

# Determination of Acceptable Levels of Preservative Treated Timber in Timber Reuse Applications

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## List of Abbreviations

ACQ	alkaline copper quaternary
APVMA	Australian Pesticides and Veterinary Medicines Authority
CCA	copper chromium arsenic
DDAC	didecyldimethylammonium chloride
EPA	environmental protection agency
FAC	Florida administrative code
GCTL	ground water cleanup target level
LOAEL	lowest observed adverse effect levels
LOSP	light organic solvent based preservative
MDF	medium density fibreboard
NOAEL	non observed adverse effect levels
OSB	oriented strand board
PAH	polycyclic aromatic hydrocarbon
PEC	predicted environmental concentration
PNEC	predicted no effect concentration
Ppm	parts per million or mg/kg
SCTL	soil cleanup target level
TBTO	tributyltin oxide

## 1 Introduction

Globally wood is the most abundant biodegradable and renewable material yet there are numerous reasons to utilize it more efficiently. Given the range of economic and social concerns about greenhouse gas emissions and forest threats due to the adverse effect of climate change, considerable incentive and opportunity exists to use wood residues and post customer wood products.

The large volume of wood waste being placed in landfill sites in Australia represents a significant opportunity. Landfill sites are becoming more selective in the content and makeup of material that they will accept. The annual disposal of timber/wood products to landfill in Melbourne alone represents enough timber to fill the Melbourne Cricket Ground 1.5 times (Taylor et al., 2005). Post customer wood provides a high volume resource for recycled products.

Generally landfills receive a range of forms of wood waste. Waste wood may be in its natural state or only mechanically worked, bonded to other materials, painted, coated, lacquered and mixed with preservative treated timber. Recycling the full range of post consumer wood products is not fully developed either in Australia or internationally. Clean wood residues are preferred for wood recycling applications such as landscaping and composting products, animal bedding, particleboards and thermal energy. The industry standards, including AS 5605-2007 *Guide to the safe use of preservative treated timber*, recommend against the use of preservative treated timber for some recycling and energy recovery applications. This recommendation is often given simply for precautionary reasons, in the absence of sufficiently detailed studies on the fate and tolerable levels of preservative in the various recycling outlets. The surest option for the timber industry often is to recommend only that all treated wood waste be sent to the appropriate landfill.

A zero treated timber policy may be seen as overly cautionary for some recycling applications. In Australia wood waste is managed by energy generators, recyclers or disposal unit operators who collect and segregate wastes. The wood resources are then sold to wood waste processors. It is likely that some preservative treated timber may be included with untreated timber, thus entering industrial recycling and energy applications.

At present, no clear guidelines or limits are given for the levels of treated wood or their preservative components that could be tolerated in the wood waste recycling streams. Even natural tree foliage and stemwood contains copper, zinc and boron (1.8 to 89.3 ppm in one study by Hagen-Thorn and Stjernquist, 2005), and these are common ingredients in wood preservatives. If growing in soils with high arsenic content such as gold mining sites, the stemwood and needles of Douglas fir can contain more than 250 ppm arsenic (Haug et al., 2004).

This project aims to provide a review of guidelines and make recommendations of appropriate allowable levels of preservatives in products from wood waste, referenced against major end use classes and dominant timber treatments. In addition, the project highlights the discrepancies between mandated exposure limits for the chemical

constituents and the recycling industry guidelines and the risks associated with the recommended concentration limits of the commercially used preservatives in wood recycling applications.

## 2 Preservative treated timber in Australia

### 2.1 Industry outline

The preservative treated timber industry in Australia is characterized by three major preservative chemical manufacturers, Arch Wood Protection (Aust) Pty Ltd, Osmose Australia Pty Ltd and TimTech Chemicals Pty Ltd as well as over 140 local treatment sites which produce approximately 80% of Australia’s preservative treated solid timber. The balance is imported, predominantly from New Zealand (Carruthers, 2003).

Preservative treatments are mainly applied to solid wood products such as round and sawn hardwood and softwood. Engineered wood products are treated to a much lesser extent (Figure 1).

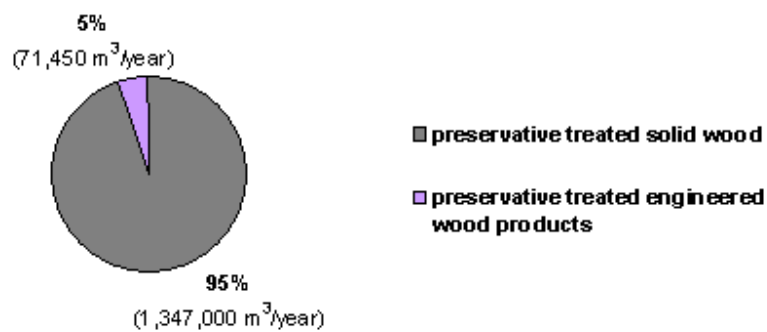


Figure 1: Total volume of preservative treated wood products sold in Australia (A3P and TDA, 2007)

From the total volume of consumed preservative treated solid wood products, more than 80% of treatments are applied to softwood (Figure 2).

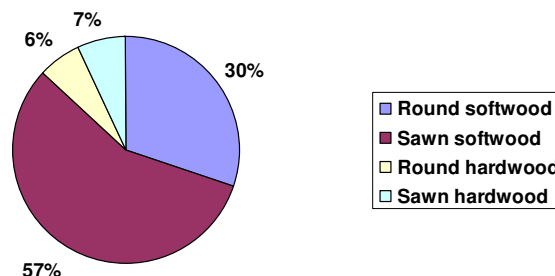


Figure 2: Market share of treated solid wood as type of products (A3P and TDA, 2007)

In the manufacture of engineered wood products, preservative treatment is primarily applied to plywood and particleboards, some LVL and glu-lam timbers are also preservative treated (Figure 3). Plywood and particleboard are treated mainly for roadside noise barriers, train carriage applications and flooring. It is estimated that approximately 20,000m<sup>3</sup> of oriented strand board (OSB) products used annually in structural applications (frame bracing or I-beams) are imported with glue line preservative treatment.

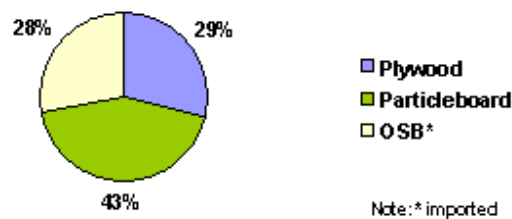


Figure 3: Market share of treated engineered wood products as type of products (A3P and TDA, 2007)

The major end use markets of preservative treated timber in Australia are:

- agriculture (vineyard posts, fencing)
- landscaping (landscaping sleepers, retaining walls and fencing)
- building (structural and non-structural applications)
- civil applications (utility poles, heavy engineering and marine structures)

The actual size of the end use markets is not clearly defined but a recent survey (A3P and TDA, 2007) has determined that the industry estimates an annual total volume of about 1.5 million cubic meters of treated timber (Table 1) is produced.

The evolution of the preservative treated wood products market is likely to be constantly affected by trends in construction practices, regulatory measures, increased occupational health and safety concerns, economic value of the protection offered by preservative treatments, their expected service life, disposal and recycling concerns. It is predicted that the proportion of preservative treated timber is growing as structural products are increasingly being treated and the softwood share of the construction market is growing compared to hardwoods (A3P and TDA, 2007).

The service life of treated timber products depends on a variety of factors. These include: natural durability of the heartwood, adequacy of preservative treatment, decay hazard and type of environment throughout the service life of the product, end use application, subsequent machining, design detailing, inspection and maintenance. The service life of treated timber products is comprehensively described in *Timber Service Life Design Guide* (MacKenzie et al., 2007). Table 2 summarizes the typical service life for onset decay of a range of uncoated preservative treated wood products.

Table 1: Estimated annual volume of treated timber by wood product in 2007 (A3P and TDA, 2007)

<b>Product</b>	<b>Total volume (m<sup>3</sup>)</b>	<b>Hazard level</b>
<b>ROUNDWOOD</b>	<b>555,000</b>	
Vineyard post (CCA)	240,000	H4
Vineyard post (creosote)	30,000	H4
Landscape and fencing round (CCA)	200,000	H4
Landscape and fencing round (creosote)	15,000	H4
Pole and pile (CCA & creosote)	70,000	H5 & H6
<b>SAWNWOOD</b>	<b>844,000</b>	
Fencing and landscaping	235,000	
Fence post and general landscape	140,000	H4
Paling and picket	80,000	H3
Sleeper	15,000	H4
<b>Structural</b>	<b>550,000</b>	
H1	30,000	H1
H2	70,000	H2
H2F (framing)	250,000	H2
H3	160,000	H3
H4	30,000	H4
H5	10,000	H5
<b>Other</b>	<b>59,000</b>	
Decking	50,000	H3
Handrails	3,000	H3
Cladding	6,000	H3
<b>ENGINEERED WOOD PRODUCTS</b>	<b>60,000</b>	
Particle board flooring*	30,000	H2
Plywood*	10,000	H2
LVL and I-beams*	20,000	H2
Oriented strand board*	NA	
<b>TOTAL VOLUME</b>	<b>1,454,000</b>	

Note: \* glue line treatment

Table 2: Typical service life of preservative treated timber for onset of decay (MacKenzie et al., 2007)

Type of preservative treated wood product		Treatment	Typical service life for onset decay <sup>1</sup> (years)				
			Zone A	Zone B	Zone C	Zone D <sup>2</sup>	
<b><i>In ground decay</i></b> <sup>3</sup>							
<b>Round wood</b> (min 200mm)		Softwood	H4, H5	>100	>60	>40	>35
		Hardwood		>70	>30	>20	>20
<b>Sawn wood</b>	Square (min 100x100mm)	Softwood (full penetration)	H4, H5	>100	>50	>35	>30
		Softwood (80% penetration)		>50	>15	>9	>8
	Rectangular (min 200x75mm)	Softwood (full penetration)		>100	>45	>30	>30
		Softwood (80% penetration)		>80	>35	>20	>20
<b><i>Above ground decay</i></b>							
<b>Fencing</b>	Sapwood	H3	>70	>50	>40	>35	
<b>Decking</b>	Sapwood	H3	>60	>50	>40	>35	
<b>Pergolas</b>	Sapwood	H3	>50	>40	>30	>30	
<b><i>Marine borers</i></b> <sup>4</sup>							
			<b>Zone A-C</b>	<b>Zone D-F</b>	<b>Zone G</b> <sup>5</sup>		
<b>Round piles</b> (300-400mm)		Hardwood	H6	20 up to 100	6 to 60-70, rarely up to 100	5 to mostly 50-70	
		Softwood		20 up to 100	6 to 60-70, rarely up to 100	5 to 30, rarely up to 70	

Note:

<sup>1</sup> The threshold estimations are given for the minimum cross-section and diameter specified throughout the table and the lowest hazard level treatment.

<sup>2</sup> Decay hazard zones in Australia. Zone D is the greatest decay hazard zone – refer to *Timber Service Life Design Guide* (MacKenzie et al., 2007).

<sup>3</sup> In the case of maintenance procedures application, the service life could be extended with up to 10 years.

<sup>4</sup> The service life estimations vary widely with the applied preservative treatment (CCA, creosote, double treatment), construction type (stand-alone pile or pile in contact with other element), maintenance measure, salinity class and marine borer resistance of wood species. Specific figures are given in *Timber Service Life Design Guide* (MacKenzie et al., 2007).

<sup>5</sup> Marine borer hazard zone. Zone G is the most hazardous – refer to *Timber Service Life Design Guide* (MacKenzie et al., 2007).

Wood preservatives are registered by the Australian Pesticides and Veterinary Medicines Authority (APVMA). In addition, state legislation exists in Queensland and New South

Wales (Timber Utilisation and Marketing Act 1987<sup>1</sup> and Timber Marketing Act Regulation 1977, respectively). The state regulations are aimed at consumer protection. Further, each Australian state government has its own Environmental Authority which can issue licensing requirements for larger facilities. Smaller facilities may be regulated by local councils. Related Australian Standards for treatment of timber include:

- AS 5605-2007: provides guidelines and recommendations on the safe use of preservative-treated timber and potential health and environmental risks associated with handling and disposing.
- AS 1604: a series of standards that set preservative and wood treatment specifications - sawn and round timber (Part 1), reconstituted panel products (Part 2), plywood (Part 3), laminated veneer lumber (Part 4) and glue-laminated lumber (Part 5).
- AS/NZS 2843-2006: specifies the requirements for location, design layout (Part 1) and operation (Part 2) of timber preservation plants.

## **2.2 Major commercial preservative types for treating timber**

The Australian standard defines a wood preservative as a chemical or a mixture of chemicals in a form suitable for application to timber in order to preserve it from attack by timber destroying agents.

A broad range of timber preservatives have been developed to extend the service life of timber products for various residential and commercial applications. The current types of preservative treatments specified in Australia and their recommended use are presented in Table 3.

At the beginning of this decade, around 70-80% of timber treated in Australia was treated with copper chromium arsenic (CCA) and about 5% with copper based alternatives. The rest of the production was characterized by the use of creosote, light organic solvent preservatives and boron type preservatives (Hata et al., 2006). Subsequent precautionary restrictions applied to application uses of CCA treated timber (such as playground equipment and decking) has decreased the amount of CCA treated wood produced in Australia.

The preservative liquids used to treat wood need to be toxic at least to certain organisms, and some are carcinogenic, which is why treatment normally occurs in specialized and regulated treatment plants (see AS 2843). However, it is important to note that after impregnation into wood, and a period of chemical fixation or immobilization, that treated wood sold to the marketplace is safe to use as recommended. This has been borne out for example by recent studies for CCA (Kwon et al., 2004; Cookson, 2008; Lew et al., 2010) and creosote (Wong and Harris, 2005).

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<sup>1</sup> Under the Timber Utilization and Marketing Act 1987, the sale of lyctid susceptible timber is prohibited in Queensland as well as registration of wood preservatives and timber treatment plants. Similar requirements apply under the Timber Marketing Act of New South Wales.

Table 3: Types of timber preservatives used in Australia (as per AS 5605-2007 and AS 1604-2005)

Types of timber preservatives	Timber preservatives	Timber product treated	Purpose of preservation	End use applications	Specific service exposures	Notes
<b>Waterborne</b>	Copper chromium arsenic (CCA)	Sawn and round timber. Plywood (mainly copper based preservatives), treated in final form. Veneer treatments, if glue bond is not affected.	Decay, borer, termite and marine borers	Prohibited in 2006 for garden furniture, picnic tables, exterior seating, children playground, domestic decking and handrails	Inside and outside, above and in-ground, contact with or in fresh water, marine water	Fluorine was used to treat veneers for plywood production, but has not/rarely been used for this purpose for over 30 years. Fluorine is a component in some remedial wood preservative rods and pills.
	Alkaline copper quaternary (ACQ)					
	Copper azoles					
	Boron type					
	Fluorine type					
	Bifenthrin (suspension)					
<b>Oil borne</b>	Creosote	Sawn and round timber	Decay, termite and marine borers	Power and telephone poles, pilings, sleepers and ground line maintenance of these applications	Outside, above and in-ground, contact with or in fresh water, marine water	Oil borne PCP has not used for the last 20-30 years
	Pigment-emulsified creosote Pentachlorophenol (PCP)					

<b>Light organic solvent borne</b>	<p>Fungicides:</p> <ul style="list-style-type: none"> <li>- Tributyltin oxide</li> <li>- PCP</li> <li>- Copper naphthenate</li> <li>- Zinc naphthenate</li> <li>- Tributyltin naphthenate</li> <li>- Propiconazole and tebuconazole</li> </ul>	Sawn and round timber	Decay, termite attack and other insects	Internal and external use (structural timber and engineered timber products used in common building applications)	Not suitable for ground contact applications or where consistent wetting will occur	TBTO and PCP have not been used as LOSP for about 20 years. Zinc naphthenate used in small quantities, mainly as brush on preservative. TBTN now almost fully replaced by azoles.
	<p>Insecticides</p> <ul style="list-style-type: none"> <li>- Organochlorines</li> <li>- Cypermethrin</li> <li>- Deltamethrin</li> <li>- Permethrin</li> <li>- Bifenthrin</li> <li>- Tanalith T</li> </ul>					Organochlorines (dieldrin, aldrin) were formulated with TBTO/PCP, so have not been used for about 20 years and are no longer permitted for use in Australia. Cypermethrin and deltamethrin rarely/not used, no product registered with APVMA.
<b>Glue line insecticides</b>	<ul style="list-style-type: none"> <li>- Bifenthrin</li> <li>- Permethrin</li> <li>- Imidacloprid</li> </ul>	Engineered wood-based products (plywood, particleboard, laminated veneer lumber)	Borers and termites	Furniture, interior joinery, beams and flooring,	Inside, above ground	

**CCA** consists of three active constituents, copper, chromium and arsenic of which the concentration or retention in wood can vary depending upon the hazard class application (AS 1604.1-1604.5/2000). The arsenic in CCA products primarily protects timber against insects and copper tolerant fungi, while copper acts as a fungicide and chromium fixes these two chemicals in the timber. Copper, chromium and arsenic are present in the natural environment (in air, food, water and soil) at low levels. The level of arsenic in soils is typically between 0.1 and 40 mg/kg, although some sulphide rich soils can be many times this level (8000 mg/kg), typically the average level of arsenic in soil is 5-6 mg/kg (Tiller, 1992). Copper is typically present at levels between 1-10 mg/kg of extractable copper, with levels below 1 mg/kg considered deficient (Tiller, 1992). Total chromium levels in soils are typically high, but the available chromium level is low, for example a soil can have 145-4540 mg/kg of total chromium and of this value less than 0.1 mg/L is able to be extracted (Tiller, 1992).

