-on treatment for newly cut surfaces of pressure-treated creosote timbers and lumber for industrial applications and handled by professional users (PMRA, 2011). The use of oil-based preservatives provides a waterproof layer to wood surfaces and to an extent also the metal fittings during service life. The use of oil-based preparations such as creosote and PCP provides 'suppleness' to treated wood which can help prevent shrinking, warping and twisting, particularly in harsh climatic conditions (UNECE, 2010). This is of particular importance for load bearing structures such as railway cross-ties and cross-arms of utility poles (Becker *et al.*., 2008). Canada (2014) states that the Canadian railway system is around 50,000 km long with approximately 90 million ties in service. Canada also states that creosote is the only significant wood preservative currently used to treat railway ties. Production and availability of creosote is tied to steel production and any market fluctuations in the steel market. PCP has been identified as an important alternative for this use, should creosote become unavailable. This highlights the importance of PCP within the resilience of the rail infrastructure for Canada.

Concerns have been raised regarding health and environmental effects of creosote. KMG (PCPTF-KMG, 2014) highlight that the main constituents of creosote are PAHs which are already recognized as a Persistent Organic Pollutant (POP) under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). FNV (2010) highlights that the use of creosote has been in discussion for several decades because of the harmful impact on the environment and health of workers carrying out preservation. Carpenters and construction workers are also likely to be exposed during use of treated wood. Both IARC and US EPA have determined that coal tar creosote is a probable human carcinogen (ATSDR 2002) and in the USA and Canada creosote is limited to industrial applications only (Becker *et al.*, 2008). In Europe it was added to Annex I of the biocidal products directive 98/8/EC, meaning it can no longer be placed on the market without authorisation (Sweden, 2014). It is also mentioned in annex XVII of the European REACH regulation (EC 1907/2006) covering specific restrictions on use. Health Canada's Pest Management Regulatory Agency (PMRA), who carried out the risk assessment for heavy duty wood preservatives, notes that the assessment for creosote is expected to have overestimated risk, and that wood treatment facilities following the TRD (labelling, storage, risk management plans) would greatly reduce the risk of exposure and environmental loss (PMRA, 2011).

Copper Naphthenate

Copper naphthenate is an oil-borne wood preservative (UNECE, 2010), which is produced as a mixture of copper salts and naphthenic acid, a by-product of petroleum refinery processes (Feldman, 1997). While the composition of copper salts is well understood, the naphthenic acid component can be of variable composition depending on the nature of the source petroleum processed (Feldman, 1997). Copper naphthenate has been approved for both industrial and domestic use in the USA (Becker *et al.*, 2008). Unlike CCA and creosote, Copper naphthenate is not a registered pesticide and can be used in domestic applications in both the USA and EU. However, there are some concerns about its non-toxic status.

Copper naphthenate holds a smaller proportion of the wood treatment market than CCA, PCP and creosote but demand is expected to grow (Becker *et al.* 2008). The US-EPA data for 2004 quotes 900 tonnes used in the USA with further potential for growth. Copper naphthenate is approved for above ground, ground and freshwater use but is considered unsuitable for coastal/marine applications. Equally it can be used in the USA within pressure treating processes as can PCP, CCA and Creosote.

Smith *et al.* (undated) quotes quality issues experienced during the mid-1990s with specific batches of product. In these cases, the product formed an emulsion during pressure treating which led to patchy treatment of utility poles and poor protection in areas where oil coverage was also poor. This notes that copper naphthenate would be concentrated in the oil fractions. Poles treated with these batches of copper naphthenate began to experience problems within four years of installation. Wood damage from fungi and pests particularly at the mid-to-top end height of the poles was experienced in a number of cases. One case study in Wisconsin, USA in 1997 quotes 217 poles where 43% were in poor repair. No recent batching issues are known to exist.

Information from the Toxnet database (Toxnet 2011) illustrates that despite its wide use the environmental profile and toxicity of copper naphthenate is poorly characterised; due in part to the variable nature of the petroleum product. This takes into account that the petroleum product component can have the presence of multiple compounds including notably benzene (Feldman, 1997). Toxn*et al.*so highlights that, like CCA, copper naphthenate leaches from wood and that studies on mice suggest that this substance may have potential to be genotoxic. However, the naphthenate acid molecule is not expected to bioconcentrate significantly; modelled bioconcentration factors (BCFs) are 1464-1659 (U.S. EPA, 2011), which are well below the Stockholm Convention criterion of 5000. US EPA (1996) also indicate potential health effects for occupational exposure when manually applying copper naphthenate to wood in domestic and residential settings, including anaemia caused by hydrocarbon contaminants.

Ammonical Copper Zinc Arsenate (ACZA)

ACZA (also traded under the name Chemonite) is an aqueous product based on active ingredients in the ratio of 5:3:2: for cupric oxide, zinc oxide and arsenic acid, respectively. The ACZA product comes pre-mixed with active concentrations accounting for 10% of the formulation and ammonia as a transfer agent. ACZA can be used in pressure treatment where evaporation of the ammonia fixes the metals compounds to the surface of the wood and additionally ammonia also provides corrosion protection of working metal parts in the tank itself during transfer of ACZA.