Some tree species take up arsenic from soil, Douglas fir growing in soils with elevated arsenic in gold mining regions was found to contain 374 ppm arsenic in new growth stems and 257 ppm in the needles (Haug et al., 2004). Some ferns are also able to take up high levels of arsenic into their biomass (Ma et al., 2001).

During combustion, the active elements can transform into different states and have the potential to impact upon both human health and the environment when released from the timber (Solo-Gabriele et al., 2004; Khan et al., 2006; EPA South Australia, 2008).

- Arsenic:
  - The toxicity of arsenic depends upon speciation, oxidation state and whether it is in an organic or inorganic form.
  - Inorganic trivalent arsenic species are generally considered more toxic than inorganic pentavalent arsenic species.
  - Arsenic is recognized as a carcinogen, mutagen and potential teratogen.
- Chromium:
  - Hexavalent chromium is classified as a Group 1 carcinogen to humans.
  - Trivalent chromium is classified as a Group 3 carcinogen.
- Copper:
  - The toxicity of copper is restricted mainly to aquatic environments where it poses risk to aquatic life.

In 2006, the Australian Pesticides and Veterinary Medicines Authority restricted use of CCA treated timber in outdoor areas where there was frequent and intimate human contact (decking, playgrounds, garden furniture and handrails). Additional requirements included clear labeling of CCA treated timber to improve consumer awareness and the introduction of greater controls on the availability and use of CCA by timber treatment facilities (APVMA, 2005; 2006).

**Copper organics (ACQ and copper azole)** are copper based preservatives that are free from arsenic and chromium. ACQ contains two active ingredients: copper oxide, which is the primary fungicide and insecticide, and a quaternary ammonium compound, which provides additional fungicide and insect resistance properties. Copper azole is a mixture

of a copper compound and tebuconazole. The use of copper azole and ACQ may increase as alternatives to CCA. New 'micronised copper' versions of these preservatives can be expected to be sold commercially in the next few years (Cookson et al., 2010). Micronised copper is more resistant to leaching than solubilized copper.

At the end of their service life such treated materials are not considered hazardous and therefore not subjected to the restrictions that apply to CCA treated wood in some jurisdictions. However, the issue of dioxin formation during combustion (Tame et al., 2007) needs further evaluation.

**Borate preservatives** are low toxic (mammalian) alternatives for protecting timber and composites from wood destroying organisms such as decay fungi and termites. Wood preservation using boron was invented in Australia (Cummins, 1939) and has been used for more than 70 years to protect the sapwood of susceptible hardwoods against lyctid (powder post borers). Borates are naturally occurring minerals that exist in trace amounts in rock, soil, water and all living things. Consequently, they have marginal environmental impact and are also essential for plants and nutritionally important for people. Borates are formulated for use as a water-based wood preservative that deliver the highest concentration of boron (maximum water solubility and rate of dissolution) at a near neutral pH. They are not defined as hazardous waste. Borate wood preservatives do not fix in the wood and in Australia are not specified for weather exposed applications.

**Creosote** is a coal tar distillate widely used as a wood preservative for commercial purposes, primarily utility poles and railroad sleepers. Creosote treated timber is also often used by equine industry as unlike some CCA treated wood, horses find creosote treated wood distasteful. Creosote consists of more than 200 chemicals of which as much as 85% are polycyclic aromatic hydrocarbons (PAH's). Some PAH's are easily emitted and are defined by the US EPA as priority air pollutants. Most PAH's remains in the wood (or are rarely emitted) but health concerns remain. The non-emitted benzo(a)pyrene is the most carcinogenic compound. Concerns exist about burning creosote treated wood under uncontrolled conditions, which could cause highly toxic 4- to 6-ring PAH's to be released into the environment (Schaefer, 2000).

In the European Union creosote, pentachlorophenol and CCA have been restricted by the Marketing and Use Directive 76/769/EEC (2000) because of their hazardous properties. Currently, consultations are being carried out to determine if creosote will be further restricted (Europa, 2008).

**Light Organic Solvent based Preservatives (LOSP's)** is the generic term used to describe preservatives formulated in solvents such as white spirit which contain fungicides and insecticides. LOSP's were introduced in the late 1960s and their use has increased recently. While some formulations originally contained PCP, TBTO, and dieldrin these were mostly excluded in the 1980s. Current formulations contain copper or zinc naphthenates, tributyltin naphthenates (TBT usage almost ceased), tebuconazole/propiconazole and permethrin.

The LOSP used in Australia today contains relatively environmentally benign biocides, such as permethrin for insect control which has low mammalian toxicity. The synthetic pyrethroids have varying levels of permanence in the environment but all of them degrade due to environmental effects with time.

### General

Identifying treated wood can be problematic and more so on weathered wood. The waste timber product, and its unpainted colour, can help distinguish some treatments at a glance. With experience, wood treated with creosote or a copper based preservative can be distinguished from untreated wood by colour. The presence of copper based preservatives can be established by a color reagent, as can boron and tin. H2F house framing treated for termite control is readily distinguished by the addition of a blue dye (blue pine framing). The determination of arsenic or chromium is less easy, and organics are not readily identified by a spot test. However they can be readily detected by portable X-ray fluorescence analyzers or laboratory chemical analysis. If the preservative treatment is known then the application the timber was used for can give an indication of the amount of preservative one could reasonably expect to be in the treated wood. This information is summarized in Table 4.

Table 4: Estimated minimum amount of preservative in treated wood by hazard class (mg/kg wood or ppm)

Chemical		Hazard Class					
		H1	H2	H3	H4	H5	H6
CCA*	Cu	87.5	800	950	1580	2500	5000
	Cr	157.5	1440	1710	2840	4500	9000
	As	129.5	1180	1410	2330	3700	7400
ACQ	Cu	1139	2350	2350	5960	9450	-
	DDAC	748	1540	1540	3920	6200	-
Cu azole	Cu	-	-	2210	4020	7330	-
	Azole	-	-	100	170	320	-
Boron	B	470	3500	-	-	-	-
TBTN	Sn	-	-	800	-	-	-
Cu N	Cu	-	-	1000	-	-	-
Permethrin		60	200	200	-	-	-
Cypermethrin		60	300	300	-	-	-
Deltamethrin		6	20	20	-	-	-
Bifenthrin		12	47	50	-	-	-
Creosote		-	-	80000	200000	245000	400000

\*Numbers are derived using the maximum ratio of elements allowed in manufacturing the preservative and provide a guide to concentration only.

### **Areas penetrated in treated wood**

It is important to note that not all wood in 'treated timber' will be treated. The heartwood of most timber species cannot be treated, or treats to a very limited extent. Therefore, treated hardwood power poles will generally have a thin treated outer sapwood band that is 10-35 mm thick and untreated heartwood representing most of the wood in the treated pole. In theory, waste treated poles could be desapped to leave untreated wood (unless the groundline had preservative diffusible rods installed). Similarly for treated hardwood sleepers, the treatment often occurs along just one corner or edge of sapwood on the sleeper, a few mm in depth from the heartwood surfaces. The problem of untreatable heartwood has been a research topic in both hardwoods and softwoods. For H2F 'blue pine framing', the treatments with pyrethroids penetrate only 2 or 5 mm because the preservative is not forced into wood using vacuum or pressure. H2F treatments are surface spray or dip treatments. Therefore, if the treated wood was homogenized so that treated and untreated zones were mixed, (such as when shredded) then the preservative concentrations found in the new material would be much less than suggested in Table 4.

It should also be noted that if treated timber is removed because it has failed or decayed, then it is likely that much of the preservative that was originally present has already degraded (due to UV or microbial activity) or it has leached or volatilized out.

### 3 End of life disposal of preservative treated timber

In accordance with the service life applications, post consumer treated wood products are normally generated from construction and demolition activities (housing renovation and replacement, industrial buildings and office strip out) as well as agricultural and landscape remediation (Table 5).

Table 5: Wood waste product and probable preservative chemical present if treated (Adapted from Humar et al., 2006)

Wood waste product	Probable preservative chemical present if treated
Railways sleepers	Creosote
Poles	CCA PEC/Creosote
Landscaping	CCA ACQ Creosote
Bridge and harbor piles	CCA Creosote
Vineyard posts	CCA Creosote
Paling fences	CCA
Decking	CCA ACQ Copper azole
Windows	PCP, TBT, dieldrin (mainly in Victoria), azoles, permethrin
Wood from demolition and buildings	All current and past approved wood preservatives except creosote Coatings, varnishes and impurities
Wood from new building sites	All currently approved wood preservatives except creosote
Solid wood for packaging/pallets	Rarely CCA
Furniture	Boron Coatings, varnishes, glues
Composite products, internal	Synthetic pyrethroids, imidacloprid, benzalconium chloride (Ruply, low volume), azoles and boron based preservatives

Composite products, external	Synthetic pyrethroids, benzalconium chloride (low volume), azoles, CCA, ACQ
Industry residues (offcuts, chips, shavings, dust)	Not applied but any currently approved wood preservative may be present depending on product

Demolition and site remediation represent a large generator of timber waste but the actual amount varies according to the type of construction involved.

The timber demolition waste usually contains all types of wood preservatives except creosote, as well as coatings, varnishes and impurities. In the USA, approximately 6% of construction and demolition landfill wood debris was found to consist of CCA treated wood (Smith et al., 2006). In Australia, an audit at landfills in Sydney found only 4% of mixed construction and demolition waste timber to be treated with CCA (Department of Environment and Climate Change NSW, 2007). A recent study of wood packaging across three states found only 1% of wood packaging was treated with CCA (Mitchell, 2008) and most of this was identified as used to transport consumer goods from New Zealand.

Forsythe Consultants (2007) identified three practices among the Australian demolishers dealing with residual timber:

- Timber is demolished with an excavator and without any attention to site separation. Most waste will subsequently go to landfill.
- Materials are site separated, usually by hand demolition, and the bulk will end up as recovered materials.
- A combination of the first method plus opportunistic salvage of materials – usually the salvage of internal timbers or pitched roofing timbers but rarely both. Much timber waste however, is still sent to landfill.

Depending on the recovery options available, timber demolition waste is usually directed to landfill and transfer stations or recyclers of low/high value timber. In most instances, the transfer stations have no reuse or recycling ability and the demolition waste going to these stations are ultimately passed on to landfill (as mixed waste). Most low value timber goes directly to landfill but in some cases, recyclers use it more productively either for energy production or as mulch reclaimed from mixed waste (used for horticultural purposes, particleboard production or also passed on for energy production). High value timber (including various hardwoods, Douglas fir and uncommonly available softwoods such as Baltic and Hoop pine) is purchased from demolishers by recyclers.

Landfill disposal of treated wood can cause problems due to emissions of wood preservatives in the percolate. These emissions can increase significantly in the presence of fungal or bacterial infestation (Humar et al., 2006), soil pH, levels of phosphorus and other soil factors. Townsend et al. (2005) found that there was minimal leaching of copper from copper containing preservatives, so that preservatives such as ACQ and copper azole would pose minimal impact to groundwater from copper leaching in Florida. They found that there was significant leaching of arsenic and chromium from CCA treated wood. However, other studies have found much higher levels of copper leaching from these preservatives compared to CCA (e.g. Dubey et al., 2007). To date no problems

with emissions has been recorded for landfills in Australia.

Vineyards are a major user of treated timber (mainly CCA, some creosote) and usually replacement of damaged posts leads to disposal in landfill. There are a number of available recycling options and facilities engineered for acceptance of CCA and creosote treated timber in most states, however the locations are limited in South Australia. It is estimated that 30% of waste posts from vineyards are reused by local farmers or the community for fence posts and landscaping timbers (Hata et al., 2006). The South Australian EPA has referred to a recent study which estimated that 60% of broken posts in South Australia are potentially reusable (EPA South Australia, 2008). Recently, an Ocloc<sup>TM</sup> clamp was commercialized for splicing broken vineyard posts.

Waste wood resource and its utilization are a key issue in Australia, and is identified as a priority by some governmental representative bodies; NSW Department of Environment and Conservation identified 16 waste streams of concern, including treated timber (Department of Environment and Climate Change NSW, 2007); in South Australia disposal become a major issue due to the state's target of zero waste to landfill and the projected need in 20-30 years to dispose of some 160,000 m<sup>3</sup> annually of mainly CCA treated *P. radiata* vineyard posts (Sinclair Knight Merz Pty Ltd, 1999); the Victorian Government listed the timber and furniture manufacturing sectors as one of five priority industry sectors for reduction of waste to landfill (EcoRecycle Victoria, 2005). A number of the active ingredients in wood preservatives are listed in the National Pollution Inventory (2010), although due to fixation reactions in wood, natural weathering, UV exposure and microbial activity, these actives may become different compounds in wood waste.

Similarly to Europe, a major potential means of managing preservative treated wood and treated wood waste is combustion, either for disposal or generation of energy. Many facilities in Australia have approval to combust offcuts and other residue from wood treated with preservatives other than CCA. In Europe, thermal processing of end of life treated wood as a small component of waste is widely used as a disposal method. The main concern for thermal conversion of CCA treated wood is the volatilization of arsenic, being supplemented by the operational problems with the plant itself (such as slagging, fouling of heat exchanger surfaces and corrosion). Successful combustion of CCA requires the control of arsenic emissions to comply with the set emission levels and the need to manage the metals and metalloids collected in the ash (TRADA Technology and Enviro Consulting Ltd, 2005).

The risks associated with thermal processing of CCA treated wood are also recognized in Australia. APVMA warns that thermal processing should occur in controlled facilities where release of arsenic to the atmosphere is minimized, and the potentially toxic ash is processed and disposed of appropriately. However, when mixed wood waste containing 5% or 10% CCA treated wood is burnt, the ash is often suitable for disposal in landfill (Borgnes and Rikheim, 2007). The amount disposed can be determined by the Toxicity Characteristics Leaching Procedure (TCLP). University of Sydney researchers cited a number of management options for recovery of CCA elements after thermal processing

from either the ash or through the use of pollution control equipment commonly used in copper smelters added to the flue (Rogers et al., 2007). The pollution control equipment was developed for copper smelters to deal with dusts containing arsenic. In the context of regulatory action available to the APVMA, it recommended that suitable label instructions be provided to prevent wood waste or other waste containing CCA products at CCA treatment facilities from being disposed of by thermal processing unless in approved facilities (APVMA, 2005).

The standard outlining the safe use of preservative treated timber, AS5605-2007, provides disposal guidelines for treated timber that discourage burning in open fires, chipping and mulching. The standard advocates general disposal for low volumes of timber, and special approval for large volumes. The disposal of 100% treated wood through recycling is an active research area. There are a number of potentially current and emerging technologies for recycling, and these are discussed in Appendix A.

#### 4 Recycling industries for post consumer waste timber in Australia

##### 4.1 Industries outline

Post consumer wood waste recycling activities were limited worldwide prior to 1990 when emerging markets started to develop and the number of recovered wood processing facilities increased.

The post consumer wood recycling industry is still in its infancy in Australia, being characterized by few established sectors (Figure 4).

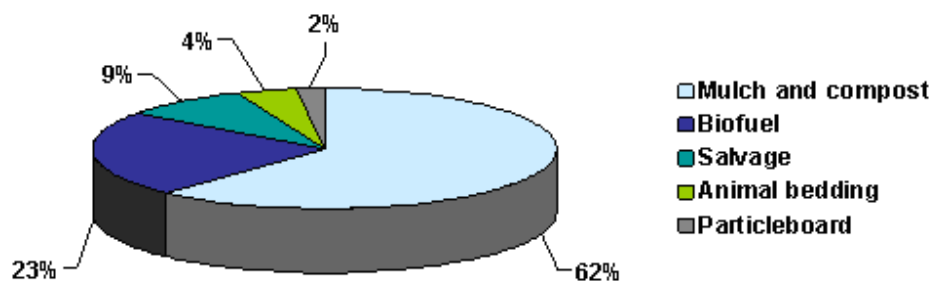


Figure 4: High value added products derived from post consumer wood waste (A3P and TDA NSW, 2007)

Compared with Europe, where the main markets for recovered wood are the particleboard industry (Italy, Germany, Belgium and the UK) and energy (Germany and Sweden) (van Benthem, 2007; The Age, 2006; The Peter Heath Consultancy, 2005), the majority of Australian wood waste presently gains value in landscaping products (mulch and compost) and thermal energy.

### ***Mulch and compost sector***

Wood and timber wastes derived from domestic, agricultural, commercial and industrial, construction and demolition sources, in solid form, including off cuts, crates, pallets and packaging, sawdust and timber shavings, are regarded as potential recycled raw materials for manufacturing and recycling organic products.

The most mature products manufactured by the organic feedstock processors<sup>2</sup> and purchased by recycled organic products market are:

- Composts, mulches and soil conditioners
- Potting mixes
- Soils for landscaping and garden use
- Playground surfacing

In Australia, landscaping products are generally used in a large recycled organic market segment but in comparison with other world regions the recycled organic industry is markedly less developed. The industry is not delivering sustainable market driven outcomes on the scale needed to support growth in organics recovery (Recycled Organics Unit, 2002a).

Organic feedstock, processed or chipped wood waste is predominantly recycled into landscaping mulch and composting bulk agent in most Australian states. In 2005/2006, 140 compost facilities were operating across Australia (Recycled Organics Unit, 2006). The number and location of other landscaping products facilities, including manufacturing of potting mixes, playground surfaces and soil conditioners, vary significantly from state to state.

### ***Particleboard sector***

Engineered wood products are an extremely efficient way to use lower grade wood resources (Taylor et al. 2005). Across the European Union, recovered wood is gaining more importance in the particleboard industry as a growing competition is developed with the biomass energy industry which heavily relies on a woody biomass feedstock.

In Australia, there are six key competitors in the fabricated wood manufacturing industry but currently only two facilities recycle wood waste into particleboards: Laminex in Western Australia and D&R Henderson in Victoria. The industry is facing various barriers which actually limit the increased use of the wood waste for particleboard products. The barriers are:

- The high cost to clean up the wood waste materials. In Australia, the industry is predominantly built around using clean materials, free from large amounts of

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<sup>2</sup> The processors for composting are classified in the following classes: mushroom substrate production; agricultural composting; compost facility licensed to Council; compost facility licensed to private operator (Department of Environment and Conservation NSW 2004).

contaminant. The equipment required is expensive and therefore suitable volumes of these lower grade materials needs to be made available to achieve a suitable return.

- The high cost of transporting enough quantity of these lower value resources in one area to make the recycling economically viable. Australia is a vast country and the large distances (the majority of panel plants are between 3 and 5 hours from major cities) makes it difficult to gather enough wood waste resource in one area to make the recycling exercise economically viable.
- When used on waste panel products, typical wet and dry milling processes tend to produce large amounts of dust. Dust represents a significant challenge as it requires more resin to hold material together hence increasing cost and chemical levels. In Europe there are installations that have been built to handle coarsely shredded panel material in an acid bath type arrangement. Slightly acidic bath liquids decompose the resin bonds by returning the material particle size to that of pre-panel manufacture. This material can then be dried, screened and reformed into a panel product. Drawbacks of the approach are: (1) it is expensive to undertake and (2) the pollutants that are derived from the process can be very expensive to manage (Wells, 2007). Depending on the input material some of the left over materials can be dangerous to handle. This process would again be limited in Australia due to the required volumes to create the necessary paybacks for capital requirements.

The Australian particleboard industry is conservative about the immediate increased use of secondary wood products. Incorporation of composite panels, used furniture and pallets in their production systems introduces greater processing complexity, and a product risk which is not offset by cheaper raw materials as the virgin resource is still low cost. Greater adoption is possible when the process economics can be made more favourable (Wells, 2007).

Chemically treated wood may be acceptable for the production of particleboards but there is an argument worldwide that there is little point or no market in using treated wood, especially CCA, in this process as most particleboards are used in low hazard areas. In addition, various studies have demonstrated that the adhesives used require adjusting to be compatible with preservative treated wood or they can suffer from a loss of internal bond strength, modulus of elasticity and modulus of rupture (Taylor et al., 2005, TRADA Technology & Enviro Consulting Ltd, 2005). Current specifications (WPIF/UKFPA/1-2000) standard set in Europe by the European Panels Federation and the Wood Panel Industries Federation) have threshold values which limit the amount of copper, chromium, arsenic and other chemicals which end up in the manufactured particleboard panels.

### ***Bioenergy sector***

The potential environmental benefits which can be derived from the use of various forms of bioenergy generated from untreated and treated wood residues are underdeveloped in Australia. Technologies such as direct combustion for heat and power and co-firing wood with existing coal power plants have been used to some extent but with a limited degree

of efficiency, typically using untreated wood residues (Wells, 2007). Energy production is currently employed by timber mills which use their untreated wood residues, and in some cases boron treated residues to produce heat and steam for drying or to operate fiberboard presses. Examples where treated wood wastes are used in Australia include:

- a. Direct combustion for heat and power:
  - Wood waste fired power stations:
    - smaller scale energy production facilities (<30MW) are widely available in the majority of sawmill sites
    - NSW Sugar Mills with Delta Energy (Condong, Broadwater and Harwood mills)
    - Rocky Point Sugar Mill (30 MW using sugar cane fibre, green and wood waste)
  - Co-generation:
    - Visy plant (NSW), Big Rivers Timber (NSW) - small projects
    - Visy (Tumut) have used wood waste in the past and are currently using harvesting and sawmill residues
    - Western Australia Biomass Pty Ltd is proposing to construct a 40 MW biomass power station in Western Australia using harvesting residues
- b. Co-firing wood:
  - Adelaide Brighton Cement (co-fired with gas)
  - Delta Electricity and Macquarie Generation (NSW) have used wood waste in the recent past to co-fire their coal fired power stations

In Australia, wood and wood waste is used much more in generating thermal energy than in generating electricity.

The bioenergy market is expected to grow in the near future as targets are set at a national level through the Mandatory Renewable Energy Target. The market is also expected to increase with awareness about the greenhouse benefits that flow from using biomass energy instead of fossil fuel energy. However, competing technologies, alternative energy sources and a lack of support from government and the community may slow the process.

The presence of treated wood is a barrier to increasing the use of post consumer waste timber streams for bioenergy (Bioenergy Australia Newsletter, 2007). Debate and projects aimed at investigating opportunities for producing bioenergy from woody biomass, as well as proposals for wood based bioenergy plants have started to intensify (Cummine, 2007).

In the European Union, preservative treated wood is accepted for combustion. The treated wood waste is used for the manufacture of activated carbon, industrial charcoal and for synthetic gas. It is also used as fuel in licensed combustion and gasification plants. Waste wood cannot be combusted in plants approved for biofuel production only (mainly forest residues (Humar et al., 2006). The most important issue regarding combustion of treated wood is the potential for arsenic emissions which can be resolved with appropriate filter systems. There are several techniques available to minimize the negative influences of combustion (Table 6). However, energy recovery from treated wood waste is strongly regulated by German legislation (The Fourth Ordinance on the Implementation of the

Federal Emission Control Act, Thirteenth Ordinance Implementing the Federal Emission Protection Law, and the Seventeenth Ordinance Implementing the Federal Emission Control Act) (Humar et al., 2006).

Table 6: Measures to minimize the combustion problems with waste wood (Humar et al., 2006)

General measure	Specific measure	Effect
Improving the fuel quality	Improved source sorting	Reducing the amount of metals and chlorine
	Sieving of the fuel	Separation of the fine fractions and thereby reducing the amount of metals
Combustion modifications	Avoid reducing conditions at the heat exchanger surfaces	Minimizing slagging, fouling and corrosion
Additives or co-combustion	Adding sulfur to the fuel	Sulfating of troublesome metal chlorides
	Injection of sulfur-containing substances in the furnace	Sulfating of troublesome metal chlorides
	Addition of additives or fuels containing silica	Absorption of troublesome metal chlorides

Construction and demolition waste was found to be cheaper to process for fuel production than to dispose of in land fill, further it was reported that combustion of properly processed construction and demolition material could produce an emission profile similar to that of virgin (untreated) wood, coal or oil (Northeast States for Coordinated Air Use Management, 2006).

### ***Salvaged wood products sector***

Salvaged or reused wood products are the highest value products obtained from wood waste. Reuse of treated wood waste can be a sound way of dealing with industrial products. Reusing treated wood and timber components has a number of barriers that need to be overcome. Timber from construction and demolition is often contaminated with paints, varnish and preservatives. This timber needs to be sorted and processed to restore the products to a working condition. This processing and handling is an additional cost that needs to be considered for the recycling to be economical (EcoRecycle Victoria, 1995 and 1999; TRADA Technology and Enviro Consulting Ltd, 2005).

Other issues can include difficulties in identifying the preservatives, control of dust generated by mechanical processing and public attitudes concerning reuse of second hand products. Further, an increased liability exists when using recycled timber as the internal condition of the wood is often unknown.

A protocol has been developed to guide generators and recyclers of redundant utility poles and bridge timbers, including those that are treated with preservatives or have other chemical residues (TDA 2008).

#### ***Other potential opportunities for the use of post consumer waste timber***

In addition to the current uses, there remains enormous opportunity for new or yet unexplored recycled wood products and niche markets: wood-plastic and wood-cement composite products, charcoal, industrial oil absorbents, insulation, specialty concrete, wooden base materials derived from biorefinery process with potential use in the pharmaceutical, textile and food industries.

Several studies (Forsythe Consultants, 2007; National Timber Stewardship Group, 2007; Daian, 2008; EPA South Australia, 2008) reveal that recyclers and implicitly the wood recovery rate, are affected by the impact of treated timber. In order to improve recycling opportunities a clear grading standard for recovered wood is required. This standard should categorize the recovered wood and the general requirements for its recycling management.

#### **4.2 Current quality requirements for the use of post consumer timber into value added products**

From a commercial industry related perspective, each of the potential markets for recovered wood has different raw material requirements and quality standards in terms of particle size, tolerance levels for contaminants, consistency of supply and environmental impacts (McConnon, 2005). The process of recycling the recovered wood needs to thus incorporate the following practices into its system: segregation, categorization, size reduction processing and quality assurance. Source segregation presents a large practical issue and will require significant education of waste producers.

Literature surveys indicate that there is a lack of grading standards for recovered wood, both nationally and globally. Notably, in 2003 Germany passed specific legislation - Ordinance on the Management of Waste Wood (German Act/Ordinance, 2002) - which categorizes the waste wood and states the general requirements for its recycling management.

The following sections describe the current requirements and quality standards for wood waste material developed and used in Australia. They are presented from the particular wood waste recycling industries and markets perspective.

##### **4.2.1 Mulch and compost sector**

Wood is one of the primary components of the compostable organic products stream. The quality of the raw material used in composting operations depends on the required performance specifications of the compost products manufactured (soil conditioners,

composts, mulches and potting mixes).

Wood residues used as a raw materials source for composted products must conform to the following key requirements (Recycled Organics Unit, 2002b and 2003):

- Any type of clean wood waste can be processed if no more than 5% (by volume) of the load contains chemical or organic contaminants.
- The initial moisture content of the wood waste is not critical.
- The particle sizes of the raw materials in a composting mix range between 3-50 mm in diameter depending on the composting product requirements.
- Composting of composite wood products is possible but not in isolation. The use of composite wood products involves a series of extra precautions in the manufacturing process (Recycled Organics Unit, 2000).
- The size, shape and quantity of the feedstock depend upon the technology types and sizes a composting facility uses for size reduction of residual wood and timber (Recycled Organics Unit, 2000).
- Australian Standard AS 4454 (2003) states that all pasteurized and composted products shall fully comply with the chemical, organic and pathogen containment provisions of the current federal or state government guidelines, whichever is the most restrictive. These guidelines include local EPA guidelines, enHealth guidelines (enHealth, 2001) and ARMCANZ (1995) guidelines, although this has been superseded in some states by local guidelines (Meehan et al., 2001) as in Victoria, NSW, WA and SA..

All products for use and disposal on soils of products derived from organic wastes, compostable organic materials and biosoloids.

#### **4.2.2 Bioenergy sector**

Bioenergy generated from wood residues is presently characterized by pilot trials and ongoing development and it is not possible to be specific in terms of the material requirements for this broad sector. However, the types of raw materials processed for bioenergy are defined by the Renewable Energy (Electricity) Regulations 2001 (Commonwealth of Australian Law, 2007):

- wood waste from the eradication of non-native woody weeds;
- a manufactured wood product or byproduct from a manufacturing process;
- waste products from the construction of buildings or furniture, including timber and timber off cuts from demolished buildings;
- sawmill residue;
- waste from harvesting native forests and plantations.

The quality related guidelines of these bioenergy feedstocks has yet to be defined and should focus around the following issues (National Association of Forest Industries, 2005):

- The moisture content, density, the amount of volatile material, size of the particles and the level of impurities in the wood waste affect how the material may be utilized, the type of renewable energy conversion technology employed and the net energy recovery from these resources.
- Usually, wood waste with moisture content less than 6% is required prior to combustion in co-firing, but up to 25% in dedicated biomass boilers.
- For low caloric value wood waste, the biofuel systems and the supply chain will need to be appropriately designed for continuous and bulk flow of wood waste.
- The shape of the wood waste feedstock may vary with the energy conversion technology to be used. The wood waste may have to be pre-treated, chipped or dried to a specific moisture content or pre-mixed with other renewable energy resources.

### **4.2.3 Animal products sector**

The main wood waste materials recycled for manufacturing animal products are clean sawdust and shavings which are further processed and graded into various types of sawdust products. Due to the increasing lack of local clean sawdust suppliers, Australian sawdust processors seek timber offcuts as an alternative resource. Timber off cuts are chipped and then processed into sawdust (Pollards Sawdust, 2007).

Although there are no standard specifications for recovered sawdust, the industry in Australia has developed its own requirements (Pollards Sawdust, 2007):

- The sawdust/shavings have to be free of any contaminants including MDF particles, glue and treated softwood products.
- Ideally moisture content of the raw material is 10-12%, although moisture contents up to 20% may be accepted for specific purposes.
- The sawdust colour is usually regarded as a quality factor, depending on the final use of the sawdust product. Light coloured animal bedding products are preferable.