ACZA is a refinement of an earlier formulation, ACA, which is no longer available in the United States. In Canada ACZA superseded ammoniacal copper arsenate (ACA) with full registration in 1999. In the USA, ACZA is more typically used in the Western States due in part to its particular ability to treat Douglas Fir, the prevalent wood type in that area (Becker *et al.*, 2008). ACZA is less widely used in the Eastern and Southern United states. Production facilities are centred in the Western United States.

ACZA, like CCA, has a high fixation rate. It can also provide better performance than CCA in protection against some species of pest (Becker *et al.* 2008). ACZA is also approved for use in coastal/marine applications with only a limited number of other approved preservatives (notably creosote). However, while CCA provides a clean, dry, odour-free finish to treated wood, ACZA treated wood tends to retain an ammonia odour which may be less suited to public locations such as pavements or pedestrian areas.

The environmental profile and concerns for ACZA are broadly similar to those for CCA with the presence of both arsenic and copper oxide. ACZA has the potential to leach from wood, including treated utility poles (Lebow 1996 and US EPA 2008c) and it also has the potential to be toxic and an irritant on direct exposure for workers (Environment Canada, 2013). Within the USA it is listed as a 'restricted use pesticide' reserved for industrial purposes (Becker *et al.*, 2008). Health Canada's Pest Management Regulatory Agency (PMRA), who carried out the risk assessment for heavy duty wood preservatives, notes that the assessment for ACZA is expected to have overestimated risk, and that wood treatment facilities following the TRD (labelling, storage, risk management plans) would greatly reduce the risk of exposure and environmental loss and that the use of ACZA is used only within closed systems.

Other Alternative preservatives for wood treatment

Alongside the chemical alternatives described above, additional chemical alternatives exist; within North America, Alkaline copper quaternary (ACQ), copper azoles and sodium borates (SBX) also form part of the mixture of wood treatment products available. These alternatives are also used within New Zealand. Additionally, (Subsport 2012) also identify silicone polymers as a viable alternative. In the European Union under the EU biocidal products regulation (EU 528/2012) there are 32 named active substances approved at EU for use in wood preservative biocidal products, including a number of those already detailed (EU biocides 2012). However, the vast majority of these 32 biocide active substances are not used for industrial wood preservation. Annex 3 provides details of these substances together with applicable legislation on use restrictions for Europe. Further detailed explanation of ACQ, copper azoles and SBX as potential alternatives to PCP is given below, as approved by the American Wood Protection Association (AWPA).

Table 1: AWPA approved uses for preservatives in wood treatment (UNECE, 2010)

Product/application	Creosote and oil borne preservatives: Creosote	Creosote-petroleum	Creosote Solution	PentaChloroPhenol	Copper Naphthenate[d]	Waterborne Preservatives: Chromated Copper Arsenate[e]	Ammonium Copper Quaternary (ACQ) – type C and type D	Ammonium Copper Quaternary ACQ – type B	Copper Azole type B	Copper Azole type A	Ammonical Copper Zinc Arsenate (ACZA)
Lumber, timbers and plywood											
C2-lumber, timber, bridge ties and mines ties	+	+[a]	+	+[a]	+[a]	+	+[a]	NA	+[a]	+a [a]	+
C9-Plywood	+	+	+	+	NA	+	+	NA	+	+	+
C22-Permanent Wood Foundations	NR	NR	NR	NR	NA	+	+	+	+	+	+
C28-Glued laminate members	+	NA	NA	+	+	+	+	NA	NA	NA	+
Piles											
C3-Piles	+	+	+	+	+[b]	+	+	NR	NR	NR	+
C18-Marine construction	+	NR	+	NR	NA	+	NR	NR	NR	NR	+
C21-Marine lumbers and timbers	+	NA	NA	+	+	+	+	NA	+	+	+
C24-Sawn timber used to support residential & commercial structures	+	NA	NA	+	NA	+	+	NA	NA	NA	+
Poles											
C4-Poles	+	NR	+	+	NA	+	NR	+	NR	NR	+
C23-Round poles and posts used in building construction	+	NR	+	+	NA	+	NR	NR	NR	NR	+
Posts											
C5-Fence posts	+	+	+	+	+	+	+	+	+	+	+
C14 – Wood for highway	+	+	+	+	+	+	+	+[f]	+[c]	+[c]	+
C15 – Wood for commercial residential construction	+	+	+	+	+	+	+	NA	+	+	+
C16 – Wood used on farms	+	+	+	+	NA	+	+	NA	+	+	+
Cross-ties and Switch ties											
C6-Cross-ties and Switch ties	+	+	+	+	NR	NR	NR	NR	NR	NR	NR

It should be noted that although these uses may be "approved" by AWPA, the actual regulatory approvals must come from PMRA in Canada and USEPA in the USA.

NA: Not available, NR: Not recommended

a. *Not for saltwater use*
b. *Land and freshwater use; not for foundations*
c. *Posts sawn four sides only*
d. *Copper Naphthenate is also approved by AWPA as a waterborne preservative for some uses.*
e. *Chromated Copper Arsenate is available for industrial applications only*
f. *Round, half-round, and quarter-round only*

ACQ is a waterborne wood preservative used in a similar fashion to CCA (Environment Canada, 2013). Since the removal of CCA from the domestic wood market in Canada and the USA in 2003, the use of ACQ has grown significantly. In 2007 ACQ (and micronized ACQ) accounted for 45% of all preservative wood treatments in the USA with CCA second placed (Vlosky 2009). However, ACQ is not currently used in the USA for utility poles and cross-arms. In Canada, while ACQ is widely used (mainly in the domestic wood market), it is not used within infrastructure applications including utility poles (Environment Canada, 2013). ACQ's widespread use has been focused within the domestic wood market and soft woods, due in part to the low occupational risk for workers and minimal risk of environmental loss (Environment Canada, 2013). ACQ is recognized as being useful for treating Douglas Fir which is typically hard to treat but is also more corrosive to metals than CCA and ACZA, particularly aluminium. The use of ACQ would require the use of stainless steel fittings in treatment facilities which can be expensive (Becker *et al.*, 2008). More recently, the advent of micronized ACQ provides a product with lower corrosivity and greater penetration, using finely ground copper oxide within the product to improve application (Vlosky, 2009). ACQ is applied by industrial vacuum-pressure impregnation at a timber treatment plant.

ACQ comes as four different products labelled types A-D that contain both copper and a quaternary ammonium compounds ("quat") as active ingredients. Of these, ACQ-A and ACQ-B contain the "quat" 'DDAC', ACQ-C contains 'ADBAC' and ACQ-D contains both 'DDAC' and 'DDACB'. All four products types are based around the ratios of copper oxide to "quat" and may contain either ammonia or ethanol amine as the carrier solution (Environment Canada, 2013). DDAC is persistent in both water and soil, while ADBAC has lower persistence issues, with a half-life of ADBAC in soil of 13 days. DDACB the active in ACQ-D is persistent and harmful to soil organisms and has guideline maximum concentrations for water at 0.0015 mg/L (Environment Canada, 2013). ACQ-A, ACQ-C and ACQ-D are all used within Canada (Environment Canada, 2013). The ammoniacal component evaporates quickly within air leaving copper oxide which is highly toxic to fish should it reach the natural environment (Dubey 2010). Copper is released from ACQ-treated wood in landfill leachates raising concerns over further contamination (Dubey 2010).

Copper azole is a waterborne product made up of copper-amine complex and co-biocides (Becker *et al.*, 2008). It is similar to ACQ, the difference being that dissolved copper preservative is augmented by an azole co-biocide rather than the quat biocide used in ACQ. Two formulations exist based on the ratio of copper to other compounds. The product is supplied as a concentrate and then diluted at point of use (Environment Canada, 2013). In the USA it is approved for above ground, ground and freshwater use but is not appropriate for use in tropical conditions or coastal/marine applications (UNECE, 2010) and is not currently used in the USA for utility poles and cross-arms. In Canada it is approved for the domestic wood market only and is not used on infrastructure applications including utility poles (Environment Canada, 2013). Like ACQ, copper azole is corrosive to metal fastenings and so stainless steel would be required, which can be expensive for treatment facility upgrades (Becker *et al.*, 2008). However, a micronized copper azole product does exist with lower levels of corrosivity and potential for deeper penetration of wood (Vlosky 2009). This particular product is still relatively new to market with an unknown long term track record for use in infrastructure applications (Becker *et al.*, 2008). Copper azole is not known to be carcinogenic (Environment Canada, 2013).

Tebuconazole (the non-metal biocide ingredient in copper azole) has a half-life of 100 days in soil and is also moderately toxic to aquatic life (Environment Canada, 2013). However, tebuconazole degrades more quickly in aquatic conditions than in soil and is largely eliminated by fish reducing the potential for bioaccumulation. The product produces irritation on direct contact with skin and long term occupational exposure can lead to lung, liver and kidney damage. Azoles such as Tebuconazole are effective against decay fungi, but not against termites or mould. Thus, they must be used with other chemicals, notably copper (Townsend, 2013). Under the EU regulation for placing biocidal products on the market (EC 528/2012); Tebuconazole has been identified as a candidate who meets Persistent, Bioaccumulative and Toxic (PBT) criteria.