The Eastern Metropolitan Regional Council (EMRC), which recycles a range of end of life wood in Western Australia, is working towards market specifications for industrial woodchip to be used as animal bedding (EMRC 2010).

### **4.2.4 Engineered wood products sector**

In the engineered wood products industry, primary and secondary wood residues are directed to particleboard production rather than MDF. When using recycled wood materials, the MDF process requires a higher degree of contaminant removal control as

any impurity can affect the binding process (Taylor et al., 2005).

To comply with the needs of the Australian engineered wood products manufacturers, the quality of the waste wood supplied for use in the particleboard process has to have the following criteria (Taylor et al., 2005; Wells, 2007):

- The types of raw materials recycled into particleboard production are: clean pallets, crates, off cuts, sawdust (particles greater than 1 mm), shavings and particleboard offcuts (not MDF<sup>3</sup>). Solid or chemical contaminants require segregation and cleaning or decontamination.
- The amount of wood waste used for particleboard production is limited. Higher quantities can degrade the mechanical properties of the final product.
- Typical moisture content of waste wood materials used for manufacturing particleboard products is 15%.

#### **4.2.5 Salvaged wood products sector**

The industry guidelines related to the quality requirements of timber demolition waste for reuse applications has been found to focus around the following issues (Forsythe Consultants, 2007):

- The key types of timber demolition waste required by the salvage wood specialists in Australia are:
  - high value waste timbers such as various structural hardwoods and certain softwoods that have a high retained market value (Baltic and Hoop Pine);
  - tongue and groove floor boards;
  - timber from warehouse demolitions, commercial buildings, timber bridges and other large demolition projects.
- Consistency of timber supply is an essential requirement in order to be able to retain the economies of scale.
- The demolisher is usually required to bend nails over, remove large metal brackets and also to strap the lengths of timber into slings that can be craned or man handled onto trucks.

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<sup>3</sup>Secondary processing of MDF induces large amounts of dust requiring more resins to hold the material together.

## **5 Review of levels of wood preservatives components in wood waste derived products**

The most common disposal option for treated timber is landfill where it is included within the general wood waste stream, and so may become incorporated into recycled products. This inclusion is often inadvertent due to the difficulty in identifying wood that has been treated, particularly if LOSP treated. CCA, ACQ, copper azole, creosote and H2F treated timbers are often relatively easy to identify so may be separated easily. These treatments can be more difficult to identify in old timbers after weathering. Treated timber that has been stained, painted or had other chemicals applied to its surface will also be more difficult to identify. These surface finishes may introduce their own range of chemicals or properties that make recycling difficult.

Most common recycling methods of the wood waste from landfills are land applications (mulch and compost) and wood fuel. For recycling applications such as salvage wood, animal bedding, mulch, wood fuel and particleboard products, the trade of wood waste in Australia is currently made between the wood waste generators and recyclers.

Potential risks to wood recyclers could be minimized if there was improved knowledge behind setting limits for maximum allowable concentrations of chemical compounds in the various wood waste products or emission levels for energy generators.

### **5.1 Wood waste derived products for land applications**

The end use of wood derived mulch and compost is broad and includes applications such as:

- Horticultural substrate (growing media) component
- Urban/suburban landscaping, gardening as well as sport, recreation and leisure
- Forestry farming/reforestation
- Land reclamation/bioremediation
- Landfill cover and rehabilitation

Limited research has been carried out on the effect of incidental inclusion of treated wood in recycled products for land applications. There are few studies which document the implications of the presence of wood preservatives in wood waste materials used for mulch, compost and soil amendments.

Unlike most soils in Europe and North America, Australian soils are generally old and highly weathered, and often lack fertility and micronutrients (McLaughlin et al., 2000). Copper deficiency is common among sandy, coastal soils, peaty soils and soils developed on copper poor parental rocks (Pietrzak and McPhail, 2004). Some soils are also deficient in boron, and radiata pine plantations can often suffer from this deficiency (Hopmans and Flinn, 1984).

### *Copper, chromium and arsenic*

Copper, chromium and arsenic are present in the natural environment at low levels. The level of arsenic in soils is typically between 0.1 and 40 mg/kg, although some sulphide rich soils can be many times this level (8000 mg/kg). Typically the average level of arsenic in soil is 5-6 mg/kg. Copper is typically present at levels between 1-10 mg/kg of extractable copper, with levels below 1 mg/kg considered deficient. Total chromium levels in soils are typically high, but the available chromium level is low, for example a soil can have 145-4540 mg/kg of chromium and of this value less than 0.1 mg/L is able to be extracted. Environmental guideline values for “contaminated” soils vary globally due to the large variation in the background value of a “typical” soil. Conservative guideline values set in 1992 for copper, chromium and arsenic were 60 mg/kg, 50 mg/kg and 20 mg/kg respectively (Tiller, 1992). These values are lower than the current Australian guidelines for health investigation levels (NEPM 1999) which are 1000 mg/kg for copper, 100 mg/kg for chromium and 100 mg/kg for arsenic. Soils with elements present below these limits are considered safe.

Copper and arsenic concentrations in agricultural soil are often high due to the widespread use of copper based fungicides (Bordeaux solution) and the historic use of lead arsenate pesticides for crops. Mining activities also produce elevated metal levels (such as chromium and arsenic) in the surrounding soils (Noble et al., 2010). A study of soils from 98 vineyards across Australia for metal contamination found that 96% had elevated copper at 24 to 159 or even 249 ppm, (Wightwick et al., 2008; 2010). Vineyards applied copper based fungicides at an annual rate of up to 35 kg per hectare. Organic standards limit the application rate to 8 kg/ha. Copper levels of more than 80-100 ppm can reduce earthworm and microbial activity in the soil. However, the environmental availability of copper varies greatly according to factors such as soil organic and mineral content (to which copper binds), pH and clay content. Wightwick et al. (2008) found that in relation to wood preservation was that chromium levels were similar to background levels in the vineyards they sampled. Given most vineyards utilize CCA treated *P. radiata* posts, these results indirectly suggest that chromium leaching from treated posts was not significant in the soil areas sampled (300 mm from the vine line).

Agricultural soils in New Zealand have also demonstrated have elevated levels of arsenic and lead (from lead arsenate insecticides), and copper (from copper fungicides). Arsenic in the soils studied by Gaw et al. (2008) ranged from 2.1 to 35.6 ppm with copper 73 to 366 ppm. Gaw et al. (2008) examined the uptake of these compounds by lettuce (representing a leafy crop) and radish (representing a root crop). Copper residues in plants increased with increasing soil copper concentrations, while arsenic levels in plants did not exceed available food standards.

In a study of floodplain sediment soils in the Riverina (Lech and de Caritat, 2007), total concentrations of arsenic (0.8–159.8 mg/kg) and chromium (29–200 mg/kg) were locally elevated above national and international guidelines. According to Lech and de Caritat (2007), four of the 284 samples exceeded the 20 mg/kg limit for arsenic defined by (1) the German maximum tolerable limit for agricultural soil, (2) the Western Australian

Ecological Investigation Level, and (3) the maximum allowable soil contaminant concentration for application of biosolids to an agricultural land. The higher soil concentrations of arsenic appeared to be associated with goldmining. Preliminary results from partial digestion experiments suggest that arsenic was mostly locked up in/on iron oxyhydroxides and more refractory phases, and was thus of low risk to human and animal health (Lech and de Caritat, 2007). The average value of chromium for world soils is 70 mg/kg, similar to the median concentration in the Riverina (69.5 mg/kg) (Lech and de Caritat, 2007). Over 75% of the overbank sediment samples collected contained more than 50 mg/kg chromium, which is the WA limit, and 14 samples were above 100 mg/kg, which is the NSW limit. Although high chromium levels may have human health implications, even the maximum total value in the Riverina is unlikely to be of concern. Chromium (III), which is likely to be the dominant oxidation state, is relatively non toxic and is normally tightly bound in soil (McLaughlin et al., 2000).

Biosolids are increasingly being reused on agricultural land in Australia and New Zealand (McLaughlin et al., 2000). Sydney Water in NSW produces approximately 200,000 wet tonnes per year of biosolids, 99% of which is put to beneficial reuse (Barry et al., 1998). In Queensland, approximately 250,000 wet tonnes are produced annually (Barry et al., 1998). There are no regulations/guidelines in Australia and New Zealand specifically limiting metal additions to land in wastes/manures/composts other than biosolids (McLaughlin et al., 2000). The Australian Standard for composts, AS 4454-2003, suggests that contaminant levels should meet relevant biosolid guidelines. The maximum permitted concentration in Grade A biosolids added to soils for arsenic is 20 ppm in most states, 100-400 ppm for chromium (100 ppm NSW and Tasmania, 200 ppm Qld, 400 ppm Victoria) and 100-200 ppm for copper (100 ppm NSW and Tasmania, 140 ppm Qld, 200 ppm SA and Victoria) (McLaughlin et al., 2000).

The National Environment Protection Measure (1999) sets Environment Investigation Levels and Health Investigation Levels in soil respectively for arsenic at 20 and 100 ppm, chromium IV at 1 and 100 ppm, and copper at 100 and 1000 ppm.

The same levels of contaminants can have very different ecotoxicological effects on plants and invertebrates in different soils, with variations caused mainly by cation exchange capacity, organic carbon content, clay content and soil pH. Heemsbergen et al. (2009) examined this effect for copper and zinc, and developed new guidelines for estimating such variation for tolerable limits in biosolids being added to soil. Phytotoxicity of copper is higher in acidic soils with low organic matter. The added contaminant limit (ACL) for copper in biosolids ranged from 8 mg/kg (for soils with low organic carbon and pH 4.0) to 970 mg/kg (for soils with high organic carbon and pH 8.0). The generated ACLs for copper were both lower and higher than the current single value guidelines in Australia for biosolids amended soils of 100–200 mg/kg for copper (NRMMC, 2004). According to Heemsbergen et al. (2009), some state biosolids guidelines have a minimum soil pH limit below which soils cannot receive biosolids (5.5 in South Australia, 5.0 in Western Australia and 4.5 in Victoria). If the limits calculated in the study by Heemsbergen et al. (2009) were adopted, copper would limit biosolids application in Western Australia due to the relatively high copper contents of their

biosolids and because many of the local soils are acidic and have low organic carbon contents. Generally in Australia (except for South Australia), nutrient loadings currently limit biosolids application rates and soil metal limits will only impinge on biosolid reuse programs if these materials are repeatedly applied to the same areas (Heemsbergen et al., 2009).

The NSW DECCW (2010) provides Resource Recovery Land Application Guidelines. Its Raw Mulch Exemption 2008 allows raw mulch to be used for compost or soil amendment. It excludes preservative treated or coated wood and engineered wood products from its definition of raw mulch. In contrast, recovered fines from building and demolition waste (typically skip bin waste with fines from brick, cement, concrete, tiles and brickies' sand and lime) can be used as a soil amendment if certain chemical contamination limits are met (known as the batch process recovered fines exemption April 2010). Relevant absolute dry weight concentrations include 40 ppm for arsenic, 150 ppm for total chromium, 200 ppm for copper, 600 ppm for zinc, 80 ppm for total PAHs, 6 ppm for benzo(a)pyrene, and 1 ppm for individual organochlorine pesticides.

Turning to wood, the presence of CCA treated wood in mulch may cause some potential risk to human health and the environment as a result of chromium, copper, and arsenic leaching. Jacobi et al. (2007) indicated that chipping and mulching increases the surface area of the timber and can produce more concentrated leachate under certain conditions. The amount and rate at which arsenic leaches varies considerably depending on local factors including climate, soil type, rain acidity and age of the timber product (ERMA, 2003).

Townsend et al. (2003) examined the leachability of the three metals and concluded that less than 0.1% of H3 CCA treated wood would lead to a mulch with potential metal concentrations which exceed 0.8 mg/kg – the residential clean soil guideline for arsenic in Florida. It is important to note that natural background levels for arsenic in Florida soils are unusually low, with a maximum of 6.2 mg/kg (Chen et al., 2001). This value is closer to the average in Australia, and much lower than its maximum of about 40 mg/kg (Tiller, 1992). Because of this difference, Florida also has very low cleanup criteria for for arsenic in residential and industrial soils of 0.80 and 3.7 mg/kg, respectively. For this reason, many of the problems for recycling options cited by research in Florida for CCA treated wood should not necessarily apply in Australia.

Speir et al. (1992 a,b) examined the effect of soil amended with 10% CCA treated *P. radiata* sawdust which increased the total soil concentrations of copper, chromium and arsenic to 64, 179 and 66 ppm respectively. Potting trials with beetroot, clover and lettuce showed that CCA amendment had no negative effect on plant growth, unlike untreated sawdust which appeared to immobilize some nutrients while it decayed. The uptake of CCA in the edible portions of the plants was low, but CCA did concentrate in the fibrous roots of the plants (non-edible portions). This addition of CCA to soil also had little effect on soil microbial biomass, soil respiration, enzyme activities, nitrification, and numbers of nematodes and actinomycetes.

The use of organo-copper preservatives such as ACQ and copper azole should not present the same level of difficulty as CCA when composting. The primary concern in composting with these compounds is the accumulation of copper in the soil. The organic components are biodegradable in compost (see below).

### *Boron*

Boron is another element that is of concern in mulch and compost products. Boron is required as a plant micronutrient in soil and can often be deficient. Typical soils have boron concentrations in the range of 4-200 mg/kg of soil. Given the release of boron is not controlled and the toxicity threshold for plants is small, boron treated wood waste is not recommended for mulch and compost. The Australian standard for Composts, Soil Conditioners and Mulches (AS 4454 2003) specifies contaminant levels for boron of less than 200 mg/kg dry mass in landscape products. It also states that if seaweed or seagrass or unseparated municipal solid wastes that have a component of cardboard packaging is in the compost product, the boron content may be above 100 mg/kg and should therefore be analyzed. For viticulture the level of boron in compost needs to be less than 100 mg/l (Cass and McGrath, 2005).

The National Environment Protection Measure (1999) sets Health Investigation Levels in soil for boron at 3000 ppm.

Speir et al. (1992 a,b) examined the effect of soil amended with boron treated *P. radiata* sawdust which increased the total soil concentrations of boron to 36 ppm. This addition of boron to soil had little effect on soil microbial biomass, soil respiration, enzyme activities, nitrification, and numbers of nematodes and actinomycetes, although sulphatase activity was inhibited. However, due to its phytotoxicity to plants, the growth of lettuce, clover and beetroot (at some soil pH levels) was inhibitory, and boron treated sawdust is generally unsuitable as a soil amendment.

### *Organic preservatives*

Several studies reviewed by Buyuksonmez et al. (2000) concerned the change in biocidal preservatives concentration via composting. It was concluded that the majority of organic biocides found in various feedstock materials (including wood and wood composites) do not cause contamination problems after composting. Most of these chemicals readily degrade in compost piles due to increased temperatures, moisture levels and biological activity. This is certainly true for permethrin, bifenthrin, tebuconazole and propiconazole (National Pesticides Information Center 1997; US EPA, 2008). According to the pesticide fate database of the US EPA (2008), the half life of permethrin in natural soil is 30 days, bifenthrin between 78 and 130 days, tebuconazole in natural soil up to 800 days, whilst the half life of propiconazole in natural soil is 60 days. These half life values are reduced when the material is being composted. The tolerable proportion of organic biocide treated timber and composite wood products in composting raw materials is unclear due to the extensive factors which influence the biodegradability of chemical components.

The presence of some fungicides in treated wood is of no greater or lesser concern than the presence of persistent garden maintenance chemicals that occur in green wood wastes from cuttings and clippings collected from the garden. Chemicals such as Roundup (glyphosate) pose a risk for organic product recycling as they are persistent in mulch and can adversely affect broadleaf plant growth. Indeed the use of treated wood products is possible, subject to the adoption of a number of safety measures (Recycled Organics Unit, 2007). Another example is that sugarcane tops and leaves are commonly sold as mulch, which seems likely to contain traces of a wide range of the pesticides used in that industry, including those pyrethroids and azoles used in wood preservation.