The use of copper-based preservative systems as a replacement for pentachlorophenol for treatment of critical structural components like utility poles and cross-arms may not be suitable because of the presence of copper-tolerant fungi widely distributed in the environment. A variety of fungi are capable of detoxifying copper-containing compounds either by immobilization or uptake (Morrell, 1991 [Cited in the risk management evaluation for endosulfan]).

Sodium borates are a waterborne preservative with varying amounts of borate (Becker *et al.*, 2008). The product comes as a powder which is then mixed to the desired strength prior to use (Environment Canada, 2013). In Sri Lanka (Sri Lanka, 2014) sodium borates are used to treat rubber wood as a diffusion treatment, but their use as a replacement for PCP is limited. Sodium borates leave wood with a clean, dry, odour-free finish. Borates compounds are toxic for reproduction in accordance with the UN GHS criteria. However, they also readily leach from wet wood affecting performance (Becker *et al.*, 2008). Sodium borates are reserved specifically for use within indoor applications or above ground where wood is continuously protected from water (UNECE, 2010) and, therefore, sodium borates are not an alternative for current PCP uses.

Copper boron azole (CBA) has been proposed as an alternative to CCA but not specifically for use on utility poles and cross-arms (ICC-ES 2013). Monoethanolamine is usually used to complex with the copper, which increases costs (Townsend 2006). Copper is released from CBA-treated wood in landfill leachates raising concerns over further contamination (Dubey 2010). Copper is highly toxic to aquatic organisms (USEPA 2008d).

Silicone polymers also provide a possible option to treating timber products. Instead of killing fungi, this approach creates a physical barrier to fungal attack. Inorganic silicone polymers and organic acid are used in a water-based wood treatment and dried under elevated temperature (Subsport 2012). The mixture encapsulates the wood fibres, creating a physical barrier on the wood surface and making it inaccessible for rot fungus. The product is sold under the trade name OrganoWood along with a surface coating for industrial uses called OW-surface coating, by Organoclick based in Sweden (Organoclick 2014). However, PCPTF-KMG 2014 and Canada (2014) note that silicone polymers appear to be untested for wide scale industrial use, particularly for utility poles and that furthermore, silicone polymers are not registered within Canada for industrial wood use. The recommendations made by Organoclick, 2014 suggest use for above soil application. PCPTF-KMG 2014 raise a concern about the use of silicone with ground contact application as a potential issue and that given the importance of ground contact for utility poles this should be considered. While silicone polymers pose an interesting option for wood treatment their largely untested nature on the wider industrial scale means that in the short term they are not a viable replacement option for PCP without further testing.

3. NON-CHEMICAL ALTERNATIVES TO PCP

Introduction

Non-chemical alternatives are materials that offer the same functionality as products made from PCP, but have a lesser impact on the environment. The primary use of PCP is as a preservative for wood treatment. Wood has applications within domestic and industrial construction for a broad range of uses. PCP-treated wood has particular application to infrastructure usage such as utility poles for electricity supply networks and cross-ties for rail networks. It is possible for these specific applications to adopt alternative materials such as:

- Concrete;
- Steel;
- Fibreglass reinforced composite (FRC);
- Heat treated wood; and
- Hardwood alternatives which are more resistant to attack from fungi and pests in some situations.

This section will explore the technical feasibility, efficacy and costs of these non-chemical alternatives. Because non-chemical alternatives are applied and manufactured in methods that are very different to PCP, it is less straightforward to compare their environmental impacts than chemical alternatives. In order to ensure the full environmental impacts of each non-chemical alternative are captured, life-cycle analysis (LCA) must be used. LCA is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. It helps to avoid a narrow outlook on environmental concerns. The full environmental impacts of different options can then be compared. Care should be taken when interpreting life cycle data, to ensure that the context is clear (i.e. geographical), so that comparisons can be made appropriately.

The application of concrete, steel and FRC provide both generic and specific technical improvements and weaknesses compared to treated wood. Table 1 below provides a brief overview of the generic strengths and weaknesses summarized within the USA EPA review (Becker *et al.*, 2008). A detailed exploration of each of these alternatives is provided in the following section.

Table 2: Generic advantages and disadvantages of non-wood alternative materials

	Concrete	Steel	FRC
Generic technical improvements compared to treated wood			
Standardised size and specification	X	X	X
Less maintenance required	X	X	-
Impervious to attack from fungi and pests	X	X	X
Generic technical weaknesses compared to treated wood			
More expensive than wood poles (based on up-front costs)	X	X	X
Non-wood poles cannot be climbed using existing equipment such as'Gaffs', but are designed to provide their own systems such as 'fixed steps'	X	X	X
Increased risk of animal electrocution requiring additional insulation	X	X	-
Heavier than wood poles	X	-	-

Steel

Steel utility poles are manufactured as hollow structures, which allow them to be lighter than treated wood poles (by 30-50%) with similar or greater load bearing strength (Becker *et al.*, 2008; ACAT/IPEN, 2014; UNECE, 2010). This reduced weight improves freight and installation costs. The USA EPA and UNECE reviews (Becker *et al.*, 2008; UNECE, 2010) note that steel poles can be open to surface corrosion which can be difficult to assess by maintenance crews. They are also susceptible to below ground corrosion. However, both of these issues can be overcome by using galvanized steel structures (ACAT/IPEN, 2014). Zamanzadeh (2006) states that the use of galvanized steels for below-ground structures alone may not be sufficient. Care is required when assessing the placement of poles as galvanized steel below ground can be subject to attack (particularly in acid soils) leading to corrosion which can significantly reduce service life. Assessment should be made during installation and where necessary additional measures, such as corrosion resistant backfill used. Unlike concrete structures, steel poles can be recycled or used again as needed similar to current treated wood alternatives (Bolin, 2011).

The main drawback for steel structures is that they need to be handled with care during transport and installation as they can be easily damaged (Becker *et al.*, 2008 and PCPTF- KMG, 2014). The USA EPA also notes that in overloaded weight burdens steel poles will buckle rather than split or break, which means that the transmission of electricity will be halted while repairs are carried out (Becker *et al.*, 2008). Additionally, as with any metal structure there is also an increased risk of electrocution not only to animals but also work crews (WPC 2014), although the poles can be insulated to prevent this problem. Steel utility poles, therefore, also have an increased susceptibility to lightning strikes, as compared to wood. This can increase the likelihood of such an event causing disruption to the transmission network.

The use of steel as an alternative material for utility poles has been investigated by some of the utilities in the USA (such as Nevada, Arizona, and Austin Texas) (ACAT/IPEN, 2014) with integration in the power generation network done on a strategic targeted basis driven in part by geographic and climatic conditions. Life cycle analysis by the wood preservative industry (Bolin, 2011) concluded that in comparison to wood-based products, the manufacture of steel poles requires greater consumption of natural resources such as water, and most importantly is linked to higher emissions of carbon dioxide and air pollutants. Studies by SGS Global (2013) and Bolin (2011) suggest the service life of steel poles is between 60 – 80 years, while estimates of wood pole longevity are 20 – 70 years. Detailed information has not been provided on how geographic climatic considerations affect the relative longevity of steel and wood poles. The SCS Global study devised a matrix of 21 environmental parameters which demonstrated the longer service life of steel poles combined with reduced maintenance needs meant that steel poles had an overall better environmental profile than treated wood poles.

There has been limited adoption of Steel railway cross-ties in the USA (Railway Technology, 2016). As a material for railway cross-ties, steel has several advantages over treated timber. They have a lesser reliance on ballast (approximately 60% less than required for concrete; 45% less than wood), which makes them particularly favourable in areas where timber is scarce (Railway Technology, 2016). Steel is also sturdier than timber and less expensive than pre-stressed concrete, as well as being 100% recyclable. However, there are several issues which are creating barriers to the use of steel in railway cross-ties. Firstly, they are susceptible to corrosion and rail operators have reported in the past that steel ties have been removed from tracks after rail seats became quickly fatigued, especially on lines with many turns. Secondly, they lack insulation. Neoprene composite insulation is used to keep steel ties separate from electrified rails, but any error can wreak havoc on a rail network. A report in the Austin American-Statesman (2010) noted that as a result of conductivity problems and signal failures, one operator had been forced to replace long sections of steel sleepers with timber at an additional cost of $90,000.

Concrete

Concrete utility poles and cross-ties provide a standardized product with high tensile strength and durability (Becker *et al.*, 2008). This allows them to carry high weight and high speed loads. For this reason, they are preferred for modern, high speed lines. They also provide greater resistance to damage from lightning strikes, fires, vibration, fungal and insect pests and wind (Bolin, 2011). Concrete poles are less likely than treated wood products to warp or twist compared to treated wood (Becker *et al.*, 2008). New Zealand (New Zealand 2014) states that for railway cross-ties the National Rail Company in New Zealand successfully switched to concrete in 1991 which is now the preferred choice of material. The enhanced durability in ideal locations, less frequent maintenance and potential longer service life than chemically-treated wood demonstrated a high level of efficacy in meeting the structural needs of utility poles (Becker *et al.*, 2008). A manufacturer's claim states that the service life of concrete poles can potentially reach 75 years (Stresscrete 2014), while Canada (Canada 2014) states the average treated wood life span has been estimated at 70 years or higher (Mankowski 2002), Other estimates provided for the potential longevity of concrete poles are between 50 and 80 years, while estimates of wood pole longevity are 20 – 70 years. Detailed information has not been provided on how geographic climatic considerations affect the relative longevity of concrete and wood poles. The strong durability of concrete poles and standardised formulation can be a key factor in maintaining a long service life and preventing failure of poles at a premature point. This also allows the use of fewer ties per mile. The most significant issue for concrete compared to treated wood is weight, where concrete poles are quoted to be three times the weight of wood (Bolin 2011). The overall weight of concrete utility poles adds to freight and installation costs (Becker *et al.*, 2008), with wide scale adoption of concrete poles likely to have implications for industry who would need to 're-tool'.