The organic components in synthetic pyrethroids and azole preservatives are better understood. These products were developed as agricultural pesticides, their fate and breakdown in the natural environment has been studied. These chemicals degrade in soils, are strongly adsorbed to the soil and are not readily translocated. Azoles are taken up into plants, providing protection against a number of pathogens. Mulch prepared using copper azole or permethrin treated wood waste may be potentially marketed as a value added product given that it is a common practice of gardeners to add pyrethroids particularly permethrin to potting mixes (Fecko, 1999).

Pentachlorophenol is no longer used as a wood preservative in Australia. It is moderately persistent in soil, and was reported to have a half life of 210 days in one study (Vernalia et al., 1997).

### *Creosote*

Martens (1982) and Moeller and Reeh (2003) investigated polycyclic aromatic hydrocarbon degradation during composting of municipal solid waste. The results showed that the degradation of PAH's was partial (31-64% removal within 25 days of composting and different temperature conditions) and that four to six ring polycyclic aromatic hydrocarbons were substantially degraded, but only in mature and not fresh municipal solid waste compost. Further research would be necessary to demonstrate the effect of composting upon the degradation of polycyclic aromatic hydrocarbons existing in treated wood residues.

Sixty to seventy percent of creosote will degrade in aerobic composts, however the conditions of composting require control (Lease, 2006). Co-composting creosote waste with cattle manure for 19 months was found to cause at least 96% degradation of selected components (Atagana et al., 2003). Accumulation of large polyaromatic hydrocarbons including benzo(a)pyrene and fluoranthracene can still occur however and thus creosote is not recommended for composts. The use of bacterial-fungal co-cultures has been found to be very effective in bioremediation trials and may be a possible technique for incorporation of creosote wastes in compost and mulch products (Lease, 2006). Soils containing greater than 0.27 mg/kg of benzo(a)pyrene are considered contaminated. The National Environment Protection Measure (1999) sets Health Investigation Levels in soil for PAHs at 20 ppm and 1 ppm for benzo(a)pyrene.

### *Overseas limits*

Several states in the US and Europe have established guidelines for chemicals in soil and groundwater. Further, England and Germany have established limits for raw materials or products from wood waste. Examples include:

- Soil cleanup target level and groundwater cleanup target level (in Florida) (Table 7).
- Toxicity characteristic hazardous waste regulatory limits (Code of US Federal Regulations Title 40 Part 261.24) (Table 8).
- Limit values of chemical components for raw materials used in the manufacture of derived timber products (Annex II – Ordinance on the Management of wood waste - Germany) (Table 9).
- Minimum level requirements for potentially toxic elements in composting product for general use (specified in a publicly available specification, BSI PAS 100:2005) (Table 10).

The groundwater cleanup target levels for Florida are based on the existing numerical standards (Florida Administrative Code), drinking water standards, monitoring and reporting, human health risk calculations or aesthetic considerations (taste, odour or colour). Contaminant leaching level is expressed as concentration in the leachate (mg/L).

The soil cleanup target levels were based on direct human contact (direct exposure) or soil acting as a source of groundwater or surface water contamination (leachability). The soil cleanup target levels refer only to direct human exposure from residential and from commercial/industrial land use. Soil cleanup target levels for various exposure scenarios can be calculated using the methodology given in *Technical Report: Development of Cleanup Target Levels (CTL's) from Chapter 62-777, F.A.C.* (Center for Environmental & Human Toxicology University of Florida, 2005).

Table 7: Groundwater cleanup target levels (GCTL's) and soil cleanup target levels (SCTL's) for the chemicals in the main wood preservatives (Florida Department of Environmental Protection, 2005)

Contaminant	SCTL's		GCTL's	
	Direct exposure		Groundwater (ug/L)	Freshwater (ug/L)
	Residential (mg/kg)	Commercial/Industrial (mg/kg)		
Arsenic	2.1	12	-*	-**
Boron	17,000	430,000	1400	NA
Cr <sup>6+</sup>	210	470	-*	-**
Chromium (total)	210	470	-*	11
Cr <sup>3+</sup>	110,000	not a health concern	-*	-**
Copper	150	89,000	-*	-**
Fluoride	840	130,000	-*	-**
Permethrin	4,200	96,000	350	0.001
Tributyltin oxide	25	570	2.1	0.05

Note: There are also several metals and organic compounds on the GCTL's and SCTL's compound list

\* = As provided in Chapter 62-520, FAC ([www.dep.state.fl.us](http://www.dep.state.fl.us))

\*\* = As provided in Chapter 62-302, FAC ([www.dep.state.fl.us](http://www.dep.state.fl.us))

- For contaminants not listed, the equations provided at Chapter 62-777 [Contaminant Cleanup Target Levels](http://www.dep.state.fl.us/waste/quick_topics/rules/default.htm), FAC ([http://www.dep.state.fl.us/waste/quick\\_topics/rules/default.htm](http://www.dep.state.fl.us/waste/quick_topics/rules/default.htm)) and nuisance, organoleptic, and aesthetic considerations may be used to calculate CTL's for contaminants found in groundwater for sites or facilities subject to Chapter 62-713, 62-730, 62-780, or 62-785, FAC.

- The Toxic Equivalent Factors and approach described in the technical report referenced in subsection 62-777.100(2), FAC, shall be used to calculate benzo(a)pyrene equivalent concentrations for evaluation of samples that contain carcinogenic PAH's.

In the US, toxicity characteristic limits of hazardous waste contaminants are regulated at federal level. The toxicity characteristic regulatory act (40 CFR 261.24) outlines the maximum concentration of 40 hazardous contaminants including the predominant chemicals of concern in treated wood (Table 8). When the concentration of any of the listed hazardous compounds for a tested solid waste (evaluated with the toxicity characteristic leaching procedure (US EPA Method 1311) exceeds the defined regulatory limit, the waste is characterized as a toxicity characteristic hazardous waste (or otherwise considered a characteristic hazardous waste) for disposal purposes.

Table 8: Toxicity characteristic for the main chemicals of concern in treated wood (CFR, 2003)

Contaminant	Regulatory level (mg/L)
Arsenic	5
Chromium	5

Note: there are also several metals and organic compounds on the toxicity characteristic compound list

In 2003 Germany passed the Ordinance on the Management of Waste Wood (German Act/Ordinance 2002) - which categorizes the waste wood and states the general requirements for its recycling management. The ordinance specifies the limit values of chemical components for wood chips used in the manufacture of derived timber products other than energy recovery (Table 9). The energy recovery of waste wood shall comply with the provisions of the Federal Emission Control Act and the issued statutory ordinance.

Table 9: Limit value for wood chips (raw material) used in the manufacturing of derived timber products (German Act/Ordinance, 2002)

Element/compound	Concentration (mg per kg dry mass)	Analysis method(s)
Arsenic	2	DIN EN ISO 11969
Chromium	30	DIN EN 1233 DIN EN ISO 11885 DIN ISO 11047
Copper	20	DIN 38406, Part 7 DIN EN ISO 11885 DIN ISO 11047
Chlorine	600	-
Fluorine	100	-
Polychlorinated biphenyls	5	-

In the United Kingdom, BSI PAS 100 outlines the minimum level requirements of potentially toxic elements and corresponding test methods, for finished products made from recycled wood waste (Table 10).

Table 10: Upper limits for potentially toxic elements in compost products (BSI PAS 100, 2005)

Element/compound	Upper limit concentration (mg per kg dry mass)	Test method
Chromium (Cr)	100	BS EN 13650
Copper (Cu)	200	BS EN 13650
Zinc (Zn)	400	BS EN 13650

Although there are established guidelines on the maximum allowable limits of chemicals in soil and groundwater, US EPA (2004 and 2007) has determined that creosote and arsenic-treated wood should not be recycled as landscaping products. Florida Department of Environmental Protection (2004) has also proposed amendments to *Chapter 62-701: Solid Waste Management Facilities, F.A.C.* to specifically prohibit the inclusion of CCA treated wood in mulch, compost or soil amendments. This proposal is yet to be approved.

The ADAS Composting Research Project (2006) in the UK examined two compost sources from kerbside collections, one being green/kitchen waste, and the other being the same but with an equal addition of solid waste fines (MSW). These feedstocks were ground to pass a 25 mm screen. The products in the solid waste fines included glass, metal, plastic and wood. Whether treated wood was included was not stated. The MSW compost was analysed and contained (from various sources) 6.5 ppm arsenic, 4 ppm boron, 172 ppm copper, 21 ppm chromium, 360 ppm zinc and 6.2 ppm PAHs (amongst other contaminants). Both composts contained large amounts of organic matter and major plant nutrients, and gave satisfactory support for plant growth. It was concluded that the MSW compost would be an effective soil forming material in land restoration.

### *Evaluation methods*

The methodologies used by several research studies (Jacobi et al., 2007; Brajesh et al., 2006; Townsend et al., 2003; Townsend et al., 2005) for evaluating the toxicity levels (risks) of wood waste derived products for land applications consist of:

- Risk evaluation to direct exposure (direct contact by inhalation):
  - Measure the total concentration of the preservative compounds in a product sample.
  - Comparison with soil cleanup target level.
- Risk evaluation to indirect exposure (exposure to groundwater):
  - Generate leachate using standard protocols (synthetic precipitation leaching procedure – US EPA Method 1312; the toxicity characteristic leaching procedure - US EPA Method 1311).
  - Comparison of the leachate concentration to groundwater cleanup target level and toxicity characteristic limits.

The German Waste Wood Ordinance (2002) outlines numerous detailed procedures for testing the chemical contamination of wood waste chips intended for manufacturing of derived products.

Crop residues such as sugar are often used for mulch and are likely to contain a range of pesticide residues approved for use on these crops, including some which are also approved for use as wood preservatives.

### *Summary*

In Australia, treated timber off cuts and wastes are not recommended for mulch as a precaution (AS 5605, 2007). However, mulches and compost are currently produced with the addition of waste wood. Up to 5% of chemical or organic contamination (by volume) is accepted by the industry. Setting allowable limits for the various components may provide greater confidence that the inadvertent inclusion of treated wood waste could occur without adverse affects. Organic pesticides used in timber preservation including permethrin, bifenthrin and the azoles can be safely composted as they are readily

degraded by active soil microbes. The presence of these compounds in mulch initially can aid plant growth by reducing fungal or insect investigations.

## **5.2 Animal bedding products derived from wood waste**

The utilization of treated wood waste in animal bedding products poses possible risks to both animals and humans due to dust, dermal contact or ingestion of the bedding material.

Humans may be at risk due to (Gann, 2007):

- Possible inhalation or ingestion of chemicals present in animal bedding as handling such products may increase the occurrence of dust and implicitly the pollutant concentration in the air.
- Dermal contact with the dust (heavy metals and other persistent hazardous substances).
- Indirect exposure via the food chain (poisoning through repetitive consumption of food products derived from cattle and chicken contaminated with chemicals present in bedding).

The potential risks from preservative chemicals to animals, which are not relevant in the food chain of humans such as horses and domestic pets (cats, guinea pigs), are associated with (Gann, 2007):

- Inhalation (scrabbling in the bedding).
- Oral exposure (ingestion of pieces of wood during feeding especially due to the salty nature of the CCA chemicals which may attract animals).
- Dermal transition (close contact to the bedding).

Gann (2007) indicated that in the case of animals relevant to the food chain, chemical contaminants like pentachlorophenol, polycyclic aromatic hydrocarbons and chlorinated compounds may be transformed and deposited from the animal skin into the blood, fatty tissue and meat. However, the transition is slow. The short lifetime of chickens intended for nutritional use prevents the uptake of the chemicals into the animal and therefore, the risks for human consumers is negligible. In the US where PCP is widely used as a wood preservative, Fries et al. (2002) found that PCP treated posts and rails were the likely source of elevated dioxin levels in cattle due to their propensity to chew objects other than food. In contrast, poultry did not have elevated dioxin levels, due to their differing feeding habits.

Wester et al. (2004) examined the potential for dermal absorption of arsenic from CCA treated wood. No increased arsenic was found in monkeys when surface deposits and residues from CCA treated wood were placed against the skin (under a bandage) for eight hours, suggesting that arsenic from CCA treated wood was not absorbed through the skin.

The presence of boron in bedding products should pose little risk to humans as it does not

bioaccumulate in animals and is relatively non toxic to mammals. However, due to this low perceived risk definitive testing has not been conducted.

A common disposal method for animal bedding is to turn it directly onto the land or into composted soil products, so that many of the considerations given in the previous section (on mulching/composting) would then apply. Organic wood preservatives in animal bedding such as the pyrethroids should degrade relatively quickly in compost due to its association with manure.

Khan et al. (2008) considered a range of parasiticides used in the beef industry and their likely fate or transference from manure to compost. Some of the parasiticides used are similar to the insecticides that have been used in wood preservation, such as the pyrethroids. The pyrethroids are often used to control buffalo flies, lice and ticks via sprays, dips, pour on formulations and ear tags. Pyrethroids are known to pass into the manure largely unchanged. This transfer can reduce the activity of manure inhabiting insects such as dung beetles, slowing the breakdown of cow pats. In soil however, the pyrethroids sorb strongly to soil, and are generally very easily degraded in the environment. Heavy metals can also pass into manure. Some lighter metallic elements (As, Co, Cu, Mn, Se and Zn) may be added to livestock feeds as essential nutrients or to improve feed conversion efficiencies, although most metal consumption occurs when cattle ingest soil (with grass). Practices such as using composted municipal waste as feedlot bedding also have the potential to contribute to the presence of heavy metals in contaminated manure. However, this is unlikely to be an issue for Australian beef feedlots since bedding is not used in outdoor feedlots and there are only a few indoor feedlots that generally use sawdust or rice hulls as bedding (Khan et al., 2008).

There are no protocols or policies available setting the permissible concentration levels of wood preservatives in animal bedding products but there are recommendations against its use (Runge et al., 2007). In Australia, treated timber offcuts and wastes are not recommended for animal bedding (AS 5605). Crop residues such as rice hulls are often used for animal bedding, and are likely to contain a range of pesticide residues approved for use on rice.

The APVMA (2010) has set Maximum Residue Levels (MRL) in animal food and feedstuff. There are a range of chemicals registered for agricultural use on crops that may be used for stockfeed. The APVMA (2010) sets the MRL for aldrin/dieldrin (0.01 ppm), bifenthrin in various dry fodders (0.01-0.02 ppm), imidacloprid (dry sugar cane fodder, 2 ppm), permethrin (non-dried pea vines, 15 ppm), propiconazole (10 ppm) and tebuconazole (50 ppm). These values apply to fodder for ingestion, not animal bedding.

### **5.3 Wood waste derived particleboard panels**

Particleboard products are mainly used for indoor applications (benchtops and furniture) and rarely outdoors. For most applications the particleboard is untreated, however, treated particleboard flooring is also available. Both fungus resistant flooring and termite resistant flooring are produced by the Australian industry (EWPA, 2008). For termite

resistance, permethrin is a common additive to 200 ppm retention. Fungus resistant flooring tends to be used in bathrooms, or to provide fungal resistance during prolonged house construction when rainwater could pool on floors. One of the fungicides that has been used for producing decay resistance is Xyligen 25F (N-cyclohexyldiazoniumdioxypotassium). Australian Standard 1604.2 specifies wood preservatives that can be added to reconstituted wood products such as particleboard and MDF to provide termite and borer resistance for indoor use (Hazard classes 1 and 2), or decay resistance for use outdoors and above ground (Hazard class 3).

These uses suggest there is scope for tolerating some level of recycled treated wood into particleboard. According to Kamdem (2006), the handling and utilization of wood waste derived particleboard products, where chemical contamination from treated wood is likely, may cause harm to human health through:

- direct exposure (inhalation and oral ingestion of airborne particles and toxic fumes when using cutting and machining on the boards. Poisoning through dermal contact is less likely).
- indirect exposure (inhalation of volatile pollutants released into indoor air).
- occupational exposure to metal ions, arsenic, formaldehyde and other organic vapours from wood dust and fouled air by hot pressing of composites.