Concrete poles have the advantage of not requiring chemical treatment with persistent and toxic chemicals that are released into the environment, thus conferring benefits to worker and environmental health. Forest ecosystem protection and conservation of trees are additional benefits of the use of concrete rather than wood poles if trees are not from commercially managed forests, but on the other hand cement and concrete come from finite resources that must be excavated and there can be other environmental impacts in production of cement, such as the use of fly ash or other harmful substances, as well as emissions of air and water pollutants (ACAT/IPEN, 2014); while wood poles from commercially managed forests represent a renewable resource. Although initial purchase costs for the concrete poles are higher as indicated in some studies (Becker *et al.* 2008), these cost differentials may be offset to some extent by added disposal costs, and there could be longer-term cost savings over the life of the poles. Life cycle analysis studies by the wood preservative industry (Bolin, 2011; Bolin & Smith, 2013; Aqua-e-Ter, 2012) conclude that in comparison to wood based products, manufacture of concrete posts have a greater demand for natural resources such as water, and importantly are linked to much higher carbon dioxide and air quality pollutant emissions (the study assumed that treated wood and concrete poles have similar service lifespan). Concrete poles are also hygroscopic meaning that they are more susceptible to freeze/thaw damage in harsh climates. The USA EPA report also quotes data from EPRI (EPRI, 1997) which suggests that concrete posts cannot be used in coastal/marine applications as sea-salt attacks the concrete. However, a major manufacturer of concrete poles, StressCrete indicates effective use of concrete in both fresh water and saltwater environments when specially formulated for this particular environment. Because of their corrosion resistance, durability, and lack of chemical treatment, they are used in proximity to sensitive water bodies and can be used in freshwater and saltwater environments. One additional drawback for concrete structures relates to end of life: while treated wood poles can be re-installed at different locations during a working life, concrete posts can only be installed once, although the material can be recycled and does not have to be consigned to a hazardous waste landfill.

Fibreglass reinforced composite

FRC-based alternatives are relatively new to market and so have a limited history of use (WPC, 2014). However, like steel and concrete, FRC provides a standardized material with known specifications (Becker *et al.*, 2008). FRC poles, like steel, are lighter than treated wood meaning a reduction in freight and installation costs. However, FRC-based products can distort when screwing down hardware (WPC, 2014) and therefore the mounting hardware may loosen over time making FRC generally not appropriate for load-bearing components such as poles and cross-arms. FRC poles are engineered for a specific configuration of cross-trees and other attachments. Post installation modification of this is not possible in most situations. FRC poles may also be more susceptible to UV radiation, which in hot dry climates can lead to delamination of FRC layers and weakening of the overall structure (USEPA, 2008). FRC-based poles are also only available in lengths under 55 feet which may prohibit some applications depending on terrain (WPC, 2014). Wood Preservative Industry reports (Aqua-e-Ter, 2012; Bolin & Smith, 2013) also provide lifecycle analysis which suggests the energy demand requirements to produce FRC poles are greater than treated wood alternatives and that FRC poles will have a greater carbon footprint than treated wood. However, this is likely to be offset by lower toxicity (including a reduced potential for eutrophication) and lower disposal costs (ACAT/IPEN 2014).

Recently, composite railroad ties manufactured from recycled plastic resins and rubber have entered the market in some regions (Polywood, 2010). Manufacturers claim a service life longer than wooden ties with an expected lifetime in the range of 30–80 years. The ties are also impervious to rot and insects (Grant, 2005) and they can be modified with a special relief on the bottom to provide additional lateral stability when surrounded by ballast. Their resistance to water means they have been applied in niche applications such as underground railway lines in mines (Cromberge, 2005). They also offer benefits on bridges and viaducts, because they lead to a good distribution of forces and reduction of vibrations into respective bridge girders or the ballast. Composite plastic ties are fully recyclable.

Heat treated wood

This approach uses thermal treatment of wood near or above 200°C in low oxygen conditions to make it resistant to decay while maintaining dimensional stability. Principal uses are restricted to above ground non-structural uses such as siding, decking, flooring, garden furniture, playground furniture, window and door frames, and indoor furniture. Therefore, heat treated wood is not a viable alternative to current uses of PCP (i.e. in ground, ground contact, water contact and structural). The treatment process varies according to the wood species and no chemicals are required. Six major processes are available including Thermo Wood (Finland), Plato Wood (Netherlands), Retification (France), Bois perdure (France) Westwood (USA, Canada, and Russia), and Oil heat treatment (Germany) (ECRD, 2001). A comparison of production costs among the various methods indicates a range from 65 – 160 €/m^3 (Wang Undated).

Hardwood alternatives

Alongside the non-wood alternatives to PCP-treated wood it is also possible to make use of alternative wood types with greater resistance to attack by fungi and pests. Hardwood varieties can have a viable service life of up to 25 years in US without the need for chemical treatment (Becker *et al.*, 2008). The main issue for greater use of hardwood varieties will be the availability of viable stock which will vary globally. Decay-resistant woods such as cedar, and hardwoods may be used without chemical treatment (UNECE 2010). These woods have greater mechanical strength than chemically-treated softwoods, although initial purchase cost is more expensive than chemically treated woods. Switching to hardwood varieties that have greater resistance to attack by pests would likely have adverse effects, both economically with additional cost of wood but also on forestry and local ecosystems with the need to meet demand for wood (Becker *et al.*, 2008). The use of hardwood varieties will have varying efficacy based on climatic conditions, application and availability of suitable stock. This is offset by the enhanced benefits of reduced chemical use and emission to environment compared to PCP treated wood.

4. SUMMARY

Overall, there are several viable chemical alternatives to PCP for wood preservation and non-chemical alternatives to wood for utility poles and railway ties.

Creosote was the first substance used for wood preservation and has well proven efficacy. Similar to PCP, it is oil-based, which provides suppleness to treated wood. However, it has many negative health and environmental consequences. CCA produces a clean, dry, odour free finish, but can also dry out wood and like creosote and there are environmental concerns surrounding the use of CCA in some applications due to its arsenic content. Both CCA and creosote are registered pesticides in the USA and EU. Unlike, CCA and creosote, copper naphthenate is an oil-based wood preservative that is approved for use in domestic applications. However, there are some environmental concerns around the substance and it is not approved for coastal or marine use. ACZA is an aqueous based preservative that has similar environmental to CCA because it contains arsenic. However, it is approved for use in coastal and marine applications. Other aqueous preservatives include ACQ and copper azoles, which have grown in popularity among manufacturers due to their lower potential for leaching and associated environmental damage. However, they are corrosive to metals. Waterborne preservatives are used primarily to treat softwoods, because they may not fully protect hardwoods from soft-rot attack. Most hardwood species are difficult to treat with waterborne preservatives. Recently, manufacturers have been applying micronized ACQ and copper azole treatments. These minimise environmental damage further by increasing the penetration of the preservative and reducing the quantity of preservative used. Sodium borates are another aqueous preservative with a low environmental profile. However, they are not suitable for water contact or ground contact applications as SBX readily leaches. Silicone polymers provide a low environmental impact method of chemical preservation, by forming a protective barrier on wood. However, their application in an industrial context remains untested.

Manufacturers are turning to alternative copper wood preservatives that don't contain arsenic, such as Copper naphthenate, ACZA and ACQ.

A summary of the potential alternatives to PCP is provided within Table 3.

Table 3: Summary of potential alternatives to PCP

CHEMICAL ALTERNATIVES

Alternative	Description	Pros	Cons
Chromated copper arsenate (CCA)	5:3:2 for chromic acid, arsenic acid and cupric oxide. Similar pressure treating process as PCP and creosote, but lower application temperatures (65ºC compared to 100ºC).	High fixation rates for CCA with the metal components - suitable for use in areas with high moisture soil content; Clean, dry, odour free finish which is easy to paint; Does not 'bleed' - more applicable to public locations; Can help prevent shrinking, warping and twisting, particularly in harsh climatic conditions.	Concerns regarding environmental and human health impacts – contains highly toxic and carcinogenic substances; Potential for leaching may cause a concern for groundwater; Corrosive to some metal types meaning that galvanized metal fastenings must be used; Difficult to treat certain wood species due to the inability of the treatment to penetrate blocked wood pores.

CHEMICAL ALTERNATIVES

Alternative	Description	Pros	Cons
Creosote-based products	Produced from the distillation of coal tars; An-oil based product used within industrial pressure, immersion or vacuum treating of wood.	Proven efficacy against a broad spectrum of harmful organisms; Can help prevent shrinking, warping and twisting, particularly in harsh climatic conditions.	Environmental and health concerns - large number of toxic substances contained in creosote including PAHs, phenol, cresols and various POPs.
Copper Naphthenate	Oil-borne wood preservative, produced as a mixture of copper salts and naphthenic acid, a by-product of petroleum refinery processes.	Not a registered pesticide and can be used in domestic applications; Relatively low bioconcentration factor.	Reported cases of the product forming an emulsion, leading to patchy treatment and poor protection of utility poles; Impact on human health and the environment is poorly characterised; Health risks due to occupational exposure.
Ammoniacal Copper Zinc Arsenate (ACZA)	Aqueous product - ratio of 5:3:2 cupric oxide, zinc oxide and arsenic acid; ACZA can be used in pressure treatment where evaporation of the ammonia fixes the metals compounds to the surface of the wood.	High fixation rate; Provides corrosion protection of working metal parts; Approved for use in coastal/ marine applications.	Environmental and health concerns – presence of arsenic and copper oxide; Retain an ammonia odour - may be less suited to public locations; Has the potential to leach from wood, including treated utility poles.
Ammonium Copper Quaternary (ACQ)	Waterborne wood preservative used in a similar fashion to CCA; Widespread use has been focused within the domestic wood market and soft woods	Recognized as being useful for treating Douglas Fir which is typically hard to treat; Advent of micronized ACQ provides a product with lower corrosivity and greater penetration.	Corrosive to metals, particularly aluminium - requires the use of stainless steel fittings which can be expensive; Environmental and human health impacts.
Copper azoles	Waterborne product made up of copper-amine complex and co-biocides, similar to ACQ	Micronized copper azole product does exist with lower levels of corrosivity and potential for deeper penetration of wood.	Corrosive to metal fastenings and so stainless steel would be required; Unknown long term track record for use in infrastructure applications, human health, occupational and environmental risks; May not be suitable because of the presence of copper-tolerant fungi widely distributed in the environment.