In Europe, the level of contamination for wood which is used in particleboard and MDF production is controlled by the European Panel Federation's standard for *Delivery Conditions of Recycled Wood* and *The Use of Recycled Wood for Wood-Based Panels*. The UK version is WPIF/UKFPA/1-2000, *Code of Practice for the Application of Wood Chain of Custody Criteria to Product Environmental Labeling in the Sawmilling and Wood Panelboard Sectors* (Table 11). These standards provide contamination limits of the final product, and use the European standard for the safety of toys (BS EN 71, 1995) as the basis when setting the limits. It is considered that if these limits are acceptable for the production of toys, then wood waste derived particleboards may be used for any other use.

Table 11: The maximum allowable quantities of contaminants permitted in manufactured particleboard according to the Industry Standard WPIF/UKFPA/1-2000 (Irle et al., 2004)

<b>Contaminant</b>	<b>Limit (mg/kg of finished product)</b>	<b>Limit (g/2440x1220x15mm particleboard)</b>
Arsenic	25	0.72
Chromium	25	0.72
Copper	40	1.14
Fluorine	100	2.86
Pentachlorophenol	5	0.14
Creosote	0.5	0.01

In Germany, the limit values of chemical components used in the manufacture of wood

waste derived products, including particleboards, are controlled by *the Ordinance on the Management of Wood Waste - Annex II* (German Act/Ordinance, 2002). Comparing with the EPF and WPIF/UKFPA/1-2000 standards, the limit values in German Ordinance are set for the raw materials and not for the finished product. In addition, most of these limits are significantly lower than the limits for the finished product established in the rest of Europe.

The German Waste Wood Ordinance (2002) aims to prevent preservative treated wood from being used in particleboard manufacture, by placing it in Wood Waste Category AIV (rather than in categories AI to AIII). This category only allows preservative treated wood to be used for the production of synthetic gas for further chemical use, or the manufacture of active carbon/industrial charcoal. To ensure that treated wood is essentially excluded from particleboard manufacture, stringent maximum allowance levels for chemical components are set for wood chips used in the manufacture of derived timber products other than energy recovery, where the limits are 2 ppm for arsenic, 30 ppm for chromium, 20 ppm for copper and 3 ppm for PCP. To check compliance with these limits a procedure is outlined for analyzing wood waste chips intended for manufacturing derived products for chemicals. It states that users of recycled wood should assess their raw material every 500 tonnes. If the wood is found to be excessively contaminated, then it must be disposed of by special incineration. The energy recovery of waste wood shall comply with the provisions of the Federal Emission Control Act and the issued statutory ordinance.

The NSW DECCW (2010) provides Resource Recovery Land Application Guidelines. Its Cement Fibre Board Exemption 2008 allows cement fibre board to be applied within road making material, or as an alternative input into thermal processes for non-energy recovery purposes in the manufacture of building products. Relevant absolute dry weight maximum concentrations include 20 ppm for arsenic, 100 ppm for total chromium, 40 ppm for copper and 200 ppm for zinc.

Kamdern (2006) provided an overview of literature investigating the use of CCA treated wood waste as a source of raw materials for particleboards and other structural and non structural wood panels and indicated that:

- Panels made from 100% CCA treated flakes showed property values lower than those of untreated flakes. The presence of CCA treated components makes flakes less flexible, limiting the formation of flake to flake bonds (weak adhesion). The addition of a coupling agent on CCA treated flakes before the application of the phenol formaldehyde adhesive is capable of increasing the physical and mechanical properties of the resulting board. The study does not indicate if it refers to freshly treated wood or CCA treated wood retired from service.
- No significant difference was observed in the mechanical and physical properties between panels made with untreated particles and panels containing 50% particles from 21 years in service CCA treated poles. The modulus of elasticity, modulus of rupture and internal bond strength of panels containing 75% CCA treated particles at 4 and 8% solid resin content was reduced.

- Particleboard panels made by using remediation methods (acid and biological treatments) to remove the CCA component from recycled treated wood showed low strength property in comparison with panels made with untreated chips.
- Limited information is reported on the migration of copper, chromium and arsenic from panels containing CCA treated particles:
  - It is documented that the amount of copper, chromium and arsenic leaching from phenol formaldehyde bonded panels containing untreated and recycled CCA treated wood appears to be low compared with chemicals leached from urea formaldehyde bonded panels (Li et al., 2004a; 2004b). It is believed that this is due to the water resistant nature of phenol formaldehyde adhesives. The greater water resistance and structural nature of phenol formaldehyde composites make it feasible for a higher allowable limit of copper, chromium and arsenic.
  - Negligible amounts of copper and chromium was reported from particleboards made from recycled CCA treated red pine poles. Arsenic was the most prominent component in the leachate. Approximately 1-3% of the arsenic was leached out within the 28 days of specimens immersed in distilled water (Munson and Kamdem, 1998).
  - The amount of copper, chromium or arsenic loss during the board manufacturing operation is reported as being negligible. Arsenic is released during the production of particles and fibres (Kamdem, 2006).

Various studies have demonstrated that the adhesives used require adjusting to be compatible with preservative treated wood or they can suffer from a loss of internal bond strength, modulus of elasticity and modulus of rupture (Taylor et al., 2005; TRADA Technology & Enviros Consulting Ltd, 2005).

Particleboard production with other treated wood wastes relate to colour and performance issues particularly for the oil borne creosote and copper naphthenate which can have reduced modulus of elasticity/modulus of rupture and internal bond strength and colour issues (Kamdem, 2006).

At this stage recommended loadings in particleboard derived from recycling treated wood waste that contain permethrin, bifenthrin or azoles have not been made. There would appear to be scope for including some of these recycled materials into particleboard flooring sold as termite or fungal resistant. Low levels of copper based preservatives such as ACQ, copper azole and CCA could also be incorporated into particleboards successfully. Composites manufactured with phenol-formaldehyde resins may be able to sustain higher proportions of waste timber if a product performance specification is adopted.

#### **5.4 Combustion of treated wood waste**

Preservative treated wood is present in unsorted wood waste from construction and demolition sources, and may therefore be combusted if not segregated. Raw materials processed for bioenergy are defined by the Renewable Energy (Electricity) Regulations

2001 (Commonwealth of Australian Law, 2007), they include:

- wood waste from the eradication of non-native woody weeds
- a manufactured wood product or byproduct from a manufacturing process
- waste products from the construction of buildings or furniture, including timber and timber off cuts from demolished buildings
- sawmill residue
- waste from harvesting native forests and plantations

The quality related guidelines of these bioenergy feedstocks has yet to be defined and should focus around the following issues (National Association of Forest Industry, 2005):

- The moisture content, density, the amount of volatile material, size of the particles and the level of impurities in the wood waste affect how the material may be utilized, the type of renewable energy conversion technology employed and the net energy recovery from these resources.
- Usually, wood waste with moisture content less than 6% is required prior to combustion in co-firing, but may be up to 25% in dedicated biomass boilers.
- For low caloric value wood waste, the biofuel systems and the supply chain will need to be appropriately designed for continuous and bulk flow of wood waste.
- The shape of the wood waste feedstock may vary with the energy conversion technology to be used. The wood waste may have to be pre-treated, chipped, dried or pre-mixed with other renewable energy resources.

The NSW DECCW provides a Guidance Note for the Assessment of Non-Standard Fuels (2005). It aims to encourage the beneficial use of non-standard fuels while ensuring that there are no unacceptable impacts to human health or the environment. Timber off cuts from building waste that do not include preservative treated wood have been accepted as non-standard fuel.

Several operational and environmental risks that could be associated with treated wood waste preparation and use in combustion facilities have been identified (Gann, 2007; Schert et al., 2007):

- Operational risks:
  - Possible toxicological risks can emerge from the pre-treatment stage of the recovered wood (crushing, hammer mill, sieving) which can contain chemical constituents from preservatives or paints. Dust emitted during the combustion process, which may contain a higher amount of pollutants than the original recovered wood, can be ingested or inhaled by workers. These operational risks are common to all wood processes, however when processing treated wood waste concerns over more immediate toxicological risks exist.
- Environmental risks:
  - Contaminated dust can be blown into the environment.
  - Arsenic has an impact on air emissions (arsenic sublimates from a solid to a

- gas phase).
- Preservative contaminants have impact on ash quality, posing disposal problems.

In the European Union, emission levels permitted for incinerators are set by the European Union Directive on Incineration of Waste which came into force in 2000. The directive covers incineration and co-incineration plants which combust wood waste originating in particular from construction and demolition and may contain halogenated organic compounds or metals and metalloids as a result of treatment with wood preservatives or coatings.

In the US, EPA regulates the emission levels of industries which combust hazardous waste (incinerators, cement kilns, chemical manufacturers, sanitary services, photographic equipment) (Table 12) as well as entities such as any state or local units using municipal waste combustion (solid waste combustion units burning municipal waste collected from the general public and from residential, commercial, institutional and industrial sources).

Table 12: Emission limits for existing and new or reconstructed hazardous waste incinerators (US EPA, 2005)

<b>Pollutant</b>	<b>Emission limits for existing hazardous waste incinerators</b>	<b>Emission limits for new or reconstituted hazardous waste incinerators</b>
Dioxin/furans	0.20 or 0.40 ng TEQ/dscm and temperature at inlet to the initial particulate matter control device <400°F	0.20 ng TEQ/dscm
Particulate matter	0.013 gr/dscf	0.0015 gr/dscf
Semi-volatile metals (lead + cadmium)	230 µg/dscm	10 µg/dscm
Low volatile metals (arsenic + beryllium + chromium)	92 µg/dscm	23 µg/dscm

Note: ng – nanograms, TEQ/dscm – toxicity equivalence (the international method of relating the various dioxin/furan congeners to the toxicity of 2,3,7,8 – tetrachlorodibenzo-p-dioxin, per dry cubic standard meter of air), µg/dscm – micrograms per dry cubic standard meter of air, gr/dscf – grains per dry standard cubic feet and ppmv – parts per million by volume

When CCA treated wood is burnt, virtually all of the copper and chromium deposits with the ash, but a significant amount of arsenic can volatilize.

Borgnes and Rikheim (2007) quote from the literature that:

- Heavy metals such as chromium and copper will mainly stay in the bottom ash,

while mercury and cadmium and to a lesser degree arsenic will follow the flue gas.

- The amount of arsenic volatilized may depend on temperature and exposure time (also for the ash), content of chlorine and sulphur and oxygen concentrations.
- Copper may catalyze reactions which give higher dioxin formation. The high copper content of CCA treated wood waste may therefore lead to increased dioxin formation.
- The incineration efficiency is of greater importance to the dioxin formation than the content of the waste.

An incineration test was done at the Klemetsrud plant in Oslo to determine emissions and composition of bottom ash, in the conditions in which 10% of municipal solid waste was CCA treated wood. The addition of 10% by weight CCA treated wood waste gives considerable increases of chromium and arsenic content in the waste. This study is significant as it was based on real tests rather than imposed limits and reported (Borgnes and Rikheim, 2007) that:

- Emission of total metals and metalloids (including copper, chromium and arsenic) is much lower than the limit value in the European Union directive on waste incineration.
- The dioxin concentration in the flue gas was 25% of the limit value in the European Union directive on waste incineration.
- The concentration of metals and metalloids in bottom ash shows levels far below the threshold value stated in the Norwegian regulations for hazardous waste.

Research at Sydney University has investigated the thermal processing of CCA treated wood (Rogers et al., 2007). By controlling the furnace conditions, better combustion and greater recovery of copper, chromium and arsenic is possible from the ash. These residues can be processed after combustion to make the process safe and minimize potential environmental issues.

After incineration, the ash may be disposed to landfill. Townsend et al. (2001 and 2004) indicate that ash from burning CCA treated wood could pose a significant leaching threat to ground water if disposed of in unlined disposal facilities. The research also showed that the ash from burning wood waste containing as little as 5% CCA treated wood could be considered a characteristic hazardous waste in Florida due to the high arsenic concentrations in the ash and the unusually low limits for arsenic in that state. Schert et al. (2007) pointed out that inorganic preservative concentration in a kilogram of wood ash is 16 times higher than in the same amount of initial recovered wood. This may cause the ash to be designated as a hazardous waste, increasing dramatically its disposal cost.

The Florida Center for Solid and Hazardous Waste Management (2005) states that generally, little treated wood goes to waste to energy facilities. The emissions from the minimum amounts of contaminants in the waste stream are believed to be adequately handled by the air pollution control equipment at each facility. However, the impacts from large scale burning of treated wood in waste to energy facilities and how much

treated wood can be safely burned is unknown due to the lack of incineration tests.

The results from the leaching tests of Borgnes and Rikheim (2007) suggest that the bottom ash from the incineration test with 10% CCA treated wood meets the criteria for depositing on landfills for non-hazardous waste in Oslo.

Combustion of copper organic based treated wood wastes such as ACQ and copper azole in industrial furnaces and co-fired installations have fewer limitations than CCA treated wood. The copper concentrates in the ash, while the organic components in the wood preservatives are readily combusted in the higher temperature furnaces. Some sawmills in NSW have EPA approval to burn ACQ treated waste in their own boiler systems, as do some sawmills in NSW and Queensland for copper azole wood waste.

Dioxin formation in the ash can be problematic when combusting wood that contains both copper and chlorinated pesticides such as permethrin and tebuconazole (Tame et al., 2007), while a number of other organic preservatives such as DDAC also contain chlorine.

Boron treated wood and shavings have long been used safely as fuel at the hardwood sawmills that treat their wood for the control of *Lyctus* borers. The boron solidifies on the furnace walls and surfaces as a glass or clinker, which needs to be chipped off for disposal (Young, 1947).

A study examining the combustion of creosote in a co-fired clean coal power station was investigated by Zanderson et al. (2006). This work determined that a power plant co-fueled with 5% of creosote treated wood waste is not only possible but will improve the heat balance of the system through the addition of pyrolytic vapour to the joint furnace (Zanderson et al., 2006). Further, if the average transportation distance of the creosote treated waste was less than 200 km the process was economically feasible.

A range of thermal processing options using recycled wood wastes are available including incineration, use as a cement kiln fuel, chartherm, sidenergie, pyrolysis and gasification.

According to a review by Environment Australia (1997), burning of hazardous industrial wastes in cement kilns has become a well accepted method for the disposal of hazardous wastes in France and a number of other European countries. When operated properly, destruction of chlorinated compounds in cement kilns can be >99.0000% complete with no adverse effect on the quality of the exhaust gas (Benestad, 1989; Jones and Heart, 1994). The contribution of waste materials to the exhaust gases are relatively minor given that the wastes are only used as a minor supplement to the main energy or raw material stream. The application of cement kilns to the treatment of mixed wastes such as organochlorine pesticide/arsenic mixtures requires careful consideration. A significant proportion of the volatile metals such as arsenic are likely to escape in the gaseous emissions. If such wastes are slowly bled into the cement kiln the gaseous emissions are unlikely to pose a significant health or ecological risk, however cement kilns could not be

considered as an effective treatment process for large volumes of arsenic containing wastes.

Bioenergy production is the most promising area for utilization of treated wood wastes. All preservative treated wood wastes can be safely combusted as support fuel in co-combustion incineration. Control of the combustion conditions is required, along with emission controls and processing of the ash to prevent pollution. For best performance, an unmixed fuel is preferred, so that the emission controls, combustion conditions, mix ratios, particle sizes and control of the ash can be tailored to the preservative treated timber fuel. Co-combustion reduces the production of carbon dioxide as wood waste incineration is considered to be part of the carbon cycle.

### **5.5 Treated wood waste for reuse applications (salvage)**

The reuse of treated wood waste provides the opportunity to extend useful service life of products with no (or minimal) additional processing. Numerous reuse applications can be found for post customer treated wood products but the reuse of the high value wood/timber components from building demolition and/or renovation in a variety of forms faces considerable barriers (Section 4.1).