CHEMICAL ALTERNATIVES

Alternative	Description	Pros	Cons
Sodium borates / Copper boron azole (CBA)	Waterborne preservative with varying amounts of borate.	Leave wood with a clean, dry, odour-free finish.	Toxic for reproduction; Leach from wet wood affecting performance; Only suitable for indoor applications or above ground where wood is continuously protected from water; Copper released from CBA-treated wood in landfill leachates - concerns over further contamination.
Silicone polymers	Used in a water-based wood treatment and dried under elevated temperature; The mixture encapsulates the wood fibres, creating a physical barrier on the wood surface and making it inaccessible for rot fungus.		Untested for wide scale industrial use, particularly for utility poles.

NON-CHEMICAL ALTERNATIVES

Alternative	Description	Pros	Cons
Concrete	Use of concrete is widely applied for both utility poles and cross ties. They are particularly preferred for modern, high speed lines.	High tensile strength and durability - allows them to carry high weight and high speed loads; Greater resistance to damage from lightning strikes, fires, vibration, fungal and insect pests and wind; Less likely than treated wood products to warp or twist; Less frequent maintenance and potential longer service life than chemically-treated wood; Don't require chemical treatment – avoids health and environmental consequences; Avoids deforestation; Material can be recycled and does not have to be consigned to a hazardous waste landfill.	Higher initial purchase costs The higher overall weight of concrete utility poles adds to freight and installation costs; Wide scale adoption of concrete poles likely to have implications for industry who would need to 're-tool'; Manufacture requires greater consumption of natural resources e.g. water, and higher CO_2 emissions; Concrete posts can only be installed once.

NON-CHEMICAL ALTERNATIVES

Alternative	Description	Pros	Cons
Steel	Use of steel as an alternative material for utility poles has been investigated by some of the utilities in the USA; limited adoption of Steel railway cross-ties.	Manufactured as hollow structures - lighter than treated wood poles (by 30-50%) with similar or greater load bearing strength - improves freight and installation costs; Longer potential service life; Recyclable; More preferable option in areas where timber is scarce.	Can be open to surface and below-ground corrosion which can be difficult to assess by maintenance crews; Need to be handled with care during transport and installation as they can be easily damaged; Increased risk of electrocution – workers and wildlife, and lightning strikes; Manufacture requires greater consumption of natural resources e.g. water, and higher CO_2 emissions.
FRC	Relatively new to market and so have a limited history of use; Recently, composite railroad ties manufactured from recycled plastic resins and rubber have entered the market in some regions.	Impervious to rot and insects; Lighter than treated wood meaning a reduction in freight and installation costs; Longer service life than treated wood; Lower toxicity and disposal costs; Composite plastic ties are fully recyclable; Resistance to water means they have been applied in niche applications such as underground railway lines in mines; Provide benefits on bridges and viaducts.	Can distort when screwing down hardware , so mounting hardware may loosen over time - makes FRC unsuitable for load-bearing components such as poles and cross-arms; Post installation modification of this is not possible in most situations; May be more susceptible to UV radiation, which in hot dry climates can lead to delamination of FRC layers and weakening of the overall structure; Energy demand requirements to produce FRC poles are greater than treated wood alternatives and that FRC poles will have a greater carbon footprint than treated wood.
Heat treated wood	Uses thermal treatment of wood near or above 200ºC in low oxygen conditions to make it resistant to decay while maintaining dimensional stability.	No chemicals are required.	Principal uses are restricted to above ground non-structural applications - not a viable alternative to current uses of PCP.
Hardwood alternatives	Alternative wood types with greater resistance to attack by fungi and pests.	Decay-resistant woods such as cedar, and hardwoods may be used without chemical treatment; Harwood has greater mechanical strength than chemically treated wood.	Availability of viable stock will vary geographically; Effectiveness will also vary depending on climate.

www.pops.int

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Designed and Printed at United Nations, Geneva – 2313817 **(E)** – October 2023 – 1 – **UNEP/BRS/2023/8/iPub**