In Australia, the main reuse applications for high value construction and demolition wood waste subsequent to reprocessing and remediation, has been found to include (Forsythe Consultants, 2007):

- floor boards, wall panels and other appearance timber products
- solid timber end matched floor boards
- board bundles (strapped into neatly packed slings then wrapped in plastic) for sale
- beam and column applications
- bench tops
- engineered timber flooring

Use of CCA is restricted under the APVMA directives but CCA treated wood is eligible for secondary use for professional and industrial applications where skin contact by general public or livestock is unlikely. The APVMA (2005) identified the following reuse options for CCA treated timber:

- fence posts
- landscape timber
- parking lot bumpers
- guardrail posts
- composting bins
- planter boxes
- shipping crates
- walkway edging

Broken vineyard posts can also be reused if spliced, such as the Ocloc<sup>TM</sup> clamp.

There are no standard limitations on the level of preservatives present in the recovered wood which is intended for reuse applications.

It is anticipated that the possible human risk associated with the recovered treated wood waste for reuse projects is of an occupational nature due to handling and reconditioning operations. The general public would not be harmed by the use of new recycled wood products as the allowable reuse options for wood waste assortments which may contain chemicals with particular risk potential (CCA and creosote) does not involve direct and frequent human contact.

In addition, both occupational and the less likely public risks are lowered by the chemical retention level of the treated wood at the end of life which is lower than the minimum standard required for recently treated wood (see Smith et al, 2006; Stefanovic and Cooper, 2006).

### 5.6 Summary of recycling opportunities referenced against major end use classes and dominant timber treatment

Following a risk assessment study, TRADA Technology & Enviros Consulting Ltd (2005) identified the potential recycling options and technologies and their suitability for specific categories of treated wood waste (Table 13).

Table 13: Potential recycling options and their suitability for dominant timber treatment (TRADA Technology, 2005)

Process or production options	Categories of treated wood waste for which process or production is appropriate			
	Creosote	CCA	Copper organics	LOSP
<b>Reuse</b>	✓	✓	✓	✓
<b>Recycling:</b>				
Particleboard	✗	✗	≈	✓
Flakeboard and OSB	✗	≈	✓	✓
Wood plastic composite	✗	≈	≈	≈
Fiberboard and MDF	✗	≈	≈	✓
Compost	✗	✗	≈	≈
Coloured horticultural mulch	✗	✗	≈	≈
Surfacing mulch	≈	≈	≈	≈
Soil improving mulch	✗	✗	≈	≈
High quality animal bedding	✗	✗	✗	≈
Standard grade animal bedding	✗	✗	≈	≈
<b>Pre-processing:</b>				
Biodegradation by fungi	≈	≈	≈	≈
Biological extraction	≈	≈	≈	≈

Chemical extraction	≈	✓	≈	≈
Steam explosion	≈	✓	≈	≈
Electrodialytic remediation	✓	✓	≈	≈
<b>Thermal treatment and destruction:</b>				
Incineration	✓	✓	✓	✓
Cement kiln fuel	✓	✓	✓	✓
Chartherm	✓	≈	≈	≈
Sidenergie	✓	✓	✓	✓
Pyrolysis and gasification	✓	≈	✓	✓
Gasification in metallurgical furnace	✓	✓	✓	✓

Note: ✗ use unlikely or prohibited; ≈ potential uncertain or limited; ✓ good potential

By combining the information contained in the limits for various products based on the WPIF standard, German Waste Wood Ordinance, UK Compost Standard for amount of allowable contaminant in various products an estimate of allowable maximum limits of preservative treated wood waste can be estimated. This information is presented in Table 14. From this table it is can be seen that one kilogram of H3 CCA treated wood waste in a total mass of 70 kg of clean material would be at the limit of the WPIF standard, and in a total mass of 720 kg to be at the limit of German ordinance. The reason for this 10 fold difference in allowable concentrations is the greater stringency that the German ordinance has on the amount of arsenic permitted. For organo-copper preservatives, 60 kg of particleboard could contain a maximum of one kilogram of organo-copper treated waste before reaching the limit of the required WPIF standard. To meet the German ordinance for derived timber products 119 kg of extra material is required. Composts have the highest allowable amount of copper as seen by the much higher values permitted to achieve compliance. Boron treated wood waste is also able to be recycled into mulch with 1 kg of boron treated wood with the limit in 20 kg of clean material, based on the US and UK standards.

Table 14: Estimated maximum limit (kg) of preservative treated wood waste in 1000 kg of wood waste according to select international regulations and standards.

Preservative	Limiting element	Standard	Treated wood Hazard class*					
			H1	H2	H3	H4	H5	H6
CCA	Cr	WPIF	143	17	14	8	5	3
	As	German Ordinance	15	2	1.4	0.8	0.5	0.3
	As	Compost UK	0	0	0	0	0	0
ACQ	Cu	WPIF	33	17	17	7	4	
	Cu	German Ordinance	17	8	8	3	2	
	Cu	Compost UK	167	83	83	33	21	
Cu azole	Cu	WPIF			17	10	5	
	Cu	German Ordinance			8	5	3	
	Cu	Compost UK			83	48	26	
Cu naph	Cu	WPIF			40			
	Cu	German Ordinance			20			
	Cu	Compost UK			200			
B	B	Compost UK	200	50				

\*These values are maximums, as they assume full penetration of treated wood.

Table 15 compares the threshold levels of contaminants permitted in soil and particleboard.

Table 15: Comparison of threshold values (ppm) in relevant international regulations and standards of metals and actives used in wood preservatives in Australia for urban wood residue to be used in land application and particleboard.

Substance	EPF	German Ordinance	BSI PAS100: 2005	AS 4454-2003	NEPM-1999 EILs <sup>1</sup> (interim urban)	NEPM—1999 HILs <sup>2</sup> (A-standard residential)
As	25	2	-	20	20	100
B	-	-	-	200	-	3000
Cr	25	30	100	100	400 (Cr III) 1 (Cr VI)	12% (Cr III) 100 (Cr VI)
Cu	40	20	200	100	100	1000
Creosote-PAH	-	-	-	-	-	20
Benzo(a)pyrene	0.5	-	-	-	-	1

<sup>1</sup>Ecological Investigation Levels

<sup>2</sup>Health Investigation Levels

## 6 Conclusions and recommendations

The current general recommendation from the wood preservation industry for the disposal of its treated wood waste products is that it be buried in landfill. Treated wood scraps arising from domestic use is generally classed as non-hazardous, and is a means of sequestering carbon in landfill. However, due to rising landfill costs and the increasing desire to recycle, the larger volume of untreated wood waste is being reused. While landfill for treated wood waste remains a preference for the timber industry, the ability to recycle untreated wood waste should not be constrained by overly restrictive limits on the incidental inclusion of treated wood. Otherwise, a number of wood waste recycling options become untenable or require excessively stringent segregation of the wood waste streams.

Mulch and biofuel production are the major market segments for wood waste. CCA, which accounts for over half of the treated timber volume produced in Australia, is not currently recommended for these applications as they ultimately release chromium and arsenic into the environment. The form of arsenic and chromium released are the least reactive inorganic species, and can be tolerated to a degree in these products with proper management systems. The opportunity and knowledge to safely combust wood containing low levels of copper, chromium and arsenic exists. Such timber can be combusted with flue gas profiles similar to untreated wood, coal or oil. A processing step for the recovery of toxic elements from the ash is then required. This process is almost neutral in respect to green house gas emissions and replaces the need to combust as much fossil fuel, coal and oil for energy production.

All preservative treated wood wastes in Australia can be safely combusted using appropriate conditions. Management of the flue gases and particles and the resulting ash and its disposal is required. Copper azoles, ACQ and synthetic pyrethroids have a wide range of recycling options and these should be capitalised upon. Creosote treated wood wastes are an excellent fuel for co-incineration plants with clean coal and can improve the environmental outcomes of these energy generators.

A zero tolerance of treated wood waste in recycled products is excessively conservative and a responsible allowance should be made. For particleboard it is reasonable to use limits based on the WPIF standard for particleboard. The anticipated maximum amount of copper, chromium and arsenic that could be safely tolerated in particleboard would be approximately 14 mg/kg of copper, 24 mg/kg of chromium and 20 mg/kg of arsenic. This gives a total active elements for CCA of 58 mg/kg of wood which is one sixth of the level required to meet the standard for H1 in AS1604 and well below the threshold required for the preservation of the timber in that hazard level. Copper organics can be tolerated in addition to the CCA on a one to one basis. Thus, a 70 kg mass of particleboard could be produced with a maximum 1 kg of H3 CCA treated wood and 1 kg of H3 organo-copper treated wood waste. This particleboard would meet the UK standard for toys.

For composting, the accumulation of arsenic, chromium and copper in soils and eventual

leaching of these components into the groundwater is considered an issue. This is more of a concern at the composting facility as the elements have the potential to accumulate. When mulches containing wood wastes which contain these elements are applied to soils they are gradually degraded by the environment with some of the elements becoming bioavailable. These elements are not accumulated by the plants, but if they are deficient in the soil (particularly boron and copper) may boost plant growth. For composting and use in mulch to be recommended, further investigation examining the extent of leaching and potential for groundwater contamination by arsenic needs to be determined. Natural arsenic levels are relatively high in some soil, however mobility is low and it is only when the soil is disturbed that problems occur. Creosote wood waste is not recommended as some of the PAH's do not break down when composted, use of materials with high organic content and microbial activity such as cow manure has shown promise as a bioremediation process but further development work is needed. Boron, ACQ and copper azoles can be mulched and composted provided the boron and copper content of the product are carefully managed. The available boron and copper need to be reported on the bags and these products can be of value in nutrient deficient soils and for plants that require additional boron or copper for healthy growth. This is also true of synthetic pyrethroids and fungicides such as azoles where their incorporation in the mulch reduces the need for pyrethroids to be added to potting mixes for disease suppression.

#### **6.1 Tolerable limits of preservative treated wood in the recycling industry**

This review brings together a wide range of information on the tolerable limits for wood preservatives in the recycling industry, where available. A summary of the review findings is given in Table 16, and suggests threshold values for actives in treated wood waste for a range of recycling options.

Table 16. Maximum threshold values (ppm) for elements of treated wood from urban wood residue in recycling applications, established or suggested.

Wood treatment	Active	Reuse <sup>B</sup>	Mulch or land topping	Animal bedding <sup>J</sup>	Particleboard		Incineration	
					General use	Treated <sup>N</sup> e.g. flooring	Cofired	Cement kiln
CCA	Cu	1580 e.g. H4	100 <sup>C</sup>	100 <sup>C</sup>	40 <sup>L</sup>	750 <sup>P</sup>	80 <sup>Q</sup>	160 <sup>U</sup>
	Cr	2840 e.g. H4	100 <sup>C</sup>	100 <sup>C</sup>	25 <sup>L</sup>	1350 <sup>P</sup>	140 <sup>Q</sup>	280 <sup>U</sup>
	As	2330 e.g. H4	20 <sup>C</sup>	20 <sup>C</sup>	25 <sup>L</sup>	1100 <sup>P</sup>	120 <sup>Q</sup>	240 <sup>U</sup>
Cu-organic	Cu	5960 e.g. H4	100 <sup>C</sup>	100 <sup>C</sup>	40 <sup>L</sup>	3500 <sup>P</sup>	300 <sup>QR</sup>	600 <sup>UR</sup>
Boron	B	3500 e.g. H2	200 <sup>C</sup>	200 <sup>C</sup>	175 <sup>M</sup>	470 <sup>P</sup>	3500 <sup>S</sup>	3500 <sup>S</sup>
TBTN	Sn	800 e.g. H3A	0.005-0.07 <sup>D</sup>	0.005-0.07 <sup>D</sup>	1 <sup>K</sup>	800 <sup>P</sup>	40 <sup>Q</sup>	80 <sup>U</sup>
Azoles		600 e.g. H3	60 <sup>E</sup>	60 <sup>E</sup>	30 <sup>M</sup>	600 <sup>P</sup>	30 <sup>QT</sup>	60 <sup>TU</sup>
Permethrin		200 e.g. H2	20 <sup>E</sup>	20 <sup>E</sup>	10 <sup>M</sup>	200 <sup>P</sup>	10 <sup>QT</sup>	20 <sup>TU</sup>
Bifenthrin		50 e.g. H2	20 <sup>E</sup>	20 <sup>E</sup>	10 <sup>M</sup>	200 <sup>P</sup>	10 <sup>QT</sup>	20 <sup>TU</sup>
Imidacloprid		50 e.g. H2	20 <sup>E</sup>	20 <sup>E</sup>	10 <sup>M</sup>	200 <sup>P</sup>	10 <sup>QT</sup>	20 <sup>TU</sup>
Creosote		200000 e.g. H4	20 <sup>F</sup>	2 <sup>K</sup>	0.5 <sup>L</sup>	0.5 <sup>L</sup>	10000 <sup>Q</sup>	20000 <sup>U</sup>
PCP <sup>A</sup>		7000 e.g. H3	35 <sup>G</sup>	1 <sup>K</sup>	5 <sup>L</sup>	5 <sup>L</sup>	5 <sup>K</sup>	700 <sup>U</sup>
Dieldrin/OCs <sup>A</sup>		900 eg H3	2 <sup>H</sup>	0.02 <sup>C</sup>	0.02 <sup>C</sup>	0.02 <sup>C</sup>	2 <sup>K</sup>	45 <sup>Q</sup>

Note that these values assume analysis of evenly penetrated wood or homogenised wood (chemical does not necessarily penetrate all wood).

<sup>A</sup>These timbers would be 25+ years old, as chemicals are no longer used for wood preservation.

<sup>B</sup>Does not exclude reuse of timbers with higher preservative retentions.

<sup>C</sup>From AS 4454 Compost standard and its references.

<sup>D</sup>WA DEC (2010) and EPA Tasmania (2009).

<sup>E</sup>Readily degrades in soil, and not harmful to animals, therefore assuming 10% could be as treated wood. Note that values for the insecticides bifenthrin and imidacloprid, which are more insecticidally active but otherwise safe like permethrin, are given the same maximum threshold values as permethrin.

<sup>F</sup>NEPM (1999), PAH Health Investigation Level.

<sup>G</sup>Moderately biodegradable in soil, allowing 0.5% as treated wood.

<sup>H</sup>EPA Tasmania (2009).

<sup>J</sup>Likely disposal method for animal bedding will be as mulch or compost.

<sup>K</sup>Essentially excluded.

<sup>L</sup>European Industry Standard WPIF/UKFPA/1-2000 (Irle et al., 2004).

<sup>M</sup>Not harmful to mammals so allow 5% as treated wood.

<sup>N</sup>Assumes particles/chips can be glued.

<sup>P</sup>AS 1604.2 Specification for preservative treatment. Part 2: Reconstituted wood-based products.

<sup>Q</sup>Allows cofiring with 5% treated wood waste.

<sup>R</sup>Issue of dioxin formation for organo-copper to be addressed.

<sup>S</sup>Long history of safely being burnt in sawmill boilers, Young (1947).

<sup>T</sup>Combustion of higher proportions of wood treated with these preservatives should be possible as a more targeted means of disposal for treated wood waste (rather than incidental inclusions).

<sup>U</sup>Allows combustion with 10% treated wood waste, efficient disposal method (Environment Australia, 1997).

## **CCA**

Currently landfill is the cheapest option for disposal of CCA treated timber. Landfill is seen as a business cost with no opportunity for value adding. Several processing options are available for CCA treated wood waste, these include:

- Energy production with co-incineration
- Wood cement composites
- Wood plastic composites
- Solid wood reuse (docking of poles to produce posts, splicing broken posts)
- Feedstock for the manufacture of particleboard

Barriers exist with the use of these recycling avenues, these barriers are able to be minimized by providing clear guidelines and specifying maximum levels for the presence of CCA in the products. Using levels established internationally, some guidelines can be produced. Further, significant development of infrastructure is required to maximise the processing potential for use of treated wood products, particularly energy production with co-incineration. For roundwood, 440,000 m<sup>3</sup> of production or about 80% is CCA treated, with at least another 340,000 m<sup>3</sup> of CCA treated timber going into the sawn wood sector meaning CCA preservative use accounts for around 52% of the total amount of treated timber in Australia. In the case for roundwood, posts are geographically concentrated in vineyard areas and this industry provides a continuing supply of treated timber on an annual basis due to replacement of trellis posts damaged during harvest operations.

## **Creosote**

Treatment of timber with creosote accounts for 8% of the roundwood market, with further creosote treatment of sawnwood and double treatment of marine piles with CCA and creosote estimated annually to account for around 9% of the total treated wood market in Australia. Most of these timbers are spread diffusely, little benefit is seen for setting up specific disposal means for these products. Reuse of piles and poles is possible, and some reuse of sleepers to the horticultural market is possible, however these opportunities are limited. Co-incineration for energy production is seen as a viable

possibility with creosote treated vineyard posts being suitable for use in these facilities.

Creosote is not seen as suitable for a range of recycling applications due to colour, smell, bonding performance and available volumes. The maximum limit for creosote in particleboard has been set at 0.5 ppm. If included with wood waste for land applications, a Health Investigation Levels for PAHs has been set at 20 ppm.

### **ACQ and copper azoles**

Volumes of wood treated with ACQ and copper azoles are set to increase as they replace CCA in the market place. This will result in more ACQ and copper azole treated timber entering the waste stream as either construction waste and as they are removed from service. Currently most replacement preservatives can be considered to be copper plus organic biocide. Typical production of ACQ treated products accounts for 12% of the total production of treated wood. ACQ and copper azole wood wastes can be recycled or processed in all applications where CCA can be but with fewer restrictions. The amount of copper in ACQ treated wood wastes is much greater than the amount found in the corresponding CCA treated timber. Use of ACQ or copper azole treated wood waste requires management of the copper content in the finished products or ash if incinerated for energy production. Copper is a potent catalyst for dioxin formation when combusted with chlorine containing compounds. Therefore if organo-copper preservatives are used as fuel chlorine content should be limited or greater care taken with the disposal of ash. This is an area in need of further evaluation. It may be possible to tolerate small quantities of ACQ treated wood waste in mulches providing the mix used has less than 200 mg/kg of copper and complies with federal and state guidelines. The usability of copper azole in compost is similar. In addition the azoles can act as a systemic fungicide providing protection to the growing plant against a range of fungal diseases.

### **Permethrin and other synthetic pyrethroids**

These compounds degrade with time and exposure to the environment and as such pose reduced risks to consumers in secondary applications. The use of permethrin and other pyrethroids for animal bedding could be considered but this use would probably need separate APVMA approval. This is a potential area of health benefit to some animals but potential for uptake would need to be examined if the animal will become part of the food chain. Limits for permethrin from treated timber could also be considered for mulches and compost. Permethrin binds strongly to soil and degrades rapidly in low organic soils and in organic soils the half life of permethrin is three to six weeks so higher limits are possibly appropriate. The presence of permethrin is found to depress the availability of sodium and phosphorous. Bifenthrin is the most persistent of the synthetic pyrethroids in field studies and has a half life of 122 to 345 days (US EPA, 1999), so would last longer in mulches.

Wood wastes containing permethrin or bifenthrin have no restriction for their use in particleboard manufacture, can be incinerated for energy production and may be tolerated to a degree in bedding material for animals.

### **Azoles**

The azoles tebuconazole and propiconazole are widely used in agriculture for crops to control fungal pathogens. Wood waste containing small amounts of azole treated wood could be safely composted, as the azoles are readily degraded by soil microorganisms. Before this degradation, some azoles could be taken up by plants, and would act as systemic fungicides giving the plant protection from a range of pathogens. Azole treated wood waste could also be tolerated in particleboard destined to be treated and sold as fungal resistant flooring.

### **Boron compounds**

Boron in timbers exposed to weather is not permanent and boron can be readily mobilized by the action of repeated wetting and drying cycles. Large quantities of boron treated wood in composts and mulches could not be tolerated as the element has a very narrow toxicity range, with soils going from deficient in boron to toxic for plants very rapidly. Use of larger quantities of boron treated wood in mulches and compost would need to specify that the product was for boron deficient soils with a recommended application rate based on soil boron content. A soil with a concentration of available boron of 0.15 ppm is deemed low or deficient whilst an available boron concentration of 0.5 ppm is high. Boron treated wood is able to be leached to remove the boron as a pre-processing step. Boron treated timber can be safely combusted in green wood boilers as the boron does not cause any undue environmental concerns, however when burning boron treated timber shavings the boron released from the timber can form a slag capable of damaging the refractory used in the kiln lining. Boron treated timbers more than any other would be ideally suited for pre-processing prior to disposal to reduce the amount of boron in the timber.

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## **Acknowledgements**

The authors acknowledge the financial contribution made by Forest and Wood Products Australia (FWPA) and the inkind support of TimTech Chemicals to complete this study. The invaluable participation of Mr. Jack Norton (Queensland Government Department of Primary Industries), Mr. Stephen Mitchell (Timber Development Association), Mr. Brett Ellis (TimTech Chemicals) and Dr. Chris Lafferty (FWPA) as members of the Project Steering Committee is greatly appreciated. We would also like to thank Mr. Nick Livanes (Osrose Australia) for his comments.

## Appendix A

### Current and emerging technologies for recycling preservative treated wood waste

Numerous options have been identified that provide a greater potential benefit for the use of preservative treated wood waste compared to the options of landfill and incineration without energy recovery (TRADA Technology and Enviro Consulting Ltd, 2005):

- Reuse - provides the opportunity to extend useful service life of the post consumer treated wood products with no (or minimal) additional processing. Reuse represents the best practicable environmental option.
- Remediation - facilitates treated wood waste recycling, reuse or recovery, by applying pre-treatments which attempt to remove the preservatives.
- Recycling - the treated wood waste is reprocessed (mechanically, chemically or biologically) into alternative products.
- Thermal treatment – treated wood waste is thermal-processed with recovery of energy, as well as additional byproducts such as industrial charcoal, furfurals, phenols and cellulose.

Table 17 summarizes the technologies which have been developed, or are still in the early stage of development, to remediate and recycle post consumer preservative treated wood waste. Extensive details regarding the development status, limitations of each technology, commercial viability of any product generated via the various technologies/processes and the environmental impact and issues associated with each technology/process are available in *Options and Risk Assessment for Treated Wood Waste* (TRADA Technology and Enviro Consulting Ltd, 2005).

CCA treated wood remediation and novel recycling technologies, such as bioremediation, extraction techniques and electrochemical processes, are expensive and currently used in specialized instances only. The economic feasibility of these alternative processes has been limited by the cost of waste wood disposal via incineration which decreased significantly over the last 10 years. In Germany the cost of wood waste thermal processing has almost reached zero (Humar et al., 2006).

Table 16: Technologies able to remediate and recycle post consumer preservative treated wood waste (focusing on CCA) (TRADA Technology and Enviros Consulting Ltd, 2005; Townsend and Solo-Gabriele, 2006; Taylor et al., 2005)

Management option	Technology	Technology description and issues related to the use of treated wood waste
<b>PRE-PROCESSING</b>	<b>Biodegradation by fungi</b> (emerging technology)	<ul style="list-style-type: none"> <li>- Removal of large levels of preservatives from wood (CCA and creosote ) by using specific fungi (brown rot fungi in particular) which produce large quantities of organic acids (Illman et al., 2000; Illman and Yang, 2006).</li> <li>- To achieve high levels of extraction, this process has to be used in conjunction with other processes such as chemical extraction.</li> </ul>
	<b>Biological extraction</b> (emerging technology)	<ul style="list-style-type: none"> <li>- Removal of large levels of preservatives from wood (CCA, creosote and pentachlorophenol) by fermentation with specific bacteria (Cole and Clausen, 1996; Clausen, 2000a and 2006).</li> <li>- To achieve high levels of extraction, this process has to be used in conjunction with other processes such as chemical extraction (Clausen, 2000b).</li> </ul>
	<b>Chemical extraction</b> (emerging technology)	<ul style="list-style-type: none"> <li>- Chemical extraction of the CCA components and copper organic preservatives from wood by using various acid formulations (Shupe and Hse, 2006).</li> </ul>
	<b>Steam explosion</b> (emerging technology)	<ul style="list-style-type: none"> <li>- Wood fiber recovery by using steam saturated wood chip subjected to high pressure which is followed by sudden pressure release, physically disrupting the wood.</li> </ul>
	<b>Electrodialytic pre-treatment</b> (at pilot scale)	<ul style="list-style-type: none"> <li>- Chipped wood is placed in an electrolyte filled tank followed by application of an electric charge. Metals migrate to the cathode and non-metals to the anode. Proven to be effective to remediate CCA and creosote treated wood waste (Christensen et al., 2006).</li> </ul>

<b>PRE-PROCESSING</b>	<b>Pre-processing for extracting the wood fiber</b> (emerging technologies)	<ul style="list-style-type: none"> <li>- Mainly applied for recycling the wood fiber from medium density fiberboard (MDF) (Remade Scotland, 2006).</li> </ul>
<b>RECYCLING</b>	<b>Particleboard</b>	<ul style="list-style-type: none"> <li>- Various studies have demonstrated that particleboard production from treated wood waste is possible but the mechanical properties may be reduced (TRADA Technology and Enviro Consulting Ltd, 2005; Taylor et al. 2005; Kamdem, 2006).</li> <li>- The inclusion of preservatives from treated wood waste is considered to have little benefit as most particleboard products are used in areas where there is little or no risk of decay. The insecticide properties of treated wood waste can be useful in areas with termites.</li> <li>- In Europe, the current industry standard (WPIF/UKFPA/1-2000) restricts the amount of copper, chromium, arsenic, copper organic, creosote and pentachlorophenol in feedstock which enters the panel industry but other preservatives may be acceptable.</li> <li>- To extend the potential use of treated wood waste in particleboard manufacture, there could be two solutions: <ul style="list-style-type: none"> <li>▪ Allow a certain level of preservative elements in all applications similar to the European standards.</li> <li>▪ Produce an alternative panel product with higher elemental concentration levels for designated applications</li> </ul> </li> </ul>
	<b>Flakeboard and OSB</b> (little commercial interest for industry)	<ul style="list-style-type: none"> <li>- The use of treated wood waste has not gained very much interest from the industry and the technology is unproved. Although technologies for particleboard are equally valid for flakeboard and OSB products.</li> </ul>

<b>RECYCLING</b>	<p><b>Wood cement composites</b> (still not used on a large scale)</p>	<ul style="list-style-type: none"> <li>- It has been demonstrated that there is a greater compatibility between cement and CCA treated wood than cement and non-CCA treated wood. This not only reduces leaching loss by 20-50 times compared with CCA treated wood in a solid wood products but may also improve the performance of the wood cement composite.</li> <li>- It is likely that there are numerous theoretical potential applications for wood cement composites made from treated wood waste, in particular for CCA treated wood.</li> </ul>
	<p><b>Wood plastic composites</b> (in the very early stage)</p>	<ul style="list-style-type: none"> <li>- Currently only untreated wood feedstock is used for wood plastic composites.</li> </ul>
	<p><b>Fiberboard and MDF</b> (little interest for industry)</p>	<ul style="list-style-type: none"> <li>- Due to the nature of the processes, the use of treated wood would complicate the clean up of process water.</li> <li>- For MDF in particular, manufacturers are not willing to commit to the use of recycled wood as a feedstock as a typical specification will be much higher than for particleboard: grit and metals will cause problems with manufacturing and subsequent machining processes.</li> </ul>
	<p><b>Compost</b></p>	<ul style="list-style-type: none"> <li>- The inclusion of treated wood waste in compost generates issues associated with toxicity: <ul style="list-style-type: none"> <li>▪ Composting products have to meet the prescribed limits for potentially toxic elements (see Chapter 6.1).</li> <li>▪ There is also potential to reject compost produced from treated wood waste on phytotoxic grounds due to accumulation of released metal ions in the soil from the decaying compost.</li> </ul> </li> </ul>

<b>RECYCLING</b>	<b>Mulch</b>	<ul style="list-style-type: none"> <li>- The quality requirements for horticultural and garden mulches is generally higher than for other mulches as the product is meant to be visually attractive and suitable for spreading by hand. Wood treated with CCA and creosote is not recommended (Urban Harvest, 2003).</li> <li>- Shredding mulches increases the surface area of the wood which may in turn increase leaching rates therefore dispersing higher levels of preservative chemicals.</li> </ul>
	<b>Animal bedding</b>	<ul style="list-style-type: none"> <li>- The use of preservative treated wood as animal bedding is not recommended or restricted (TRADA Technology and Enviro Consulting Ltd, 2005). Further investigations are needed.</li> </ul>
<b>THERMOCHEMICAL CONVERSION</b>	<b>Combustion with energy recovery (heat and/or power generation)</b> (widely available)	<ul style="list-style-type: none"> <li>- Concerns regarding the volatilization of arsenic from CCA and the formation of toxic polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans.</li> <li>- Operational problems with the plant itself (such as slagging, fouling of heat exchanger surfaces and corrosion).</li> <li>- The need of arsenic emissions to air to comply with the set emission levels.</li> <li>- The need to manage disposal of the ash.</li> <li>- Heat has to be used or converted immediately.</li> </ul>

<b>THERMOCHEMICAL CONVERSION</b>	<b>Co-combustion</b>	<ul style="list-style-type: none"> <li>- The inclusion of CCA treated wood waste in different waste streams is not an issue for co-combustion (Hlsen and Van del Bulk, 2006): <ul style="list-style-type: none"> <li>▪ Compliance with emission legislation may be easier due to dilution effects.</li> <li>▪ Arsenic may be scavenged by the calcium present from other waste streams.</li> <li>▪ Co-combustion with coal results in the formation of nonleacheble compounds in the fly ash because arsenic is effectively bonded with these materials.</li> <li>▪ The use of generated fuel is highly variable.</li> </ul> </li> </ul>
	<b>Cement kilns</b>	<ul style="list-style-type: none"> <li>- The cement industry has not yet recognized treated wood waste as a potential fuel source. The use of CCA treated wood in particular constitutes a barrier as it has to be restricted by the need to control chromium levels in the cement.</li> </ul>
	<b>Pyrolysis (slow and flash)</b> (developed at industrial scale but not widely available, Chartherm in France)	<ul style="list-style-type: none"> <li>- A wood waste heating process in a controlled environment (with no oxygen) to produce varying quantities of oil, gas and charcoal. The gas can be burnt to produce electricity and the bio-oil can be used as a chemical feedstock or as a substitute for diesel fuel by stationary power generators.</li> <li>- There are concerns regarding the arsenic based treated wood because the metal is distributed throughout the three pyrolysis products - char, gas and oil. There is no time-temperature threshold for zero arsenic volatilization and it is clear that process control is critical to maintain emissions from pyrolysis of CCA treated wood waste within set limits.</li> </ul>
	<b>Sidenergy</b> (not widely available. Present in France)	<ul style="list-style-type: none"> <li>- It is a process for producing charcoal from creosote treated wood, where thermolysis occurs at 500°C with combustion of the gases.</li> </ul>

<b>THERMOCHEMICAL CONVERSION</b>	<b>Gasification</b> (not fully developed)	<ul style="list-style-type: none"> <li>- The process is similar to pyrolysis but operates at higher temperatures (1000-1200°C) and the concentration of hydrogen in the syngas from gasification is greater, which can be used to generate electricity.</li> </ul>
	<b>High temperature gasification in a metallurgical furnace</b> (at pilot scale in Finland)	<ul style="list-style-type: none"> <li>- This method involves incineration followed by processing of the ash in a metallurgical furnace, which requires expensive, pure oxygen.</li> <li>- This process could theoretically provide energy in the form of heat or electricity in addition to the recovery of copper, chromium and arsenic from the treated wood waste. The method requires a well designed plant to enable removal of all the volatile and particulate arsenic. Not all metal products are transformed into usable forms.</li> </ul>

